



White colour and surface quality of appliances

- Finish clinic and analysis of varnishing process; dishwashers, washing machines and tumble dryers

by

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A collage of photographs of different models of appliances from Asko Appliances AB;

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Abstract

The customers of today have high desires and requirements on products and they select which products to purchase based on a large awareness of the market. Therefore, the key to all business success is to fully understand what gives the customers the largest possible usefulness and satisfaction out of the products. The next step is then to create a manufacturing process that is in statistical control, has small variations and that to a great extent meets the specified desired output.

This master's thesis focuses in different ways on the perception of different hues of the colour white and on surface deviations on varnished surfaces. To understand which hues of white that are perceived as attractive and which surface defects that are noticed and how they are perceived, an extensive customer inquiry has been performed. To better understand the market situation a smaller survey of the competitor's colours has also been made. A challenge with the current varnishing process at Asko Appliances AB has been to develop more detailed knowledge about how the output and perceived quality can be controlled by small changes of input parameters. Therefore, an extensive statistical analysis based on data collected from differently designed experiments has been performed. The possibility of using measurements of surface waviness to judge surfaces with orange peel structure has also been investigated.

The customer inquiry elucidated that white hues that contain small amounts of blue or only negligible amounts of yellow most often are found as attractive and that some defects are considered to be more critical than others. Another important conclusion is that the results of such an experiment are highly depending on the context and environment where it is performed. Several interesting observations were made during the analysis of the varnishing process and it was found that the process is somewhat more complex than expected. However, the effects of some controlling factors such as temperature, time and position on the hanger during curing were found to affect the hue more than others.

Keywords: *colour, hues of white, spectrophotometer, perception, varnishing process, statistical variation, surface defect, quality, surface waviness*

Sammanfattning

Dagens kunder har höga önskemål och krav på produkter och baserar sina inköp på en stor medvetenhet om vad som finns på marknaden. Därför är nyckeln till all affärsframgång att till fullo förstå vilka egenskaper hos produkter som kan ge kunden största möjliga användbarhet och tillfredsställelse. Nästa steg är att skapa en tillverkningsprocess som är i statistisk kontroll, endast innehåller små variationer och som i stor utsträckning når specificerat önskat resultat.

Detta examensarbete handlar på olika sätt om hur olika nyanser av vitt upplevs samt om ytavvikelse hos lackerade ytor. För att nå insikt om vilka vita kulörtoner som upplevs tilltalande, vilka ytdefekter som noteras av kunder samt hur defekterna uppfattas, så har en omfattande kundstudie genomförts. För att få en bättre överblick över konkurrenternas vita kulörer så har även en mindre konkurrentundersökning genomförts. En utmaning avseende dagens lackeringsprocess hos Asko Appliances AB har varit att utveckla mer kunskap om hur processens output möjligen kan styras genom mindre justeringar av kontrollerande faktorer. Med anledning av detta har en omfattande statistisk analys genomförts vilken har baserats på resultaten av mätningar i processen, bland annat mätningar som resulterat av försöksplanering. Även möjligheten att använda mätning av en ytas vågighet för att bedöma huruvida ytor med apelsinskalsstruktur är godkända ur finishsynpunkt har undersökts i detta projekt.

Kundstudien klargjorde att vita kulörer som innehåller en viss mängd blått eller som endast innehåller försumbara mängder av gult uppfattas som tilltalande av majoriteten av kunderna. Det var även tydligt att vissa ytdefekter oftare noterades än andra och att vissa ansågs vara mer kritiska än andra. En minst lika relevant slutsats var att resultatet av ett test av denna typ är strängt beroende av omgivningen det genomförs i. Under analysen av lackeringsprocessen gjordes många intressanta observationer och det uppdagades att processen är något mer komplex än väntat. Även vissa identifierade faktorer noterades ha större effekt på processens resultat än övriga faktorer, såsom till exempel temperatur, tid och position på lackeringsgalge.

Sökord: kulör, vita nyanser, spektrofotometer, perception, lackeringsprocess, statistisk variation, ytdefekt, kvalitet, ytojämnhhet

Preface and acknowledgements

This master's thesis project has been performed at the department of Materials and Manufacturing Technology at Chalmers University of Technology in Gothenburg and Asko Appliances AB in Jung. The author of this project has performed this thesis project as her final part of her education at the Master Program Advanced Engineering Materials and of the Swedish engineering degree civilingenjör in Industrial Design Engineering. The author's background is a Bachelor of Science in Industrial Design Engineering from the department of Product and Production Development at Chalmers. This project (30 credits) has been performed between January and June 2011.

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Thank you all!

Jung, June 2011

Isabelle Andersson

"Quality is what makes it possible for a customer to have a love affair with your product or service. Telling lies, decreasing the price or adding features can create a temporary infatuation. It takes quality to sustain a love affair.

Love is always fickle. Therefore, it is necessary to remain close to the person whose loyalty you wish to retain. You must be ever on the alert to understand what pleases the customer, for only customers define what constitutes quality. The wooing of the customer is never done."

- This was how Myron Tribus defined quality in ASQC Statistic Division Newsletter, 1990, No. 3, p.2. (Bergman & Klefsjö 2007, p. 27)

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1. Introduction

In this chapter the background, purpose and objective of this project will be presented. Also the organization of the project and the delimitations of it will be described, as well as the company will be briefly introduced.

1.1 Asko Appliances AB

Asko Appliances Group has its headquarter and ASKO brand centre in Jung outside Vara in Sweden. One of the two factories is situated in the same facilities as the headquarter and the second one in Lahti in Finland. Since the autumn 2010 Asko Appliances Group is a part of the Slovenian Gorenje Group. Asko Appliance Group has two different brands; ASKO that is a high-end worldwide brand and UPO that is a Nordic mid-end brand. Another important source of income is also to be an original equipment manufacturer (OEM) for certain other brands. The most important of these other brands is Cylinda (ASKO Appliances AB 2010).

The facilities in Jung accommodate Asko Appliances AB that among other activities manufactures dishwashers, washing machines and tumble dryers. Approximately 1100 machines are produced in the factory every day. Attributes that are important for the ASKO brand are among others Scandinavian design, simplicity to use, top performance, that the machines are “built to last longer” and to be environmentally friendly. ASKO is for example the only brand that has dishwashers and washing machines that are labelled with The Swan, which is a well known Nordic eco label (ASKO Appliances AB 2010).

In the continuation of this report Asko Appliances AB will be denoted only as Asko to make the text more comfortable to read.

1.2 Background

Today’s customers and users of high-end brand appliances have high requirements and expectations on the products they purchase and use in their everyday life. To satisfy and retain the customers it is important to meet these requirements and provide quality to them. However, to have too high quality requirements in production and too narrow tolerance ranges makes the production unjustified expensive. To be able to have an appropriate quality level the customers’ requirements, needs and opinions must be well known and understood, as well as they must be the foundation for all quality work. To have the ability to meet the requirements in a satisfying way knowledge must also exist about which possibilities the production processes have and how the output can be controlled.

At Asko today, there are defined tolerance limits for the target hue of white and some in-process inspections are performed. However, there is an uncertainty about how the output of the varnishing process can be controlled in an explicit way and why observed variation occurs. There are also questions about which white hues that are perceived as attractive by the customers. An appearance-specification defines which deviations that are tolerated for different surface defects and if any uncertainty concerning surface finish is found in production a group called the “appearance-group” examines the component in a specially adapted examination room. This examination does then decide whether the defect is tolerated or not. There are nevertheless some uncertainties about how the examined defects are perceived in a natural context of usage and the opinions about them.

1.3 Purpose

The purpose of this project is firstly to collect data about the output of the varnishing process for the white colour and to analyze and interpret this information to investigate which factors that mainly affects the output. Secondly, it is to generate knowledge about which white colour that is

perceived as attractive by customers and users and how different surface defects on varnished surfaces are perceived and what the customers' opinions are about these. The investigation about the white colour should also contain a survey of the competitors on the market as well as of how the context in which the machines are examined can influence the perception of them. Finally, the purpose of this project is also to measure waviness of varnished surfaces and investigate if this method is suitable for classifying when surfaces are perceived as smooth and attractive or rough and less attractive.

1.4 Objective

The objective of this project is to determine how the output of the varnishing process can be controlled and give recommendations about how the process can be improved. It is also to give recommendations about the white target colour and its tolerance limits based on the customers inquiry and partly also on the competitors' colours. The objective is as well to provide a foundation for a possible update of the appearance-specification based on how customers in reality and natural context perceive surface defects. Finally, it should be determined if measurements of surface waviness can be a useful tool for judgement of surfaces with orange peel structure.

1.5 Delimitations

This project will not include examination of surfaces with other colours than different hues of white. In the investigation of the varnishing process only the hue of white will be considered and all other possible defects will not be included in that study. Only the surfaces visible from the outside of the machines will be examined in the different parts of this project.

1.6 Project organization

Even though this project is not a typical product development project the basic ideas of Bligård (2011, pp. 43) have been the base for the development of the process plan which is shown in figure 1.

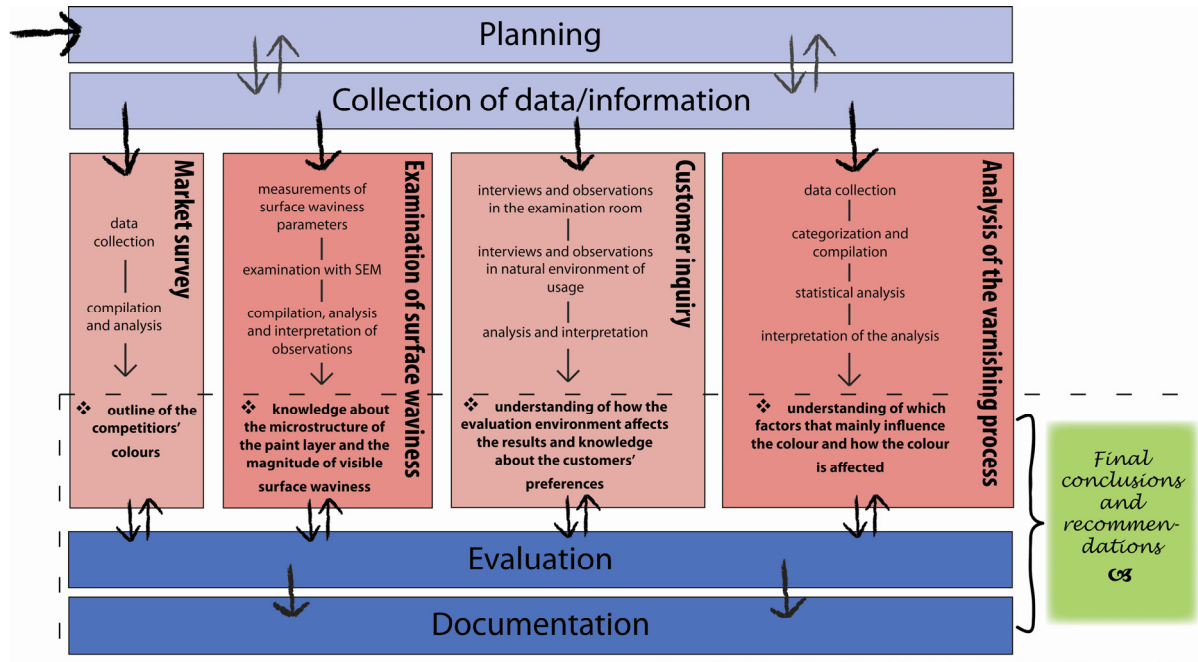


Figure 1: The process plan of this master's thesis, showing the layout of the project.

The process plan displays the overall layout and organization of this project. The project is in general composed of four different parts; Market survey, Examination of surface waviness, Customer inquiry and Analysis of the varnishing process. Depending on the expressed importance for Asko of the work with the different parts they have been assigned different number of weeks for work. The size of the red fields in the process plan roughly indicates this distribution of work, even though it is not a completely correct distribution in the figure to enhance the readability of the figure.

This project started in the middle of January and extended to the beginning of June 2011. Parallel with this master's thesis project a six sigma quality improvement project was arranged at the company. The different phases of the six sigma project, which will be described further in section 2.1.3, was planned to run parallel with the more or less corresponding phases in this master's thesis project. The author of this report participated as an active member in the six sigma team and during the Measurement phase she had a significant role when collecting the data, also the interpretation of the statistical analyses in the Analysis phase was an important part.

A result of the involvement in the six sigma project is that not completely all work related to this project is made solely by the student. Some of this parts will however be presented in this report to enhance the understanding of the parts where she was more responsible for the output. When such parts are presented it will be clearly stated in the related text. Some examples of such parts are operation of the SEM instrument and parts of the analyses with Minitab.

During this project the student has mainly worked at Asko's facilities in Jung but during shorter periods has the work also been performed at Chalmers. For example the analyses with optical microscope and scanning electron microscope have been performed at Chalmers.

The width of this project demands a rather extensive chapter presenting the theory used. Often whole paragraphs are based on the same reference which is then presented in the end of the paragraph. In specific cases when only a certain sentence or similar is based on a reference it is presented directly after the sentence.

2. Theory

This chapter will present theory relevant for the project. Fields of theory that will be covered are among others user requirements and quality, colour, powder coating, surface waviness and finish as well as statistics and probability.

2.1 User requirements and quality theory

2.1.1 The necessity of focus on customers and users

According to Sörqvist & Höglund (2007, p. 28-29) the foundation of the success and even existence of a company is to understand the customers and to fulfill their requirements and needs. There are several different but similar definitions of quality, among others the one by Bergman & Klefsjö; "The quality of a product is its ability to fulfill or even more preferably exceed the customers' requirements and expectations" (2007, p. 26). This quotation has been translated by the author of this report from the Swedish edition of the book. However, the important fact is that the whole definition is based on the customers' experiences of the products. In other words, quality cannot be evaluated as a phenomenon separated from the customers.

Karlsson (2007, p.3) presents some motives for the nowadays self-evident approach with "putting the customers in centre";

- There are a large number of products on the market; this makes the competition hard for new products.
- The modern customer is more aware of the selection of products and is therefore not immediately impressed by a product just because it is new.
- The customers' expectations have changed and today functionality is not enough, additional values such as comfort, usability and satisfaction are also needed.
- The fact that the length of life of the product on the market has shortened, results in little or no space for errors and the product has to be right the first time it is introduced to the market.

2.1.2 The Iceberg theory and Kano model

To be able to find and fulfill the customers' and users' requirements and desires it is crucial to understand the nature and the attainability of them. One theory that is commonly used to illustrate the attainability of requirements is the Iceberg theory. According to this theory only a fraction of the total amount of requirements and desires are directly attainable while the rest are hidden and therefore major efforts can be needed to find the complete picture (Karlsson 2007, p. 18-19).

The Kano model developed in the 1980's does also describe the attainability of the requirements and desires; it does also classify them according to how high customer satisfaction fulfillment of them results in. The model is displayed in figure 2. The three major types of attributes are marked with line A-C where C represents the threshold or basic requirements, B is expectations spoken by the customer and A is desires that are unspoken by the customer. D is also marked in the figure and represents requirements that do not have any importance for the customer satisfaction. When one reflects over the division of the customer requirements into these groups one realizes that the model simultaneously describes which attributes that are perceived as essential for a product and which attributes that differentiates a product from the others available at the market (Good Design Practice Program 2010) (Gupta 2004, p. 115) (Karlsson 2007, p. 19-21).

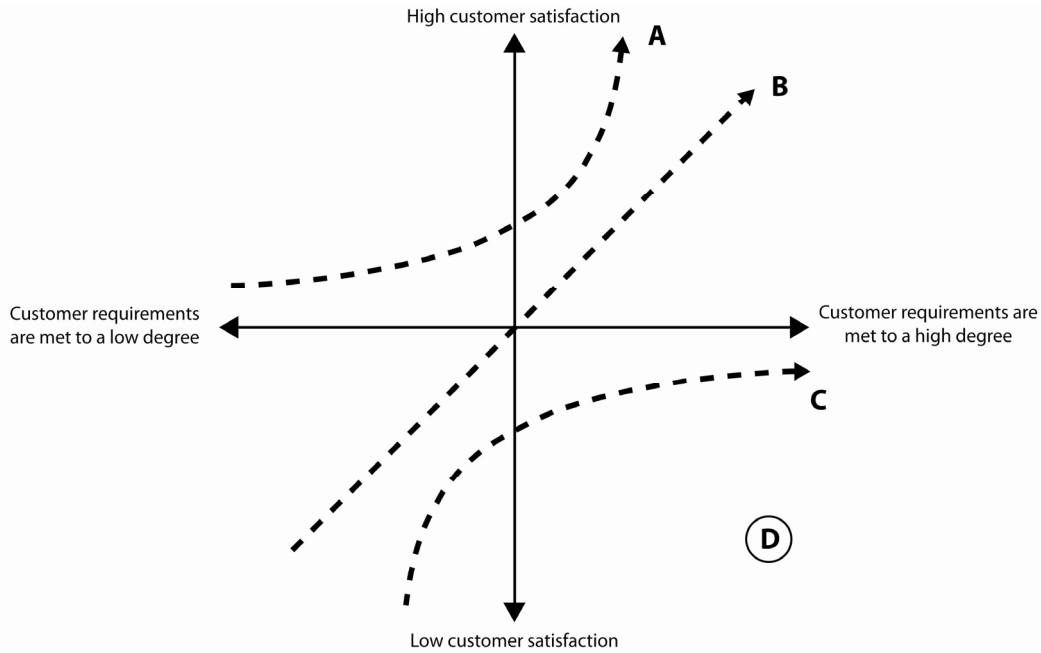


Figure 2: Illustration of the Kano model, showing how the fulfilment of different customer requirements and needs is related to the customer satisfaction. This figure is primarily based on the information presented by the Good Design Practice Program (2010).

The basic requirements (C) are often unspoken by the customer because they are self-evident, an example of a self-evident requirement is for example that a car in some way should be possible to steer. If such a requirements is not fulfilled the product is totally uninteresting for a customer while good execution just makes the customer neutral towards the product. The requirements that the customer is aware of and explicitly communicates (B) form a linear relationship between the customer satisfaction and the functionality and quality of execution. The unspoken desires (A) are also known as unknown or latent needs or customer delights. It is the fulfillment of such desires that causes really great customer satisfaction. New features that fall in to this category do not always solve a former problem but can instead be features that anyway drastically increase the value of the product for the customer. It is the class A features that can make the customers willing to pay a considerably higher price for the product. It is also these desires that demand extensive observations and examinations before they are found and can be translated into features on new products. It is also important to remember that the customers' desires change over time, in other words features that today is class A will probably sometime in the future become a class B feature instead (Good Design Practice Program 2010) (Gupta 2004, p. 116) (Karlsson 2007, p. 19-21).

The Kano model can for example be used as a tool for visualization or agreement in the team in quality improvement project such as for example when the six sigma methodology is used (Gupta 2004, p. 25).

2.1.3 Six sigma

Six sigma can be implemented on several different levels in the organization and is an area of study and research in its own; therefore the following presentation can only be regarded as a basic introduction to the methodology and terminology.

Six sigma is a methodology that was developed in the early 1980s at Motorola in the USA, the concept is a strategy to impel improvements in performance and profitability of an organization. (Gupta 2004, p. 17-21). Important cornerstones for successful work with six sigma are among others strong result oriented leadership, personal commitment through the whole hierarchy of the organisation as well as aggressive goal setting (Sörqvist & Höglund 2007, p. 32).

The name six sigma is based on the idea that it preferably should be a distance of ± 6 standard deviations (σ) between the upper and lower tolerance limits and that the mean value (μ) should not be allowed to shift more than $1,5\sigma$. Different statistical terms will be presented further in section 2.4. This definition of six sigma is in most cases only used as a philosophy for inspiration to quality improvements and as a guideline (Sörqvist & Höglund 2007, p. 28).

The six sigma level of performance means that each operation in the product chain must be performed almost perfectly, in figures this means that the failure rate at each operation is supposed to be maximum 3,4 parts per million (ppm). It is important to have high yield at each step of the process because each of these steps contributes to the overall quality of the final product. The net yield for a product is much lower than the individual net for all of the sub process and therefore a low failure rate in each step of the processes must be ensured. In other words, a six sigma level of performance results in drastically improved field performance, reduced waste and improved profitability (Gupta 2004, p. 17-21).

One approach to six sigma is called the DMAIC-methodology. DMAIC is an abbreviation for the different phases of which a project of this type is composed of; Define, Measure, Analyze, Improve and Control. These five different phases have a rather strict sequential order in a project (Gupta 2004, p. 23). Each of the phases represents the basic advantages with the six sigma approach; to understand the problem, to base the solution of the problem on facts, to identify underlying primary causes, introduce effective solutions and to control that the desired objectives will be fulfilled by the work with the solutions (Sörqvist & Höglund 2007, p. 73).

In the define phase the problem should be formulated and described as clearly and specific as possible. The impact of the problem on the customer satisfaction, stakeholders, employees and profitability should also be identified. Typical matter to define is customer critical requirements, objectives and goals of the project, roles and responsibilities in the team, project scope and resources as well as a process map with Supplier, Input, Process, Output and Customer (SIPOC). As also mentioned earlier, in elucidating the customers' requirements the Kano-model can be very useful (Gupta 2004, p. 23-25). Based on the most important requirements of the customers and other important properties, factors that are critical to quality (CTQ) are established (Sörqvist & Höglund 2007, p. 77).

For a quality improvement project to be successful it should be based on facts. Therefore an important activity is to systematically gather data about the problem and the process; this is done in the measure phase. If data is not collected in a well-planned and structured way the risk

is impending that improvements are based on opinions and ideas. Studies have shown that analyses based on facts often leads to other conclusions compared to those only based on opinions. Before the measuring it is of great importance to elucidate the need of data in the project, identify important measurements that needs to be measured, select methods for measuring, plan the execution of the measuring and define the present situation. In projects where the collection of data is extensive the collection can preferably be regarded as a sub project in the six sigma project (Sörqvist & Höglund 2007, p. 79-82).

In the analyse phase the objective is to find the root causes to the problem (Gupta 2004, p. 31). It is also desirable to determine the relation between different factors (x) and how they influence the result of the analysed process (Y). The analyses can be performed in various different ways depending on the character of the project. However, the analyses does almost always involve some kind of statistics and probability analysis, relevant terms for such analyses are presented in section 2.4 of this report. Analyses of variation and hypothesis testing are often of relevance (Sörqvist & Höglund 2007, p. 82-85).

When the project has come to the improve phase it is time to find good solutions to the problem and implement them in the organisation. The improvements can be more or less demanding to find depending on the problem. Typical stages in this phase are to identify possible solutions, select a solution, test the selected solution, plan the implementation of the changes in the process and after for example a pilot test with the new improvement verify the result. In this phase extensive work with attitudes and resistance to changes among employees may be crucial (Sörqvist & Höglund 2007, p. 88-92). In this work the role of leadership is important and the leader should be responsible for the creation of an organization culture “that embraces change rather than fights it” (Gupta 2004, p. 39). If the improvements are not fully accepted or confirmed by the employees that are working with the actual process the result is not fully satisfying.

In the final control phase the improvements should be properly consolidated in the production process and routines for follow-up should be implemented to ensure that the new improvements are used. In this phase final evaluation and verification of the project should also be performed as well as sharing of the experiences with other parts of the organisation (Sörqvist & Höglund 2007, p. 92-96).

2.1.4 Variation

Reduction of variation in processes is often desirable and can lead to dramatic improvements. To be able to decrease the variation it is firstly important to understand the variation. There it is said to be two different types of variation; random and assignable. The type of variation is always a result of the type of factors that cause the variation. An example of a random cause can be the ambient temperature in the production. The random causes are inherent in the process and happen as routines and are responsible for approximately 95 % of the variation in a process. The remaining 5 % are related to assignable causes which can be regarded as exceptions. Assignable causes happen for a specific reason and an example can be a machine breakdown in the production. The difference in the nature of the two types indicates that the random variations often are difficult to identify and that several can act together concurrently (Gupta 2004, p. 27).

When discussing variations in processes it is also important to clarify that it is the primary causes of the variations that should be attacked if the variations should be eliminated in a sustainable way. The attack of assignable causes can be described rather as deviation handling while successful quality improvement work identifies and eliminates random causes (Sörqvist & Höglund 2007, p.29-30).

2.2 Colour theory

2.2.1 Human perception of colour

Figure 3 shows that only a fraction of the electromagnetic spectrum is visible to the human eye and it is this part that is called “visible light”. It is the wavelengths between approximately 380 and 780nm that can be perceived by the human eye. The sensation of a colour is created firstly when the electric signals from the retina reaches the brain that interprets the input. It is the composition of the light that is reflected from a surface that results in the perception of a certain colour. White light contains an equal distribution of all visible wavelengths; this is the case for normal daylight. In other words, when white daylight reaches for example the surface of an object that is perceived as green all wavelengths except the green light are absorbed by the surface and transformed into thermal energy. The green light is however reflected and can be registered by the observer’s eyes and interpreted by the brain and the human experience to see the green colour (Johansson, Lundberg & Ryberg 2008, p. 67-68) (Konica Minolta Sensing, Inc. 2007) (McDonald edit. 1997,p. 57).

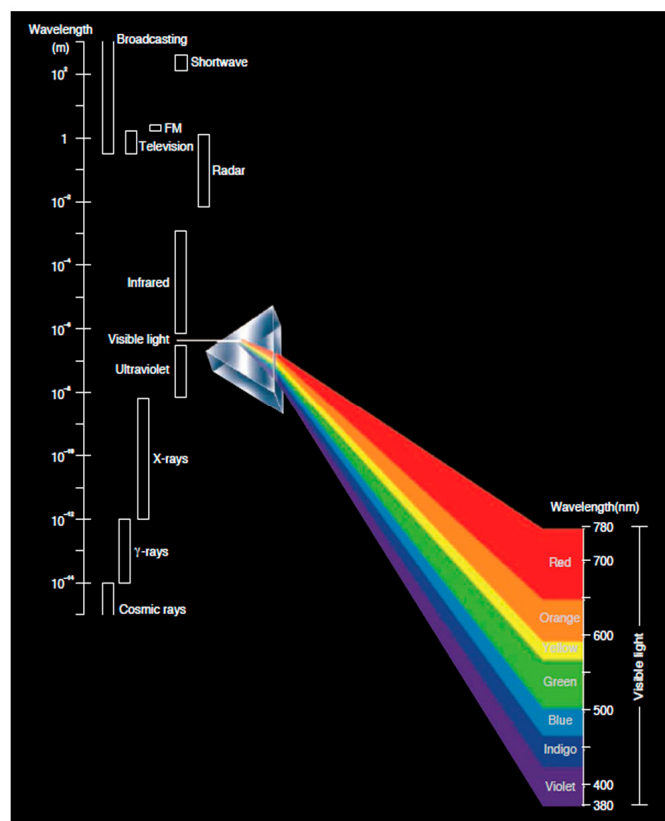


Figure 3: The electromagnetic spectrum showing the region between 380 and 780 nm that is called visible light (Konica Minolta Sensing, Inc. 2007). The usage of this figure is authorized by Eva Dahlman at Konica Minolta.

On the retina in the eye there are two different types of light detectors, they are called rods and cones. The rods are sensitive to differences in light intensity. The cones on the other hand, are of three types which have different sensitivity for different wavelengths; they have peak sensitivities for blue, green respectively red light. Figure 4 displays a cross section of the human eye and figure 6 shows the different types of cones' sensitivity for different wavelengths in the visible spectra. It is the combination of the stimuli of these different types of cones that is interpreted as the approximately 10 million different colours that humans can perceive. The cones can only function when the intensity of the light is rather high; this explains why we only see different shades of grey when it is dark (Johansson, Lundberg & Ryberg 2008, p. 68-69) (Konica Minolta Sensing, Inc. 2011). The fovea is an area without any rods but where most of the cones are located (Nilson 2004,p. 45-46).

The human eye and perception of colour are not completely understood but today some different theories or models are believed to together give a rather adequate description. This model of the colour vision with three different types of cones that are sensitive to three primary wavelengths is called the Young-Helmholtz trichromatic theory. In conclusion, colour is a psychophysical phenomenon and the perception of it is individual and subjective (Johansson, Lundberg & Ryberg 2008, p. 68-69) (Konica Minolta Sensing, Inc. 2011) (Kuehni 2005, p.191) (McDonald edit. 1997,p. 454).

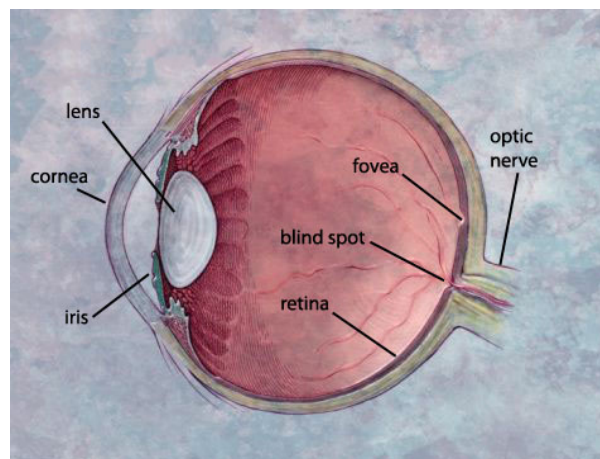


Figure 4: Cross section of the human eye, showing some parts that are important for the perception of colour. This figure is based on a royalty free illustration from www.gettyimages.com and modified by the author according to McDonald (edit. 1997,p. 427).

Two of the other most well-known colour vision theories are Hering's opponent colour theory and Land's retinex theory (McDonald edit. 1997,p. 455). The basic principle of the opponent theory is that some pairs of hues such as red/green, blue/yellow, and black/white cannot be perceived simultaneously (Green & MacDonald edit. 2002, p.115).

2.2.2 Colour terminology

When communicating colour (kulör) many different terms are available to enhance the unambiguousness. However, some of these terms can be difficult to understand at the first glance and therefore some of them are briefly described here. The Swedish translation is also given in brackets.

- Chromaticness (kulörthet) = the resemblance to a colour of the same hue and that has the maximum colour intensity. A chromatic colour corresponds to a certain hue (Green & MacDonald edit. 2002, p.115-116) (NCS Colour Centre for the UK and Ireland 2011).
- Colour space (färgrymd) = a three dimensional model with an included coordinate system that contains all possible colour perceptions ordered in a systematic arrangement (Kuehni 2005, p.185).
- Hue (kulörton) = an attribute that denotes the combination of the two nearest elementary colours that a colour is perceived to resemble (NCS Colour Centre for the UK and Ireland 2011).
- Lightness (ljushet) = can also be described as relative brightness. It indicates if a surface of a certain colour emits less or equal light compared to a perfectly white surface. The range of the lightness scale is from light to dark (Kuehni 2005, p.188).
- Nuance (nyans) = how the colour is related to black and the maximum colour intensity (NCS Colour Centre for the UK and Ireland 2011).
- Saturation (färgmättnad) = denotes how strong a hue is or how pure a colour is. Colours that lie along straight lines through the black point in a NCS constant hue triangle have equal saturation (NCS Colour Centre for the UK and Ireland 2011).

2.2.3 CIE L*a*b*

The CIE-system is the only device independent colour system that can be used for unambiguous and precise colour communication. CIE is an abbreviation for Commission Internationale d'Eclairage which means the International Commission on Illumination (Johansson, Lundberg & Ryberg 2008, p. 78).

There are several different variants of the CIE-system such as CIE XYZ and CIE L*a*b*. The CIE L*a*b* is the system that is most commonly used in industry today, is an updated version of the elder CIE XYZ-system. The idea with the CIE L*a*b*-system is that a measured colour difference of a certain magnitude should be perceived as a colour difference of equal size independent on which colour that is being measured; it should measure real perceived differences in colour. The CIE L*a*b* colour space is described by figure 5, where the colour solid and a cross-section through it are shown. The L* component describes the lightness; 0 is darkest possible and 100 is brightest possible. The a* component indicates the colour's position on a scale from green (-a*) to red (+a*) and b* indicates the position on a scale between blue (-b*) and yellow (+b*) (Johansson, Lundberg & Ryberg 2008, p. 78).

It should however also be mentioned that the red, green, yellow and blue colours that represent the axis of this colour solid are not pure elementary colours, instead they are in average represented by B75G, R20B, R80B respectively G95Y if the NCS notations for hue is used (Sisefsky 1995, p. 105). It can also be seen depending of the spherical shape of the colour solid the maximum value for a* and b* vary with L*.

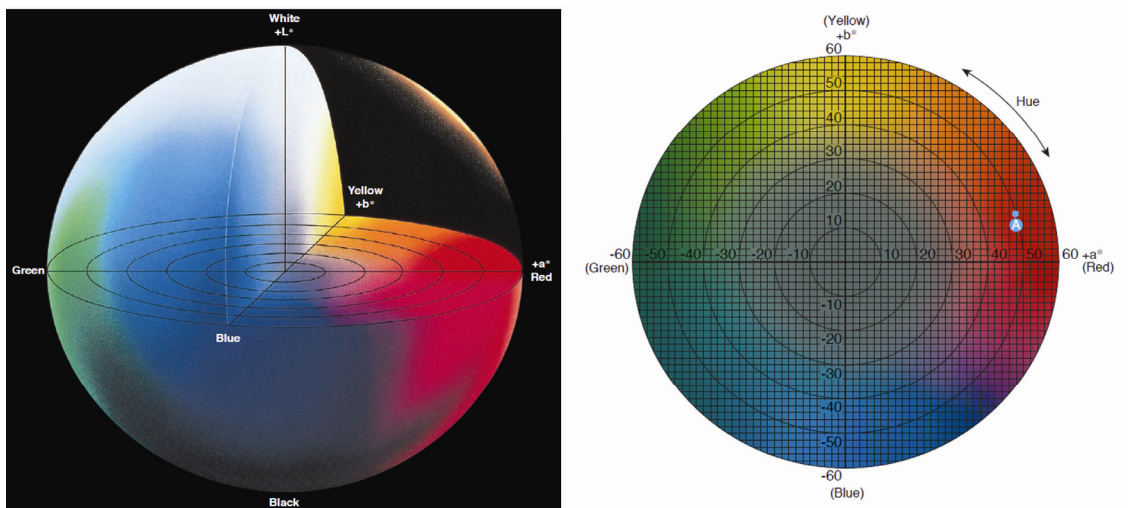


Figure 5: The CIE $L^*a^*b^*$ colour space presented as a colour solid to the left and to the right a plane through the solid intersected at $L^* \approx 50$. The figure displays the positions of the three different axis of the colour system. (Konica Minolta Sensing, Inc. 2007). The usage of this figure is authorized by Eva Dahlman at Konica Minolta.

The basis for the CIE system is extensive investigations made in the early 1930's about how humans perceive colours. The basis for the trichromatic theory was then found but it was also found that individual variations occur, therefore the mean perception was calculated which are said to represent the perception of a "standard observer". The curves of spectral response that represent the standard observer are displayed in figure 6 (Johansson, Lundberg & Ryberg 2008, p. 78).

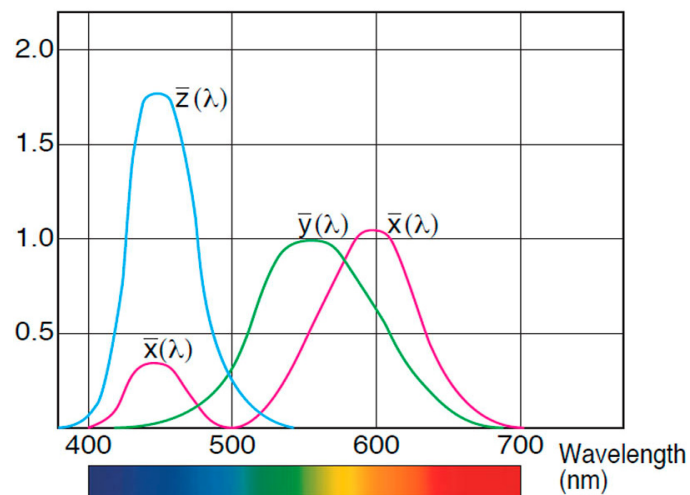


Figure 6: The spectral response that corresponds to the human eye. The figure illustrates the sensitivity of the three different types of cones at different wavelengths (Konica Minolta Sensing, Inc. 2007). The usage of this figure is authorized by Eva Dahlman at Konica Minolta.

The CIE L*a*b* values are calculated based on the tristimulus values (x,y and z) which results from consideration of three factors that together unambiguously and device independent determine the exact colour of a surface;

- the spectral composition of the illuminant
- the reflection of the surface
- the spectral curves representing the sensitivity of the standard observer

(Johansson, Lundberg & Ryberg 2008, p. 78) (Largo AB 2011, p.37).

ΔE^* is a measure of the perceived difference between two different colours (CIE 1971, p. 9). The parameter ΔE^* has been constructed so that a value of approximately 1 is what maximum can be or should be accepted in commercial matters, if the value is less than 1 it is not obvious that the colour difference is perceived by a human (NCS Colour Centre for the UK and Ireland 2011). ΔE^* that also is called the Euclidean distance is calculated as;

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

where ΔL^* , Δa^* and Δb^* are the differences between the two colours that are being compared (Green & MacDonald edit. 2002, p.56) (McDonald edit. 1997,p. 111).

Today the standard observer that was defined by CIE in 1964 is used; the main difference compared to the old definition is the increase from 2° to 10° field of view for the observer (McDonald edit. 1997,p. 103). As mentioned earlier, there are several variants and updates of the original 1931 CIE colour system. However, the CIE L*a*b* system used today is also called the 1976 CIELAB because it was in 1976 that this particular system was improved to better correspond to the human perception of colours (McDonald edit. 1997,p. 111). It is important to use the *-marks when using the CIE L*a*b* system, otherwise the colour can easily be mistaken to be defined according to Hunter's Hunter Lab system from 1958 (Hunt 1991,p. 161-162). It can also be useful to know that a CIE L*a*b* colour also can be described with the polar coordinates L*, C* and h* as well. L* is still lightness, C* presents the chroma and h* is the hue angle (Kuehni 2005, p.101).

2.2.4 CIEDE2000

CIEDE2000 is also called the colour difference formula CIE 2000, it has been invented as a result of noticed problems with some differences between perceived difference in colour compared to what is measured, ΔE^* . These problems occur because the human eye has a colour discrimination threshold below which a colour difference is not noticed, the CIE L*a*b* has no such threshold. In figure 7 a part of the CIE L*a*b* chromaticity diagram is displayed, the marked white ellipses show areas of colour discrimination threshold. The human eye cannot perceive any difference between any two colours within any of these ellipses. It can be seen that the ellipses vary in size and orientation but some general conclusions have however been drawn (Konica Minolta Sensing, Inc. 2007,p. 49-50).

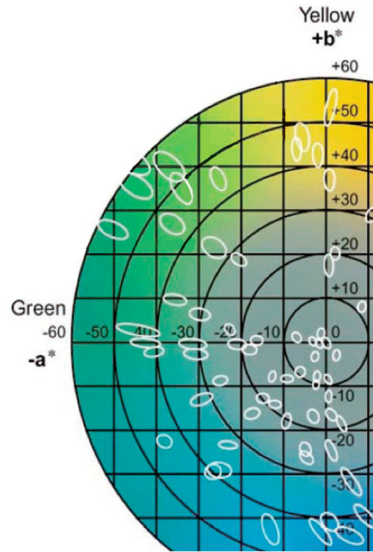


Figure 7: A plane through the CIE $L^*a^*b^*$ colour solid intersected at $L^* \approx 50$ showing ellipses according to the CIEDE2000 theory. The human eye cannot perceive any difference between any two colours within any of these ellipses (Konica Minolta Sensing, Inc. 2007). The usage of this figure is authorized by Eva Dahlman at Konica Minolta.

Firstly, it has been determined that the eye is rather insensitive to colours with high saturation; the ellipses are large and elongated in the direction of the saturation. The shorter axis of the ellipses is in general oriented in the direction of the hue in the diagram. For the colours with lower saturation is the eye much more sensitive for changes in all directions; the white marks are small and circular. Secondly, for colours with equal saturation does the sensitivity also change in the hue direction between different hues; ellipses in some directions are narrower than others. It has been found that there are thresholds also in the lightness direction even though it cannot be seen in the figure. Studies show that the sensitivity is maximal around $L^* = 50$ and smaller for both higher and lower values. Finally, it has also been found that the ellipses in the blue region are not aligned with the direction of increasing saturation. This causes severe differences between measured and perceived colour differences (Konica Minolta Sensing, Inc. 2007, p. 50-51) (Kuehni 2005, p.102-104).

If measured colour difference would have been marked in the figure as well it would have been perfect circles for the $L^*a^*b^*$ coordinates. The shape difference between a perfect circle and the ellipses in the figure can then be said to illustrate the differences between the measured and perceived colour. The CIEDE2000 formulas assign certain weight coefficients to the different Δ -values and through this the desire is to remove the inequalities between measurement results and visual evaluation (Konica Minolta Sensing, Inc. 2007, p. 51-52).

2.2.5 NCS and NCS S

NCS is an abbreviation for Natural Colour System. This system includes all 10 million colours that the human eye can perceive. The system was developed in Sweden by Tryggve Johansson, Sven Hesselgren and Anders Hård and was presented the first time in 1972. The first edition of the NCS colour atlas was introduced in 1979 and is sometimes called NCS edition 1979. The NCS is an international system that is national standard for colour communication in some countries, for example Sweden, Norway and Spain. The system is based on the human ability to characterize colours (the Hering's opponent theory); it is based on the resemblance to the six

elementary colours white (W), black (S), yellow (Y), red (R), blue (B) and green (G) (Green & MacDonald edit. 2002, p.115) (Skandinaviska Färginstitutet AB 2005).

An example of a typical NCS code is NCS 1050-Y90R, the principle of interpretation of such a code will be explained for this example, which also is marked with a bold line in figure 8. 1050 describes the nuance; 10 means that the colour contains 10% of black (S) and 50 indicates that the chromaticness (C) is 50%. Y90R describes the hue, which is the amount of different elementary colours. This specific colour contains yellow (Y) mixed with 90% red (R). A completely neutral grey colour has no hue; therefore the denotation for the hue is an N for neutral. 0300-N denotes a white colour and 9000-N is black, the neutral colours are also known as achromatic colours. The NCS colour space can be divided into the two dimensional hue circle and constant hue triangle, which are displayed in figure 8 (NCS Colour Centre for the UK and Ireland 2011) (Skandinaviska Färginstitutet AB 2005).

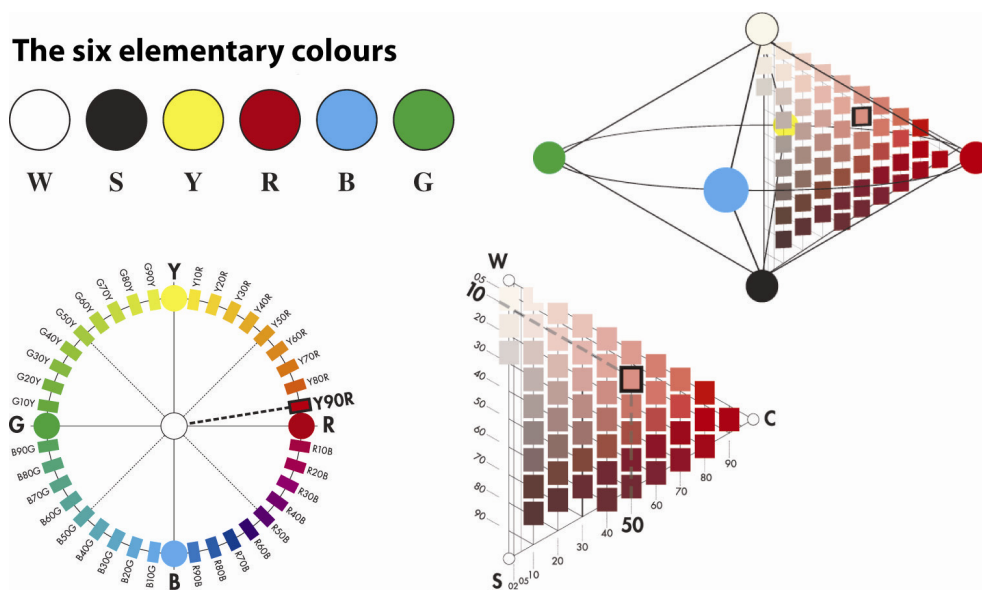


Figure 8: The NCS. From the top to the left; the six elementary colours, NCS colour space, NCS hue circle and constant hue triangle (Skandinaviska Färginstitutet AB 2005). The usage of this figure is authorized by Kenneth Johansson at Skandinaviska Färginstitutet AB.

In 1995 was the NCS revised and the new version that is standard today is denoted as NCS S for Natural Colour System Second edition. This revision implied addition of 261 new colours, subtraction of 46 old colours and that approximately 1000 old colours were slightly changed. In 2004, 200 additional new pale colours were included in the NCS S. In other words, the revision to edition two resulted in that the same colour can have different notations in the old and new system. Today it is the NCS S that is used as national standard in Sweden. When NCS S is compared to NCS it is found that NCS S has higher accuracy (NCS Colour Centre for the UK and Ireland 2011) (Skandinaviska Färginstitutet AB 2005). However, the difference between steps in the model cannot be said to always be perceived as of equal size independently of which colour that is being evaluated (Kuehni 2005, p.65).

When measurements of different standard colour swatches were made at DuPont in 2009 the following CIEL*a*b*-values were presented;

NCS 0502-B; L*= 92,16 a*= -2,18 b*= 2,24

NCS S 0502-B; L*= 93,97 a*= -1,59 b*= -1,15

For this colour the difference is large between the two editions, especially for b* where $\Delta b^* = 3,39$.

2.2.6 Light conditions

The perceived colour of an object is partly dependent on the colour of the light in which the object is viewed; therefore it is important to give some basic facts about light conditions and standard illuminants (Johansson, Lundberg & Ryberg 2008, p. 72).

The CIE has recommended some standard illuminants that should be used for general colourimetry. Some of these illuminants and their relative spectral distribution are displayed in figure 9. Illuminant C is a representation of average daylight excluding the region of ultraviolet wavelengths, it has a correlated colour temperature of approximately 6774 K. D65 is also a representation of average daylight but includes the ultraviolet light and has a correlated colour temperature of approximately 6504 K (CIE 1971, p. 11) (Konica Minolta Sensing, Inc. 2011, p. 14). The warm light from a light bulb can be described by illuminant A that has a correlated colour temperature of 2856K (Largo AB 2011, p.37).

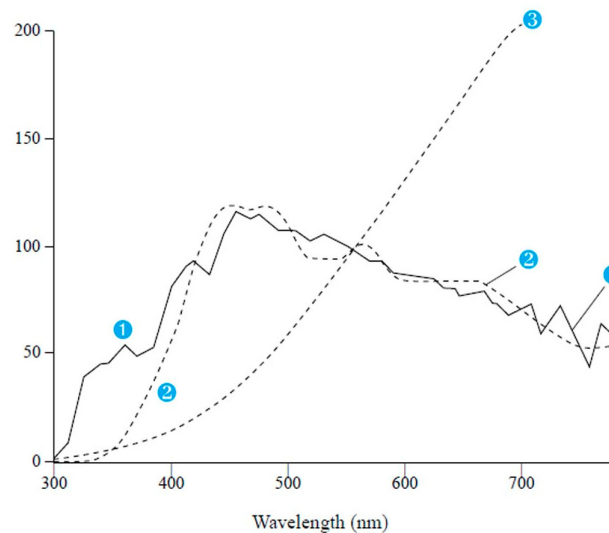


Figure 9: Some standard illuminants; 1 = D65, 2 = C and 3 = A. The figure displays the distribution of light with different wavelengths for the three types of standard illuminants. The values on the y-axis indicate the relative spectral power (Konica Minolta Sensing, Inc. 2011). The usage of this figure is authorized by Eva Dahlman at Konica Minolta.

The correlated colour temperature is the “absolute temperature on the Kelvin scale of a blackbody emitting light that gives rise to the same colour perception as a given test light” (Kuehni 2005, p.186). The scale that is normally used for description of light sources ranges from approximately 1000K to 11 000K. The colour of a blackbody that is heated to a temperature of 1000K emits a light of a warm orange colour, and 11 000K gives a cold blue light. It is a little bit confusing that a higher temperature gives a light that is perceived as colder but as mentioned the definition is based on the heating of a blackbody. A neutral lighting has a correlated colour temperature of 5000K; this is a mean value of the temperatures that normal

daylight generally consists of. The light a sunny day has approximately a correlated temperature of 5000K while it is 5500-7000K a rainy day. Depending on the light the same colour is perceived as different in different lighting (Johansson, Lundberg & Ryberg 2008, p. 72-73).

2.2.7 Effects of contrasts

Colours can be perceived as different depending on which colour adjacent surfaces or fields have. The difference in perceived colour can in certain cases be so significant that it can be hard to understand that the perceived colour of the test samples really is the same. This phenomenon is known as effects of contrasts (Johansson, Lundberg & Ryberg 2008, p. 73).

When different colours are experienced at the same time on areas placed close to each other they always influence the perceived difference between them to increase. This can both be seen for colours with different lightness as well as for colours of different hues. Contrasting effect of lightness is when a bright colour will be perceived as even brighter when it is placed close to a field of a dark colour. In the same way the dark colour will be perceived as darker when it is close to a brightly coloured field. The effect of different types of contrasts is always more obvious when one of the colour fields is significantly smaller than the other one (Nilson 2004, p. 60).

A colour sample often appears to have a colour that is closer to the complementary colour of the adjacent colour field (Jacobs 2004). This effect is known as contrasting effect of hue. The complementary colours are divided into three pairs; red & green, orange & blue and yellow & violet. The definition is that if a mixture of two colours can result in a neutral grey colour they are complementary colours (Nilson 2004, p. 26, 61).

2.3 Theory on surface waviness and roughness parameters

Surface waviness or roughness of varnished surfaces contributes to the overall perception of the surfaces' quality. Deviations in topography of a surface that are of macro geometrical size are called form deviations. Smaller deviations are said to be micro geometrical; the larger of these is called surface waviness (W) and the smaller is surface roughness (R). Waviness can often be seen as periodic variations of a surface's topography (Hågeryd, Björklund & Lenner 2007, p. 60-61).

However, there are several measures of waviness and roughness but only those that in some way are relevant for this project will be briefly described in this section. In this project the focus has been on measuring waviness since the roughness of the surfaces is too fine to perceive in a clear way with the human eye. Roughness and waviness parameters are calculated in the same way, it is only the letter R or W for the parameter that gives information about if it is a parameter that characterizes the roughness or waviness. It is the same for the raw signal called primary (P) that contains both the roughness and waviness information, as can be seen in figure 10 (Whitehouse 2002, p. 10-11). The suffix after the capital letter indicates how the parameter has been calculated (Griffiths 2001, p. 111).

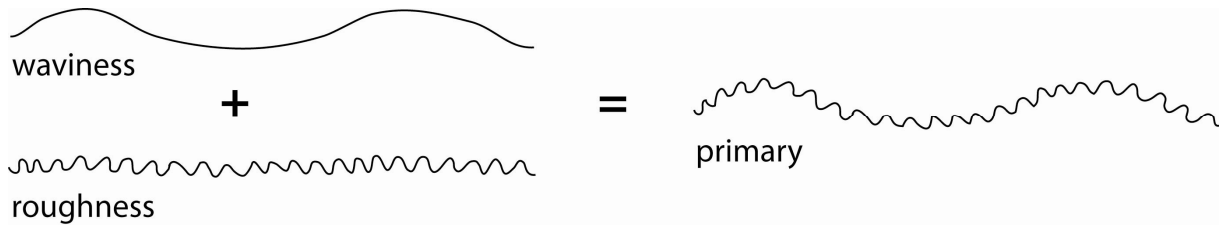


Figure 10: Schematic illustration of how a surface's primary profile is composed of the waviness and roughness profiles. This figure is based in the information on p. 58 (Griffiths 2001).

The 2D parameters are categorized in different groups depending on what they measure. Examples of height parameters are W_a , W_q , W_v , W_p and W_t (Griffiths 2001, p. 112-113). W_a is the center line average or the “arithmetic mean deviation of the assessed profile” (Griffiths 2001, p. 113). The center line is another term used to describe the mean line. The definition of this line is that the area between the 2D surface profile and the mean line should be of equal size above and below the mean line (Whitehouse 2002, p. 41). Basically to find W_a , when the mean line of the profile is found all negative deviations (valleys) should be transformed into positive deviations (peaks), W_a does then represent the average height of the profile above the mean line (Whitehouse 2002, p. 51).

W_q is the RMS average or the “root mean square deviation of the assessed profile” (Griffiths 2001, p. 114). It is very similar to W_a but is calculated as the RMS deviation to the center line instead (Whitehouse 2002, p. 51). W_t is the distance between the highest peak and lowest valley within the evaluation length (EL). This measure is rather extreme and includes the effect of any abnormal values if there are any. W_t is also equal to the sum of W_v and W_p (Griffiths 2001, p. 113-115).

W_v is the valley depth that is measured as the distance from the lowest valley to the mean line. W_p is a similar measure but measures instead the distance from the highest peak to the mean line and is called peak height parameter. Both W_v and W_p are evaluated for the sampling length (SL) which is the “fundamental distance over which the surface parameter is assessed” (Griffiths 2001, p. 20, 114).

W_{sk} and W_{ku} are examples of height or amplitude distribution parameters (Griffiths 2001, p. 112-113). W_{sk} measures the skewness or in other word the symmetry of the profile relative to the mean line. It can be used to evaluate if profiles with similar W_a and W_q has different appearance. A profile with positive W_{sk} value appears as a rather smooth profile below the mean line but with some peaks that reaches above the mean line. A negative value on the other hand indicates a profile that is rather smooth above the mean line but with some valleys down below the level of the mean line. W_{ku} on the other hand measures the normalized kurtosis of the profile, which gives information of the sharpness of the profile (Whitehouse 2002, p. 58). W_{ku} is equal to 3 for a profile that is normally distributed. A higher value indicates a sharp profile with some occasional extreme peaks and valleys while a lower value indicates a less sharp profile (Griffiths 2001, p. 118-119).

The most commonly used spacing parameters are W_{Sm} , HSC and P_c (Griffiths 2001, p. 112-113). W_{Sm} is the average peak spacing. It is measured at the mean line and specifies the average distance between profile peaks (“the highest point of the profile between an upwards and

downwards crossing of the mean line”) (Griffiths 2001, p. 122) (Whitehouse 2002,p. 55). HSC is an abbreviation for high spot count, it is calculated relative to the mean line or a parallel line suitably positioned for the study. HSC determines the number of complete profile peaks that is found above the selected reference line. Pc, peak count is another way to give information of the profile’s number of peaks. It is the number of peaks that pass completely through a region marked by two horizontal lines at a certain distance centered around the mean line. Pc is presented as number of peaks per centimeter (Whitehouse 2002,p. 56).

2.4 Statistics and probability theory

One of the most important tools in quality improvement projects according to the six sigma methodology is to use adequate statistics and probability analyses, therefore the theory supporting these analyses is important to understand.

2.4.1 Normal distribution and the Central Limit Theorem

A normal distribution is sometimes also referred to as Gaussian distribution. This is the most commonly used model for the distribution of a random variable. A simple form of the Central Limit Theorem (CLT) states that “the sum of n independently distributed random variables will tend to be normally distributed as n becomes large”. For this theorem to be valid it is necessary that the variances of all the individual random variables are small when they are compared to their sum. However, there are a few different variants of the theorem that all have somewhat different conditions for their validity (Montgomery & Runger 2007, p. 121, 752).

A normal random variable X has the expected value $E(X)=\mu$ which is equal to its long-term average value, where $-\infty < \mu < \infty$. It has also a variance $V(X)=\sigma^2$, where $0 < \sigma$. The notation $N(\mu, \sigma^2)$ is a convenient way to denote the normal distribution and its attributes. When $f(x)$ is plotted versus x for a normal random variable the curve has a characteristic symmetric bell-shape. The exact position of the curve along the x -axis varies with μ and the width is determined by σ^2 , a smaller value of σ^2 means a narrower distribution. A normal random variable $N(0,1)$ is called a standard normal random variable. (Montgomery & Runger 2007, p. 122-123, 754).

Probabilities are associated with the normal distribution as displayed below;

$$\begin{aligned} P(\mu - \sigma < X < \mu + \sigma) &= 0,6827 \\ P(\mu - 2\sigma < X < \mu + 2\sigma) &= 0,9545 \\ P(\mu - 3\sigma < X < \mu + 3\sigma) &= 0,9973 \\ P(\mu - 4\sigma < X < \mu + 4\sigma) &= 0,99994 \\ P(\mu - 5\sigma < X < \mu + 5\sigma) &= 0,9999994 \\ P(\mu - 6\sigma < X < \mu + 6\sigma) &= 0,999999998 \end{aligned}$$

(Montgomery & Runger 2007, p. 122-123) (Bergman & Klefsjö 2007, p. 303).

2.4.2 Sample mean, variance, standard deviation, SE mean and ANOVA

The sample mean \bar{x} and the sample standard deviation s are calculated from a sample of n observations selected from a larger population. This is a way of estimating the statistical parameters for the population that is of interest.

If x_i is the i :th observation of the property that is desired to be estimated then;

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$$

and
$$s^2 = \frac{\sum_{i=1}^n (x_i - \bar{x})^2}{(n-1)}$$

s^2 is the sample variance, s is always the positive square root of s^2 (Montgomery & Runger 2007, p.199-200). A convenient way to grasp the magnitude of the standard deviation for the specific analyzed sample is to calculate the relative standard deviation (RSD). The RSD is equal to $100s/\bar{x}$ and is given in percentages.

SE mean is an abbreviation for the standard error of the mean; this is a measure of the sample's variability. The SE mean is calculated as the standard deviation for the sample divided by the square root of its size (Minitab 2010).

ANOVA is an abbreviation for Analysis of Variance. When an ANOVA is performed in Minitab some other abbreviations are also commonly used; DF = Degrees of Freedom, SS = Sum of Squares and MS = Mean Square (Montgomery & Runger 2007, p. 507-509, 751).

2.4.3 Box plot, quartiles and median

Box plots are a graphical way to display results of statistical analyses and especially to compare data from different samples. Important features of the analyzed data that can be seen from a box plot are for example centre, spread, identification of outliers and departure from symmetry. To be able to interpret and fully utilize these plots some description about what information that can be found in the plots is useful (Montgomery & Runger 2007, p. 214-216). A schematic illustration of a box plot can be found below in figure 11.

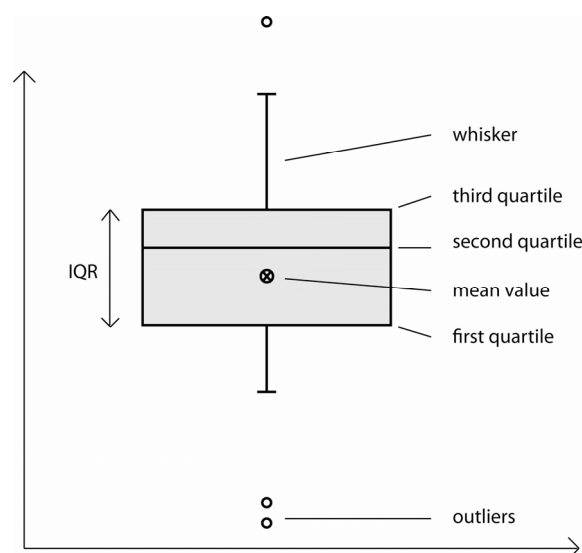


Figure 11: Schematic illustration of a box plot explaining the terminology used.

This description assumes that the boxes are arranged so that their whiskers are vertically oriented. The lower edge of the box displays the first quartile q_1 , which means that approximately 25 % of the observations are below this value. In the same way the upper edge of

the box displays the third quartile q_3 . The line horizontally placed inside the box is the second quartile q_2 or the 50th percentile, a value that also often is called the median. The median shows the central tendency of the analysed data. In some box plots there are a dot inside the box, this dot represents the mean value. The observations included in the box, between q_1 and q_3 are called the interquartile range (IQR). The IQR is a measure of the variability of the sample data. The lines that extend from the top and bottom of the box are called whiskers. The whiskers extends to the smallest respectively largest data point within 1,5 IQR from q_1 respectively q_3 . Data points that are even further away from the box are plotted as individual dots. If such a dot is placed within a range of 3 IQR from the box it is called an outlier, if it is even further away it is called an extreme outlier. (Montgomery & Runger 2007, p. 207-208 & 214-216).

2.4.4 Confidence interval, hypothesis test, P-value and T-test

The interval between L and P is called a confidence interval if L and P only are functions of the gathered sample data and if it is possible to make a probability statement of the form $P(L \leq \Theta \leq U) = 1 - \alpha$, where Θ is a parameter. The probability statement can be interpreted as; the probability of that the parameter Θ is greater than or equal to L and less than or equal to U is equal to $(1 - \alpha)$. Confidence interval is abbreviated CI and is often expressed in percentages, for example for a 95% CI this means that $\alpha = 0,05$. The interpretation of a confidence interval is that the statement that $L \leq \Theta \leq U$ will be correct 100(1- α)% of the times that such a statement is made (Montgomery & Runger 2007, p.33 & 752).

Hypothesis testing is a procedure used to determine if a hypothesis can be accepted or rejected on statistical basis. When the parameter of interest is identified a null hypothesis (H_0) is stated. H_0 is often a conservative hypothesis that means that it is no difference, for example between the data samples that is being compared if the analysis is of that kind. The counter hypothesis is called alternative hypothesis (H_1). The goal of the further analysis is then to determine whether H_0 can be rejected or not. If the difference between two groups of samples is tested a CI that includes 0 suggests that there is no difference between the two groups (Montgomery & Runger 2007, p.301-302).

When H_0 is rejected the test statistic and data is commonly said to be significant. The term P-value can then be explained as the smallest level of α that leads to rejection of H_0 , in other words at which the data are significant. In practice this means for example that if the P-value for the analyzed sample is less than a preselected level of significance α it leads to rejection of the null hypothesis. The smaller the P-value is, the smaller is the risk that a rejection of H_0 is a mistake. α can also be described as the "maximum acceptable risk for rejecting a true null hypothesis" (Minitab 2011) (Montgomery & Runger 2007, p.300-301).

There are some different types of types of t-test, only the type used in this project will now be presented briefly. A t-test is a method for hypothesis testing and it will in this project be used for testing of the difference in means between two samples where the variance is unknown. If it is fairly reasonable to assume that the variances of the two samples are equal $\sigma_1^2 = \sigma_2^2$ and that the two populations are independent normal, the following reasoning can be used. The hypotheses for a t-test of this type are $H_0: \mu_1 - \mu_2 = \Delta_0$ respectively $H_1: \mu_1 - \mu_2 \neq \Delta_0$. The test statistic T has a t-distribution with $(n_1 + n_2 - 2)$ degrees of freedom when H_0 is true. Therefore, if $H_1: \mu_1 - \mu_2 \neq \Delta_0$ the rejection region for H_0 is $t_0 > t_{\alpha/2, n_1+n_2-2}$ or $t_0 < -t_{\alpha/2, n_1+n_2-2}$. The value of $t_{\alpha/2, n_1+n_2-2}$ is found from a

table of percentage points of the t-distribution. It is the test statistic t_0 that sometimes is called the t-value (Montgomery & Runger 2007, p. 354-357, 715, 761).

2.4.5 Process capability and control limits

The capability of a process is a measure of its ability to achieve fulfilment of stated requirements. It is determined as the requirements on the process related to the natural spread of the process. One way to specify the capability is as $C_p = T_U - T_L / 6\sigma$. T_U and T_L are the upper respectively lower tolerance limits and 6σ denotes the spread of the process. Traditionally C_p is recommended to exceed 1,33 for already existing process, exceed 1,5 for new process that should be implemented and the goal with six sigma is by definition a C_p equal to 2,00. This measure of capability does not consider if the process is centred around the target value or not. Therefore, users must be observant when using this measure (Sörqvist & Höglund 2007, p. 105-106).

Another measurement of the capability that also considers the centring of the process is the corrected capability index $C_{pk} = \min \{ (T_U - \mu) / 3\sigma, (\mu - T_L) / 3\sigma \}$. This capability index does however assume that the target value is in the middle of the tolerance interval. $C_{pL} = (\mu - T_L) / 3\sigma$ is defined as the lower corrected capability index while $C_{pU} = (T_U - \mu) / 3\sigma$ is the upper corrected capability index. C_{pL} and C_{pU} are called one-sided capability indexes and are used if there is only a lower or upper tolerance limit. Because of the fact that the usage of C_p and C_{pk} considers different characteristics of the analyzed data, it is good to study both of them to receive a more complete picture of the process capability (Bergman & Klefsjö 2007, p. 291-293) (Sörqvist & Höglund 2007, p. 107).

If the capability is calculated from data that is collected from random samples during a longer time from the process, this capability reflects the actual or long-term capability which is also called the overall capability. This is the capability that the customers experience in reality because it includes all the variance and shift of the sub processes that the overall process includes. The designation P_p is sometimes used for the long-term capability and stands for Process Performance. Another way to measure the capability is the potential or short-term capability, also known as within capability. The potential capability ignores the subgroups and indicates how well the process could perform if the shift and drift of the subgroups is eliminated. (Minitab 2011) (Sörqvist & Höglund 2007, p. 108).

When analyzing a process it is of great importance to find out if it is in statistical control or if some systematic variations make it unstable, in other words out of control. If the capability of the process should be estimated in a correct way the process must be in control. A commonly used method to analyse this is different kinds of control charts where the data is plotted together with a lower (LCL) and upper control limit (UCL). Normally, these control limits are positioned 3 standard deviations below and above the centre line of the process. The basic principle of the control chart is then that if the process is in control almost all data (99,73%) will be between LCL and UCL according to the expected random variation. If any of the subgroups behave in a different way than expected according to the random variation the point will be outside the control range and represent a warning of the process. It is important to remember that control limit is not the same as specification limit or tolerance limit (Minitab 2011) (Sörqvist & Höglund 2007, p. 108-109).

3. The procedure and methods used today

This chapter will provide the reader with insight in the production process and methods used today at Asko. A brief introduction about this is necessary to explain why the conclusions and recommendations that will be presented later on are motivated.

3.1 The coating process

The varnishing or powder coating process is central in this project; therefore some basic information about it will now be presented. Figure 12 displays a schematic sketch of the sequential order of the different steps of the varnishing process. The components that are being treated in the process are placed on hangers that are individually designed for the different types of components. The hangers are then transported through the process by a conveyor system. The conveyor is very long and transportation around the whole system takes several hours.

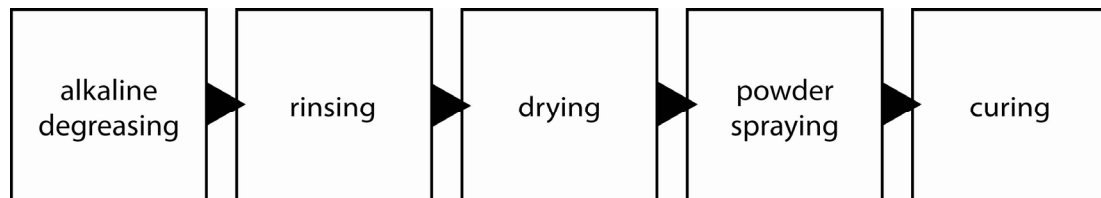


Figure 12: Schematic illustration of the sequential order of the steps of the varnishing process.

When the components have been positioned on the hangers the next step is an alkaline degreasing followed by rinsing the components twice. The next step is that the hangers pass through a tunnel with heated air for drying, which is followed by the step where the surfaces are covered with the dry powder coating material. There are three different varnishing boxes, two of them are automatic; one for white and one for other colours. There is also a manual box where an operator spray the powder onto the components. The final step is curing in an LPG furnace followed by cooling. Approximately 68 tonnes of powder is being consumed each year (ASKO Appliances AB 2009).

In figure 13 a schematic layout of the curing furnace is displayed. The four different sides of the hanger have been named 1-4 according to the denotations that the operators in the spray painting shop use. The automatic powder spray box has four different rows with four spray guns in each and the origin of the denotation is that side 1 is sprayed by the first row, side 2 by the second row etcetera. There are somehow indications that operators in some parts of the process denote the sides of the hanger related to the orientation of the hook in top of it instead. The second way of denotation does however provide neither continuity nor information of the orientation of the hangers' sides relative to the steps and layout of the process and it will therefore not be used from now on.

As also can be seen the furnace has four LPG burners with open flame. The burners are placed in top of the furnace, above the hangers. The LPG that is used in this furnace is of the type propane 95. In the furnace there are ventilation-channels in the walls that push down the hot air to the bottom of the hangers. The inner walls of the furnace are covered with some sort of metal. The conveyor has a constant speed that is not possible to easily change; the passage through the furnace takes approximately 18 minutes. The temperature in the furnace is regulated by a computer that controls the burners' activity. The distance through the furnace is long enough to maximum store approximately 70-75 hangers at the same time.

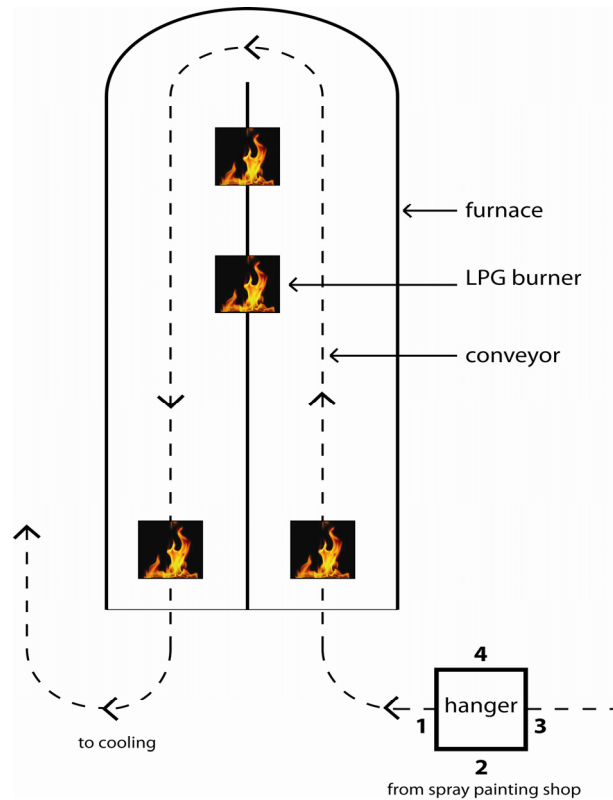


Figure 13: Schematic top view of the LGP furnace showing how the positions of a hanger are related to the positions of the burners in the furnace. All the burners are positioned above the conveyor and the hangers.

The white powder that is being used for the coating is based on a mixture of epoxy and polyester. Three different curing times are presented as guidelines for the curing of the powder; 20 minutes at 160°C material temperature, 10 minutes at 180°C material temperature or 5 minutes at 200°C material temperature (DuPont Powder Coatings Scandinavia AB 2011).

According to Thomas Jacobsson at DuPont (2011) the first property that is affected if the powder coated components are cured in too low temperature or for too short time is the adhesiveness to the metallic substrate. A film with a smooth appearance is created rather fast and without enough curing. The epoxy and the polyester acts together as binders in the powder and the pigment that provides the white colour is titanium dioxide. Each order of powder is being produced after each ordering so basically no powder is stored for longer periods. From each order that is sent to Asko a small amount of powder is saved during the next year, to provide some traceability. It is also interesting to know that approximately 1-2 % of the powder evaporates during curing when the temperature is between 100 and 120 °C. It is therefore important that venting pipes are carefully isolated to prevent the powder from covering the inside of the pipes.

Control measurements of the thickness of the varnished layer (TVL) are usually made three times each day. The thinnest thickness that is OK according to the process specifications is today 60µm. The measurement device (MiniTest 900) is thought used with the setting called "ferrous" which means that it measures the distance to the ferrous substrate and that the sheets' galvanized layer with a thickness of approximately 10µm also is included in the measurement.

The target colour for the white colour is defined as NCS 0502-B. This definition is according to edition 1979 of the NCS system and can be interpreted to contain 5% blackness, 2% chromaticness of a hue that is the elementary colour blue (B). The spectrophotometer that is used for control of the colour is set with a target colour with the following values $L^* = 92,20$ $a^* = -1,88$ $b^* = 0,85$.

The target value is rather close to the target value of the powder manufacturer ($L^*=92,78$, $a^*=-1,63$, $b^*=0,57$) that is measured where the TVL is approximately $70\mu\text{m}$. The target colour programmed in the spectrophotometer compared to the target value from DuPont; it is darker ($\Delta L^* = -0,58$), greener ($\Delta a^* = -0,25$) and yellower ($\Delta b^* = 0,28$). In other words, the powder producer compensates for the increased yellowness that appears after the curing in the LPG furnace by producing a powder that is less yellow than the desired colour of the finish products. However, compared to the NCS 0502-B standard colour swatch that was control measured for comparison at DuPont in 2009 the differences are rather large. The colour of NCS 0502-B was found to be; $L^*=92,16$, $a^*=-2,18$, $b^*=2,24$ and the difference is especially significant for b^* . Therefore, it is not really appropriate to say that the target colour today is NCS 0502-B.

The colour is control measured three times each day and after each change of powder batch. The tolerance limits that are used today are according to the CIE $L^*a^*b^*$ system;

$$\Delta L^* = \pm 0,6$$

$$\Delta a^* = \pm 0,3$$

$$\Delta b^* = \pm 0,65$$

The recommendation from the manufacturer is to measure on a spot with a TVL of approximately $70\mu\text{m}$. After the start of this project when the focus on control measurements increased, colour and TVL is measured and noted for approximately the same spot of a surface. The colour is measured on specified positions of certain components which can be seen in figure 26.a and 26.d. No recommendation exists about from which side of the hanger the samples should be collected.

3.2 Powder coating

To enhance the understanding of the varnishing process some further information about powder coating and some of the materials and elements involved in the process will be presented in this section.

3.2.1 Powder coating

The powder coating has mainly two purposes; to protect the surface underneath and to create a surface that is perceived as attractive by the customers. Besides the finish of the surface it is the colour that makes a surface attractive, the constituent in the powder that gives the varnish its colour is called colour pigment. To make the powder coating protective against for example corrosion, wear, environmental effects and mechanical abrasion it needs to contain a binder. Powder for coating does not contain any solvent (DuPont Powder Coatings Scandinavia AB 2005).

When the powder should be applied in the painting shop the powder is dry and it is applied to the desired surfaces by electric attraction. The powder particles are forced through nozzles of

painting guns by compressed air streams and the friction between the particles and the nozzle results in electrically or statically charged powder particles. The component that should be varnished is electrically grounded usually through the contact with the conveyor system to which it is attached. The grounded component then attracts the charged powder particles and the next step in the process is to cure the paint. Basically, in the curing the powder melts and forms a smooth strong surface layer that is properly attached to the surface (DuPont Powder Coatings Scandinavia AB 2005) (Operators in the paint shop at Asko 2011) (Thomas Jacobsson at DuPont 2011).

The mainly polymeric powder is somehow insulating and as the powder is sprayed onto a surface, areas with thin powder layer attracts the powder more than area insulated by a thicker layer. In this way the resulting layer is often rather uniform in thickness (Ashby & Johnson 2010, p. 319)

3.2.2 Coating defects

When powder coating components, an abundance of different kinds of surface defects and deviations can occur. Some of the defects that have been observed or investigated in this project will be briefly presented in this section.

One rather simple but annoying defect is small particles of dust or dirt in the coated surface. A more complex type of defect is craters. They look like small bowl-shaped marks in the coating, often they do also have raised edges which makes them even easier to detect. Craters are caused by low surface-tension contaminants that can be of several different types and occur of several different reasons. The contaminant is often evaporated during curing and therefore the exact reason to each crater is very difficult to trace (Ryntz & Yaneff edit. 2003, p. 206-207).

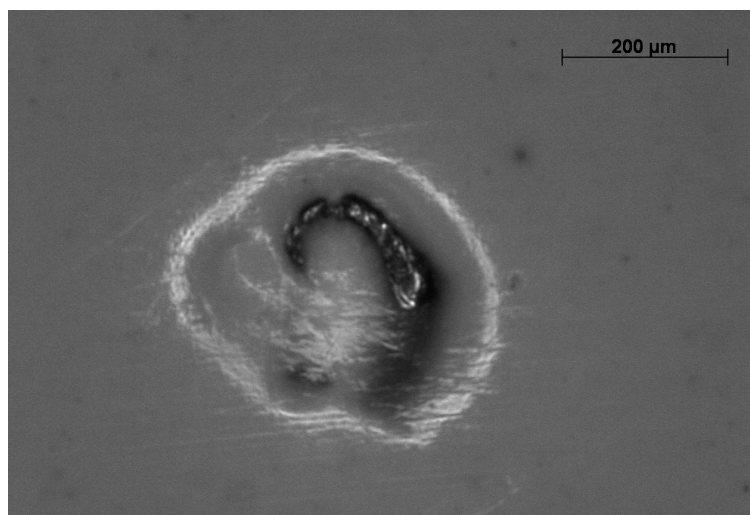


Figure 14: An example of a crater that was found during this project.

Solvent pops are another type of defects that look like pinholes, small bubbles or crater-like blowouts. These are caused by air or volatile solvents that are trapped under the coating film during curing and that pops out through the film instead of diffuse through it (Ryntz & Yaneff edit. 2003,p. 213). One of the surface defects that are most interesting in this project is orange peel structure; it is called to be a flow-related defect. The bumpy appearance of orange peel structure is caused by either too high viscosity of the heated powder or that the temperature is

raised too fast so that the powder is cured too fast and has little time to flow out and form a smooth layer. On the other hand if the viscosity is too low or if too much paint is applied this can cause runs on the surface (Ryntz & Yaneff edit. 2003,p. 215-216).

3.2.3 Materials in the coating powder; epoxy, polyester and titanium dioxide

Epoxy and polyester are designations of two different families of polymeric materials. Polyesters are polymers that are composed of monomers that contain an ester group (McCrum & Buckley 1997, p. 44). There are both thermosetting and thermoplastic polyesters. The different types of unsaturated polyester (UP) are all thermosets, the curing of UP is enabled by its carbon-carbon double bond. The curing of polyester needs some kind of initiator. Some polyesters are thermoplastic instead; two examples are polyethylene terephthalate (PET) and polybutylene terephthalate (PBT) (Institutionen för material- och tillverkningsteknik 2010, p. 28,34-35).

Epoxies are thermosets that are characterized by their epoxide group, such a group is a ring of three atoms; one oxygen and two carbon. The curing of epoxy needs at least the addition of a curing agent. Epoxies often have high performance properties and are therefore often much more expensive than for example UPs (Institutionen för material- och tillverkningsteknik 2010, p. 28,34-35,37). Epoxies are often used as engineering adhesives; they are of special value because they bond well to metals (McCrum & Buckley 1997, p. 286). Titanium dioxide is also known as titania (TiO_2) and is a ceramic material; it is often used as a colour pigment because of its clear white colour (Nationalencyklopedin 2011) (Richerson 2006).

3.2.4 Liquefied petroleum gas (LPG) used for curing of powder coatings

LPG is a gas that is stored in its condensed liquid state of aggregation. The type of LPG that is most commonly used in Sweden is called Gasol propan 95, translated to English this means LPG propane 95. LPG is a kind of fuel that today is used in various different ways, for example to melt, dry or cure material (Preem 2004).

Even though the concentration of different constituents in the LPG propane 95 basically is the same, small differences in the composition can be noticed when the products from different manufacturers are compared. The LPG from Statoil described below can be regarded as a rather representative example of LPG propane 95. This type of LPG contains minimum 95 gas volume-% propane (C_3H_8) and maximum 5 gas volume-% butanes (C_4H_{10}). It does also contain small amounts of other alkanes, alkenes and dienes. To facilitate that a possible leak of LPG is noticed an additive with a very strong smell called ethyl mercaptan ($\text{C}_2\text{H}_5\text{SH}$) is added. LPG propane 95 with added ethyl mercaptan contains maximum 16 mass-ppm (mg/kg) sulphur (Statoil 2006), (EnergiLink 2011).

The relative density of LPG gas is approximately 1,55 if it is 1,00 for air. In other words LPG gas is rather much heavier than air. In air the LPG has its thermal ignition point at approximately 460 °C and the maximal temperature of the flame in air is around 1900 °C. A mixture of LPG and air is ignitable only if it contains 2-10 volume-% of LPG gas (Statoil 2006).

LPG is a rather space effective fuel, 2 litres of liquid LPG weights approximately 1 kg and when transformed to gas form it results in around 500 litres of gas (AGA 2010). These figures about the volume of the fuel is approximate and are assumed to be valid under normal usage circumstances, because factors as temperature, pressure and so on influences it strongly. When

1 kg of LPG is incinerated in air the combustion process theoretically consumes 12 m³ air (AGA 2010).

In reality there is always an excess of air that is not consumed during the combustion. The excess is estimated to be around 20 % of the air, which results in that a more realistic figure of the necessity of air is 18 m³ when 500 litres of LPG gas is incinerated (Preem 2004). Therefore, the supply of air needs to be very good to enhance highest possible degree of combustion in the process.

Only if the mixture of gas and air is optimal the combustion process can be close to complete. This would then result in that only carbon dioxide (CO₂), nitrogen (N₂) and water (H₂O) would be the rest products from the process (AGA 2010). However, in reality at least some nitrogen oxides (NO_x) are produced as a rest product of the combustion (Statoil 2010). Some NO_x gases are always produced by combustion in air (Nationalencyklopedin 2011).

3.2.5 Necessary for combustion of LPG; Air

Since air also is one of the most important constituents for combustion of LPG and curing of the powder the composition of normal air will be briefly presented. The composition of dry air is normally; 78,1 vol.% nitrogen (N), 20,9 vol.% oxygen (O), 0,9 vol.% argon (Ar), 0,04 vol.% carbon dioxide (CO₂) and traces of many other gases. The content of water steam is in general 3-15 ‰ (Nationalencyklopedin 2011).

3.2.6 Sulphur in LPG and coating powder and nitrogen oxides in exhaust gases

Sulphur (S) is a non-metallic element. It is most commonly found in its α-phase, where each molecule is formed of eight sulphur atoms. Sulphur in this form has a yellow colour. This element is among others found in fossil fuels and in different minerals in the bedrock. The compound of sulphur and hydrogen has an acidification effect on the environment. The reactivity of sulphur is high and it can react with most types of other elements, especially it often reacts with oxygen and form different oxides such as for example sulphur dioxide (SO₂) and sulphur trioxide (SO₃) (Nationalencyklopedin 2011).

Nitrogen oxides (NO_x) is a designation for all compounds between nitrogen and oxygen. Some of the most common compounds and their properties/usage are nitrogen oxide (NO) in among others exhaust fumes from combustion of fossil fuels, nitrogen dioxide (NO₂) which is a poisonous gas with a powerful brown/red colour and dinitrogen oxide (N₂O) which is more commonly known as laughing gas. Another term that is relevant in the context is nitrous gases. This is a designation for a mixture of different gaseous nitrogen oxides, mostly NO and NO₂. Inhalation of these nitrous gases is harmful (Nationalencyklopedin 2011).

3.3 Examination of varnished surfaces

The procedure for examination and assessment of appearance related deviations and defects is defined by a document called The general appearance specification. When any significant kinds of deviations or defects are noticed, the actual component is examined and evaluated by the appearance group in the examination room. The purpose of examination in this specific environment is to every time perform the assessment in a similar way and to evaluate the finish in the same way as a customer would do based on the customer's expectations.

The examination room is a room without any windows and according to the specification all colours of the fixture and walls in the room should be neutral and have an achromatic colour. The lighting should be perceived as white and slightly warm. The procedure of assessment is performed according to a specified routine. Different areas of the machines are assigned different importance because of their position relative to the customer.

When the examination room was briefly examined in this project it was found that the colour of the walls and fixtures were;

• White walls;	L*=93,43	a*=-0,15	b*=2,13
• White skirting-boards;	L*=91,78	a*=-1,11	b*=8,43
• White doors to cupboards;	L*=84,05	a*=-0,26	b*=4,02
• Grey worktops;	L*=62,35	a*=0,47	b*=1,18

It can be seen that the colours have relatively neutral a^* values but some of the white surfaces are definitely too yellow to be called neutral. A completely neutral or achromatic colour would have both an a^* - and b^* -value equal to 0. The colour of the lighting is perceived as neutral or possibly cold. However, the correlated colour temperature has not been measured; therefore these perceptions cannot be justified in a numerical way.

4. Methods

In this chapter will the methods and instruments used in this project be presented. It will be described how they work and also how they were customized to the requirements of the project as well as why they were selected.

Before the start of this project the purpose and objective was clearly stated. The methods or ways that would generate this knowledge was not specified. However, it was decided that a six sigma project about improvements of the varnishing process should be performed parallel with this diploma thesis project. It was also decided from the beginning that the author of this report should participate as an active member on this project. Thereby it was also predefined that statistical analysis should be a part of the project since it is one of the most powerful tools when using the six sigma methodology. Besides these few predefined guidelines for the project the author of this report was responsible for the selection of methods, design of experiments as well as the evaluation of them. Since the scope of the project is wide and the selection of methods was left for the author she was also responsible for how the questions and problems should be attacked during the project.

The methods and tests performed during the project are more or less based on and combinations of recognized methods. However, in the current project they were customized to be as beneficial as possible for the current questions and problems. The methods and instruments will be presented in four different sections corresponding to the different sections of the project, see the process plan in figure 1. Some of the methods and instruments have been used in several different parts of the project but will only be described the first time it is relevant in this chapter.

4.1 Market survey

The objective of this part of the project was to create an outline of the competitors' white colours based on a smaller market survey.

4.1.1 Design of the survey

ASKO is a premium brand that is developed for the upper market segments. The selection of the machines that were measured in the survey of the competitors' white colours was based on maps of market positioning which earlier have been compiled at Asko. For example, one of the main competitors was the brand with the largest representation in the survey.

All colour measurements are given as Δ -values when the results of the survey is presented. This is because it was of interest to investigate how the competitors' colours are compared to the ASKO-white colour. During this survey a spectrophotometer was used for correct measurement of the competitors' machines. The spectrophotometer is more detailed described in section 4.1.2.

In total the colour was measured on surfaces of 29 different machines of 12 different brands, totally 107 surfaces were examined. Due to secrecy the brands or models of the measured machines are not revealed in this report. To make the resulting data of the measurement more easy to overview it was colour coded. To make the connection clear to the production process at ASKO and the current target colour the tolerance limits used in production today was used for the colour coding.

4.1.2 Spectrophotometer

A spectrophotometer is equipment for measurement of colour. The spectrophotometer used in this project was a portable Konica Minolta CM-2600d, only this model and mainly the used settings will be briefly described in this section. The settings used during this project were those normally used for control in production at Asko. The basic function of a spectrophotometer is that it measures the light at different wavelengths that is reflected from a surface and presents a reflection curve or numerical values of the colour (Largo AB 2011, p.37).

This spectrophotometer is a d/8 instrument, which means that the illumination is diffuse and that the viewing angle is 8°. The measurements were made with the SCI setting, which means Specular Component Included. The wavelength range of the instrument is 360-740nm and the wavelength pitch is 10nm. The light sources in the instrument are three pulsed xenon lamps and the standard illuminant D65 was used, which is further described in section 2.2.6. The setting with a circular measurement area with a diameter of 8 mm was selected (MAV). The repeatability of the instrument is specified as having a standard deviation of the colorimetric value ΔE^* within 0,04 (Konica Minolta Sensing, Inc. 2001). Even though the repeatability is good many of the presented colour measurements are mean values of several measurements.

The 10° standard observer was selected, which is according to the recommendations of CIE1964 (Konica Minolta Sensing, Inc. 2001). The CIEL*a*b* colour space was used for the measurements.

4.2 Customer inquiry

The objective of this part of the project was mainly to generate knowledge about how customers perceive different white colours and surface defects and to find the customers' preferences about these features.

4.2.1 Target group for ASKO

To enhance the understanding of which type of customers that the ASKO products are designed and developed for, a summary of the description of ASKO's predefined target group will follow.

The target group is mainly women in the age between 35 and 65, but also couples and families. Members of the target group have middle to high income and education from college and/or university. The majority of the members own their house/apartment and many of them consider themselves to be the one that makes decisions about the choice of white goods. Characteristics that are assumed to be important for the target group are among others; quality, design, environmental friendliness, brand reputation and competitive price of the products (ASKO Appliances AB 2010).

4.2.2 The overall design of the tests

The tests were performed to understand how customers and users perceive different hues of white and what they prefer. It was also performed to receive knowledge about which surface defects that are noticed and how they are perceived by customers. For the different tests different machines and sheets were selected because of their colour or defects and acted like demonstration objects. These objects are further described in the sections below related to the more specific description of the two different parts of the investigation.

In total, 103 persons participated in the tests. This large amount of participants was selected to give a statistically secured result; it must also be remembered that the tests were conducted in different variants (Karlsson 2007, p.45). The participants were mostly officials but some participants were also staff from the production. One of the reasons to this was that ASKO has a booking system where it is possible to book meetings with all officials; therefore it was more convenient to perform the tests this way. Probably, the higher representation of officials does also match the defined target group better as well. It is important that the opinions in a study of this kind represent the true customers'.

However, the officials were carefully selected which resulted in a rather high representation of most of the different departments such as marketing, research, development, economy, quality, after sales and so on. The author has also tried to attain an even distribution of female and male participants. It is possible that the participants and their opinions are biased by their work at Asko, therefore the representation of many departments were important; the sum of different biases then probably result in a compilation that is satisfying close to the reality of a true customer. The participants in the test can therefore be said to be theoretically representative participants (Karlsson 2007, p.33). It can however not be neglected that some of the participants can be regarded as expert users because of their experience of the actual types of products and defects (Karlsson 2007,p.45).

The tests were performed in two different environments; the examination room and an ordinary room with normal light and windows. The examination room was described more in detail in section 3.3. The tests were performed in these two environments to elucidate differences and similarities in the results and thereby how the surrounding environment affects the judgement of colour and defects. The examination room is normally used for assessments about whether an identified defect on a component in production is critical or not. On the other hand do the customers almost always experience the products in different kinds of ordinary rooms with windows of different sizes and different lighting from various directions.

For that reason, not only the outcome of each individual test is important but also the difference between the tests. The appearance of an ordinary room differs from day to day and for different times during a day; for example because of the weather outside the windows and the direction of the sunshine and lighting. Therefore, a short notation about the conditions in the ordinary room will be made for each test when the results are presented; one of the days when the inquiry was made in the ordinary room was a sunny day while the other one was cloudier. The room selected for the representation of a random ordinary room was ASKO Showroom at Asko. In these two environments, the demonstration objects were also ordered in different arrangements and the idea behind the overall design of this inquiry is the method called customer clinic which is further described in section 4.2.3.

During the test the participants were asked to answer some questions about how they perceive the demonstration objects that were prepared for them. Questions about attitudes or personal preferences were also given. The complete questions during the inquiry are presented together with summaries of the results in section 5.2.1 and 5.2.3. The questions were somewhat changed for the different arrangements because due to the large amounts of participants it was then possible to receive statistically representative information concerning more aspects of the colour and surface finish. The interviews were personal and semi-structured, the reasoning

considering these interviews and the product representation is further presented in section 4.2.4. The show machines were of different brands but the logos were covered with black masking tape to make it less obvious for the participants of which brands the machines were. The participants were also asked to try to only consider the colour and finish of the surfaces and machines and to neglect design, details and similar.

When judging the colour the participants were asked to go not too close to the machines to better simulate for example the situation when searching for a machine to purchase in a store. In the later part of the test when the finish was judged the participants were asked to rather quickly wipe the surfaces of the machines as if they were dirty and to “think out loud” and report what they directly noticed. The results for the inquiry about the colour and the finish are presented separately in section 5.2.1 and 5.2.3, but during the inquiry each of the participants were first asked about the colour and then about the finish.

4.2.3 Customer clinic

During a clinic the customers examine or test real product samples and present their opinions or ratings about them (Karlsson 2007, Appendix A 25). Therefore a clinic often represents a rather realistic user situation that stimulates different senses and by that enhances the generation of comments and results as well as ensures the correctness of the results (Karlsson 2007, p. 41). To better understand the mental process behind the comments and act, it can be an advantage to ask the participant to “think out loud”, in other words to all the time tell the clinic leader how she/he thinks and why (Karlsson 2007, 31).

4.2.4 Personal semi-structured interviews and product representation

One person at a time was interviewed; the reason was that answers that were not biased by the presence of other co-workers were wanted. The possibility that the presence of the interview-leader herself could bias the answers must however be remembered. The interviews were carried out during the customer inquiry about colour and finish and were of semi-structured type. The foundation for the interviews was a series of predefined questions with predefined answers but complementary questions like “How?” and “Why?” were frequently used to evoke reflection and afterthoughts (Karlsson 2007, p. 26-27).

For those questions where the participants were asked to rate something on a scale, an odd number of alternatives were selected to make it possible for the participant to choose the neutral option in the middle. This was done because the nature of the question was such that a neutral opinion was not unlikely. During the interviews also additional information that the participants shared was documented.

The participants were interviewed in an environment where several different models of the concerned type of product were found. A proper product representation enhances all kinds of interviews and observations and it has been found that the more realistic product representation the more detailed information is given by the participants (Karlsson 2007, p. 42).

4.2.5 Research concerning white colour

For examination of how white colours are perceived five machines were selected as representative demonstration objects based mainly on their Δb^* -value. The machines and their colours are further described in appendix II - Description of show machines in colour inquiry. It

can also be seen that for some machines does ΔL^* and Δa^* vary significantly as well. The machines are due to secrecy not completely described but however they were designated according to this;

- A:** Brand 3 XXX, washing machine
- B:** Brand 7 XXX, tumble dryer
- C:** ASKO DW90.1, dishwasher
- D:** Brand 5 XXX, tumble dryer
- E:** Brand 1 XXX, washing machine

In the figures that show the arrangement of the machines they are coloured according to their Δb^* -value, and not their absolute colour value since it is the difference compared to the target colour of ASKO today that is interesting.

The tests concerning white colour were first conducted with two different arrangements of the machines in the examination room, called arrangement 1 and 2. In the next step the test was performed with another arrangement in ASKO Showroom, called arrangement 3 and 4 to better correlate with the finish tests. Illustrations of the arrangements are displayed in figure 15 and 16.

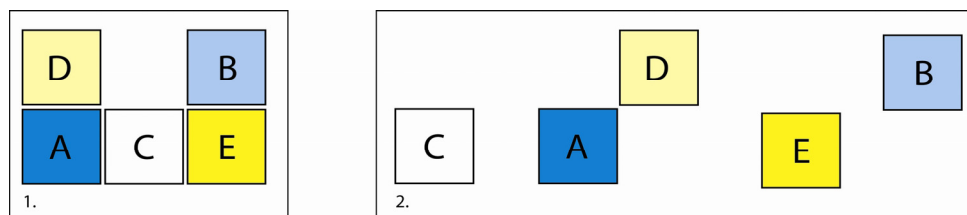


Figure 15: The order of the machines in arrangement 1 and 2 shown in front views. In arrangement 2, the arrangement is shown in a panorama view since the machines were placed along the walls of a small room.

In the test with arrangement 1 did 52 persons participate; 23 participants (44,2 %) were female and 29 were male (55,8 %). 20 participants gave their opinion about arrangement 2; 6 of them were female (30 %) and 14 were male (70 %). In conclusion, 72 persons participated in the examination room; 29 women (40,3 %) and 43 men (59,7 %).

In the test with arrangement 3 did 17 persons participate; 4 participants (23,5 %) were female and 13 were male (76,5 %). 14 participants gave their opinion about arrangement 4; 50 % of them were female and 50 % were male. In conclusion, 31 persons participated in the test in ASKO Showroom; 11 women (35,5 %) and 20 men (64,5 %).

The day when arrangement 3 was used was a sunny day with strong and warm light from the window. The next day, when arrangement 4 was used it was cloudy and the sunlight was perceived as not as strong and with a cooler colour. The arrangement was the same both days and is displayed below in figure 16.

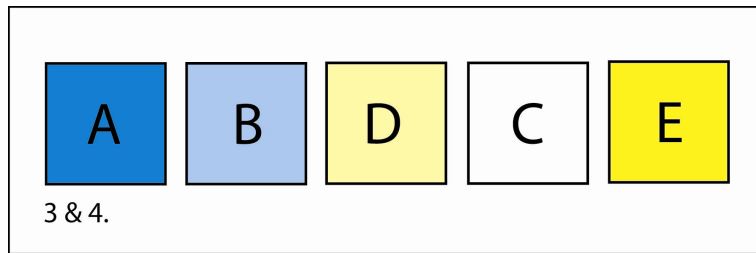


Figure 16: The order of the machines in arrangement 3 and 4 shown in a front view.

4.2.6 Research concerning surface finish

During the inquiry after that the colour was investigated the participants were asked to examine the surface finish of some machines and separate sheets and share their thoughts about finish of this types of machines.

The show machines and sheets in this part of the test were designated by Greek letters and their finish defects were designated with figures. In the list below are the demonstration objects and their defects presented. The objects were selected because of their different types of defects but the participants did also find other defects that are presented below as well.

Description of the demonstration objects;

α A single sheet; the door of a dish washer.

1. In the middle region of the sheet; inward bending marks from the press forming can be found.
2. The surface texture has a slight tendency to look like orange peel.
3. In the upper left corner and in the middle there are scratches.

β A single sheet; the door of a dish washer.

1. In the lower region of the sheet; there is a dot of dried paint.
2. The surface texture has a slight tendency to look like orange peel.

γ A single sheet; the side sheet of a washing machine/tumble dryer.

1. The sheet has a surface texture similar to orange peel and this texture is arranged in horizontal stripes along the surface.
2. In the upper region of the surface there are some scratches in the paint.

δ A complete machine (F); ASKO dish washer of model DW90.1.

1. Paint has run down the door which has resulted in thicker marked edges of the lower corners.
2. There is a sharp edge around the round displays.
3. There are small dots in the paint around the handle.
4. The edge of the white details on the round displays is not smooth.
5. The panel is not properly fitted to the front sheet, this results in a shadow between the two components.

ε A complete machine (G); ASKO washing machine of model WM70.1.

1. In the upper area of the front and side sheets the layer of paint is thinner than normal. This has resulted in a surface texture slightly similar to fine sandpaper in these regions.
2. The top sheet has a surface texture similar to orange peel.
3. There are some scratches in the plastic panel.

These finish defects are difficult to document in a fair way with photographs because of reflections and that some defects are only visible when they are viewed from a certain angel of view. However, some of them are displayed below in figure 17.

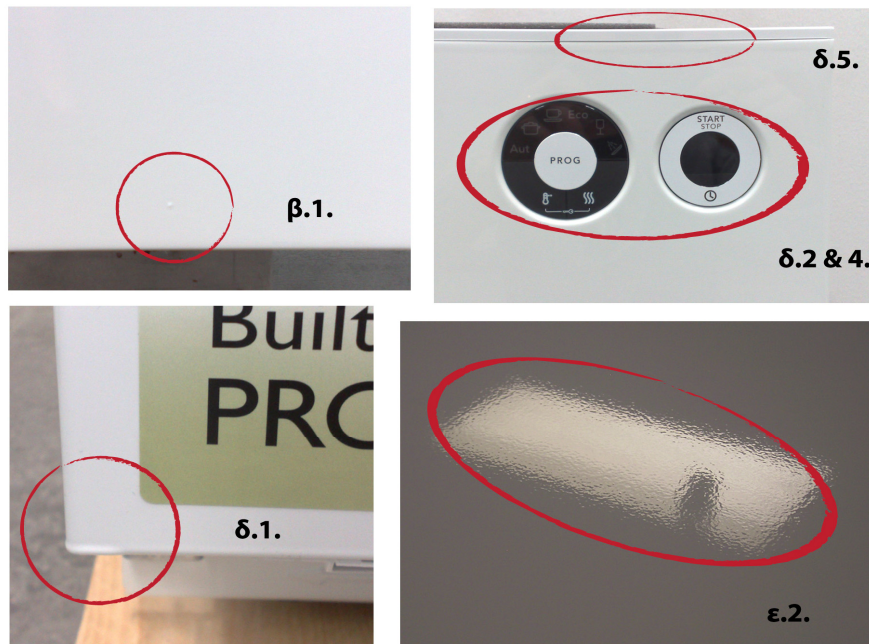


Figure 17: Some of the surface deviations found on the demonstration objects. β.1.; a dot of dried paint. δ.1.; paint has run down the door. δ.2.; a sharp edge around the displays. δ.4.; the edge of the white details is not smooth. δ.5.; the panel is not properly fitted to the front sheet. ε.2.; orange peel structure.

It was also of interest during this inquiry to investigate how the participants preferred to examine the surfaces. The reason for this was to collect data that confirm that the procedure defined by the general appearance specification is suitable or to propose changes. This was investigated through direct observations, a method further described in section 4.2.7.

How the customer examined the surfaces;

Alternative 1: The participant contemplated the surfaces from different angles at a distance of approximately 50cm and used the cloth just to make some few wipes.

Alternative 2: The participant did only contemplate the surfaces from different angles at a distance of approximately 1m.

Alternative 3: The participant wiped the surfaces carefully as if they were dirty and examined them visually.

Alternative 4: The participant examined the surfaces mainly by touching them gently with hands and fingers and examined them visually from few angels at a close distance (30 cm).

When the demonstration objects were examined in the examination room they were arranged as figure 18 shows.

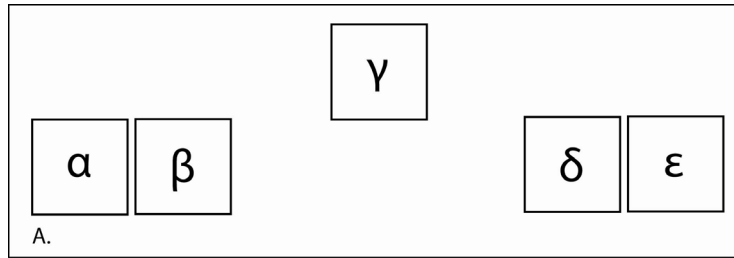


Figure 18: The order of the demonstration objects in arrangement A shown in a front view. The arrangement is shown in a panorama view since the machines and the sheets were placed along the walls of a small room.

In the test with arrangement A of the machines and surfaces the number of participants who have examined each specimen varies slightly because in the beginning of the test some more surfaces and machines were added after a while. However, the deviations are probably not large enough to affect the results. In total, the samples that were examined by the maximum number of participants were examined by 54 persons; 20 women (37,0 %) and 34 men (63,0 %).

Arrangement B and C that was used for the inquiry in ASKO Showroom is displayed in figure 19. As already mentioned, the first day when arrangement B was used was a rather sunny day and the next day when arrangement C was used was cloudier.

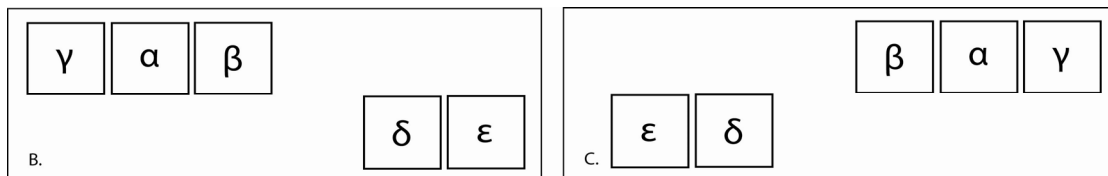


Figure 19: The order of the demonstration objects in arrangement B and C shown in front views. The arrangements are shown in a panorama view since the machines and the sheets were placed along the walls of a room.

When the surfaces were examined in arrangement B, 17 persons participated; 4 female participants (23,5 %) and 13 male participants (76,5 %). In this arrangement the three single sheets (α , β and γ) were placed in a spot with more light (both from the lighting and the sun) compared to the two complete machines (δ and ϵ). The next arrangement C, was judged by 14 participants; 50 % woman and 50% men. In this arrangement the two complete machines (δ and ϵ) were placed in a spot with more light (both from the lighting and the sun) compared to the three single sheets (α , β and γ). To sum up, 31 persons participated in the tests in ASKO Showroom; 11 women (35,5 %) and 20 men (64,5 %).

4.2.7 Direct observations

During the customer inquiry direct observation of the participants was used to investigate how a potential customer most naturally examines the surface finish of a dishwasher, tumble dryer or washing machine. The results were then analyzed and four generalised alternatives of examination procedures were found. The results of the study were then categorized into these four alternatives and a result was found. Direct observation is a good method to use when investigating how users act in different situations or handle products, it can also give information that is unbiased by the interviewer (Karlsson 2007, p. 30).

4.3 Examination of surface waviness and microstructure

The objective of this part of the project was mainly to determine if measurements of surface waviness can be used for assessment of surfaces with possible orange peel structure.

4.3.1 Examination of waviness with stereo microscope

The idea with the measurement and examination of different surface waviness parameters was to investigate how a varnished surface with orange peel structure could be identified by this method. If the values of waviness parameters for surfaces with this undesired structure are understood it can also be understood what the profile looks like microscopically and what causes the unattractive appearance. The roughness has not been considered in this study because the size of the marks forming the orange peel structure is significantly larger and more clearly visible to the human eye than the roughness is. The instrument used for the waviness measurements was an optical stereo microscope which is further described in section 4.3.2.

During this part of the project ten different white varnished components were analysed, five of the components had a mainly smooth and attractive surface while the other five components had a less attractive orange peel structure. However, a single component can offer very many different positions for measurements. Therefore, an extensive amount of measurements were made on these ten components. By sorting and comparing the results of the measurements the information that will be presented in section 5.3.1 has been elucidated.

The exact value of the different parameters differs for different measurement instruments, different magnifications as well as for different λ -values. The λ -value is set by the user of the equipment and filters the roughness from the waviness. Therefore the settings that were actually used during the measurements will be presented as well when the value of the parameters are presented in the results. This is important to increase the repeatability of the study and enhance the usage of the found values and limits.

The parameters that were automatically measured by the software were W_a , W_q , W_{sk} , W_{ku} , W_v , W_p and W_t . The spacing parameters W_{Sm} , HSC and P_c were manually calculated from the generated surface profiles. If a spacing parameter is desired to be calculated in a more automatic way this can for example be performed with the aid of a rather simple algorithm in for example Matlab that analyzes the generated profile values. For the measurement of all the spacing parameter an assessment length of $1300\mu\text{m}$ was used. The reference line for the measurement of HSC was positioned $20\mu\text{m}$ above the mean line. The P_c was measured for a region of $\pm 20\mu\text{m}$ around the mean line.

Extensive iterations with different combinations of magnifications and λ -values were made. Finally, the selected combination was 60 times magnification and a λ -value equal to $200\mu\text{m}$. This magnification was high enough to measure the topography with enough accuracy but still low enough to include the effects of the orange peel structure in the part of the surface being analyzed. The data was collected along different drawn profiles as in figure 20 and rectangles as in figure 21. The software's automatic measurement of the surface topography was not accurate enough because sometimes when the slices of measurements were not aligned totally correct abnormal edges of the surfaces as in figure 22 were the result of the calculation.

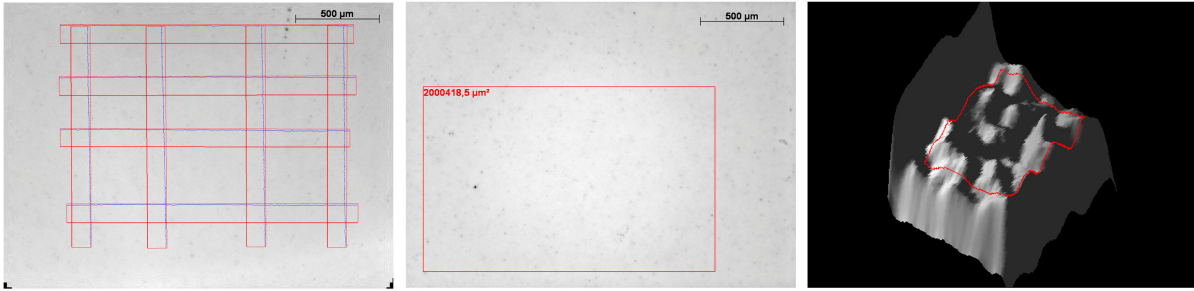


Figure 20, 21 and 22: Profiles along which the waviness have been measured, a rectangle along which the waviness has been measured and a 3D model of a measured surface showing the resulting edge of improper alignment of the individual measurements of each slice.

4.3.2 Optical microscopy

Optical microscopy is commonly abbreviated OM. The type of instrument used in this project was a Zeiss stereo microscope of the model SteREO Discovery .V20. The software that was used for the analysis of the images was Axio Vision rel. 4.8.2.

When opaque samples are examined, as in this project, the light from the illumination system that is reflected from the sample is examined. It is when the reflected light beams are reflected in different directions that a picture of the specimen is possible to see for the observer. Besides the illumination system the optical system is the other basic element of the light optical microscope (LOM). Most often this type of microscopy is used for examination of microstructures of prepared samples (Callister 2007,p. 98).



Figure 23: The stereo microscope used in this project.

In this study when it was used for measurements of the surface topography no sample preparation was needed except for wiping the samples clean from dust and grease. When using the stereo microscope together with the software the topography of the sample's surface is measured for many thin slices of the uppermost surface layer. The result of these measurements is then aligned and compiled to a representation of the total surface's structure.

4.3.3 Examination of appearances of microstructure with SEM

The material that was analysed in this study was a varnished white side sheet belonging to a washing machine/tumble dryer with obvious horizontal striped orange peel structure and a TVL of approximately 80-90 μm . The samples were first cut into suitable size with a low speed diamond saw, ethanol ($\text{CH}_3\text{CH}_2\text{OH}$) were used as coolant. The samples were cleaned by a quick dip in isopropanol followed by a short rinsing in ethanol.

The samples that are analysed with a SEM, an instrument further described in section 4.3.4, must be electrically conductive. Therefore the samples were coated with a thin layer of carbon. The carbon layer is so extremely thin that it is not visible in the micrographs during examination. The samples were mounted onto small sample holders which were placed on a larger holder device which made it possible to rotate and change between the samples in the SEM. In figure 24, the two mounted samples are shown as well as a pen to illustrate how small the samples were.

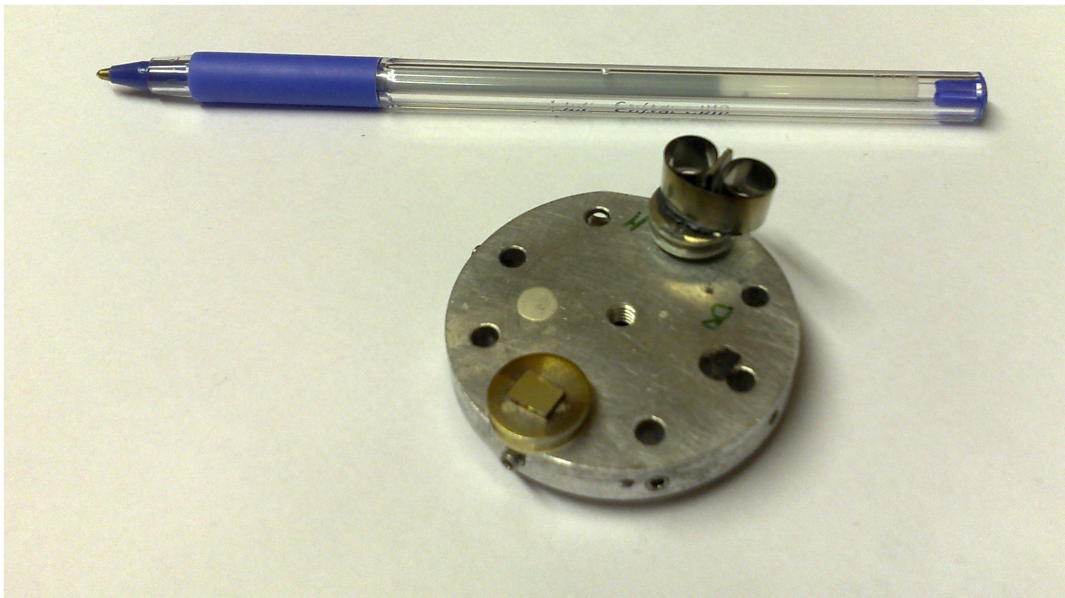


Figure 24: Mounted samples ready to be examined with the SEM.

4.3.4 Scanning electron microscopy

A common abbreviation for scanning electron microscopy is SEM. The instrument used in this study was a LEO Gemini, which is a FEGSEM; field emission gun scanning electron microscope.

Electron microscopy has the possibility to be used for examination at considerably higher magnification than optical microscopy. During examination with a SEM, electron beams are used instead of light as for the OM. Magnetic lenses are used to focus the beam on the sample and create images that can be analyzed. The very high magnification of these microscopes is possible because the electrons are accelerated across very high voltages. The resulting wavelength of the electron can then be as small as fractions of a nanometre (Callister 2007,p. 98, 100-101).

However, the samples must be electrically conductive if an analysis with a SEM should be possible. In addition to that extremely high magnification is possible, also great depth of field is provided with this instrument (Callister 2007,p. 98, 100-101). There are different types of

electrons that can be analyzed, for example backscatter electrons (BSE) and secondary electrons (SE). X-rays can be used for chemical analysis of the sample, such an analysis is called EDX; energy dispersive X-ray spectroscopy. The instrument used in this study had three different types of detectors, which are used for different purposes. The SE2 detector views the sample from the side and cannot indicate chemical differences of the examined objects while the InLens detector examines the surface with high accuracy from directly above the sample.

4.4 Analysis of the varnishing process

The objective of this part of the project was to understand how the output of the varnishing process can be controlled and is affected by different process factors. It was this part of the project that was an important part of the six sigma project arranged at the company, this part was also the most extensive one.

4.4.1 The overall design of the analysis

The analysis of the varnishing process was extensive and included several different experiments and statistical analyses because of the complexity of the analyzed process. Initially in this part, in cooperation with the rest of the six sigma team, the historical colour measurements from the varnishing process was analyzed to possibly reveal historical trends. An initial process study was also performed to improve the understanding of the process and to reveal factors and corresponding effects that were of interest to investigate in this analysis.

For the analysis of historical colour measurements, data were available from the beginning of 2008 until Mars 2011 when this analysis was performed. The number of measurements for each of the first three years was approximately 600 and for 2011 so far it was 120 measurements.

When the extensive amount of data later was collected from the actual process it was important to collect as much data as necessary to make the results of the analysis statistically reliable. Difficulties to adjust the process parameters and the order of the components on the conveyor, made the process itself to a limitation of the amount of collected data. Therefore, constant survey of the process and which data that were possible to collect set the upper limit for the data that was collected from the varnishing process.

4.4.2 Execution of colour measurements during the project

To enhance the understanding of the protocols from the colour measurements, how the data was collected and how the statistical analyses were performed some general information will now be presented about it.

The first of the several experiments in this part of the project resulted from a design of experiment (DOE) plan of Taguchi design, this method is further described in section 4.4.3. In this first experiment the three levels for the factors time and temperature were based on the recommendations from the technical data sheet for the powder, which is further discussed in section 3.1. To make the text more readable “thickness of varnish layer” is frequently abbreviated with TVL in the following text. The TVLs designated as thin, normal and thick in the first experiment do not imply a strict range of thicknesses. Since the TVL is difficult to set in the process the designations describe a wider range of thicknesses achieved by manual painting, painting in the regular spray painting box or a combination of these.

The time that is stated in the protocols of the measurements indicates approximately when the hangers after the curing furnace passed the table with measurements equipment after the cooling. This information is given just to inform roughly about when in the day the measurements were made. To designate the different sides of a hanger the designations in figure 25 are used. These designations are partly based on the hanger's orientation when it enters/exits the furnace and was further discussed in section 3.1. Figure 26 illustrates where the measurements have been performed on different types of components. That the measurements have been made on standardized spots is an essential and basic requirement for being able to collect data that an analysis can be based on. However, in the first experiment where the TVL was altered the colour can have been measured on other spots if the varnish was too thin to cover the surface properly at the regular spot.

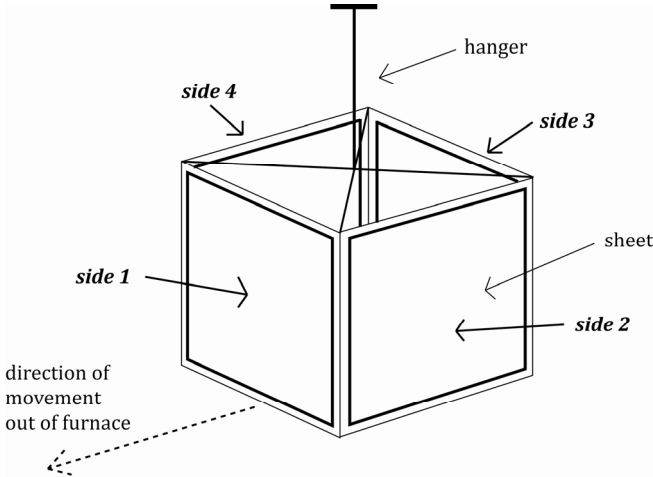


Figure 25: The designations of the different sides of a hanger related to its direction of movement.

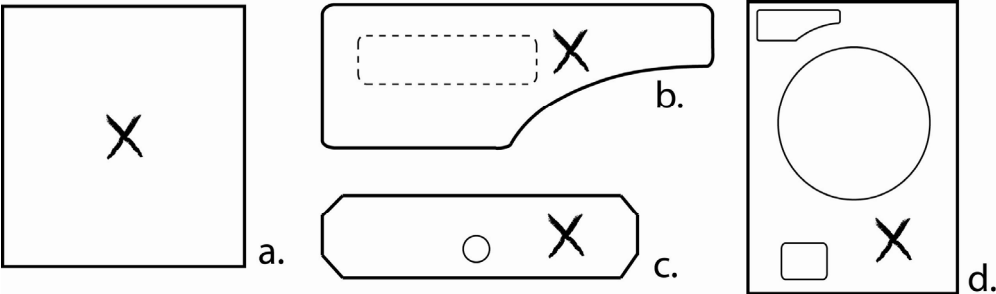


Figure 26: A schematic sketch showing where the measurements have been made on different types of components; a. square/rectangular sheets such as top sheets and front doors, b. lid to detergent pocket (with or without hole), c. reinforcement plate to the bottom sheet of a DW d. front sheet to a WM. The components are sketched in different scales to enhance the understanding.

The analyzed data in the analyses in section 5.4 come from samples with unequal sizes. In some analyses data from such unequal samples will be compared and the difference in sample size might then be relevant in other cases it is of less importance. In the appendices (VIII-XXIV) with the complete compilation of the data and the analyses from Minitab, complete information about the sample sizes can be found.

In all the statistical analyses in this part of the project the parameter α is set to 0,05. This is a fairly common value on this parameter and it is consistent to use the same value through the whole analysis process. The analyses about if there is a statistical difference or not between specified samples are based only on the extensive amount of gathered data in this project. The software that was used for the calculations and statistical analyses was Minitab.

4.4.3 Design of Experiment; Taguchi design

Design of Experiment is often abbreviated DOE. The DOE is a way to plan an experiment in a statistical way so that two or more variables are changed simultaneously. This is the opposite to the traditional approach of finding factors that causes a problem where one variable is changed at a time and the other ones are held constant. The traditional approach often demands an extensive amount of measurements and is therefore very time consuming; neither can different combinations of variables be analyzed. With the DOE also the experimental error is found and by that the confidence level in the results can be analyzed (Gupta 2004, p. 36-37). Genichi Taguchi began to develop a way of DOE that focuses on variation in the 1950's. His ideas are often used still today for planning of experiments (Bergman & Klefsjö 2007, p. 206). In this project, the first experiment resulting in the measurements called Measurement A-B is based on Taguchi's ideas about design of experiment.

4.4.4 Special measurement of temperature in the curing furnace

To better identify and understand the temperature differences between sheets on different positions of a hanger and between different positions along the same surface further temperature measurements were needed. This was done with the aid of self-adhesive temperature labels from SPIRIG of the model CelsiStrip CS-D. These labels have marks for eight different temperatures between 166 and 204 °C. These labels measure material temperature and the white indicators become black when the specified temperature has been reached during less than 1 second (ALATÉ AB 2010). These measurements were made around noon 2011-05-06.

Nine labels were mounted according to the pattern visible in figure 27 on the front of four top sheets. The labels were mounted on positions that are intersected by line A-D from the earlier colour measurements. In total, nine labels were also mounted on the back of the top sheets on different positions such that one of each position was represented in total. These four sheets were placed on the same hanger and were sent through the LPG furnace during normal operation without being varnished.

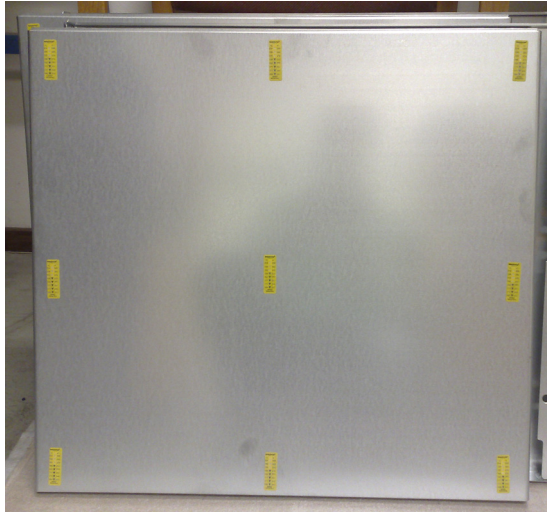


Figure 27: A top sheet with nine mounted temperature labels.

5. Performance and results

In this chapter the results of the project will be presented, also more details about the performance will be presented. The chapter is divided into four different parts that correspond to the different parts of the project.

5.1 Market survey

In this section of the report will an outline of the competitors' white colour be presented.

5.1.1 The competitors' white colours

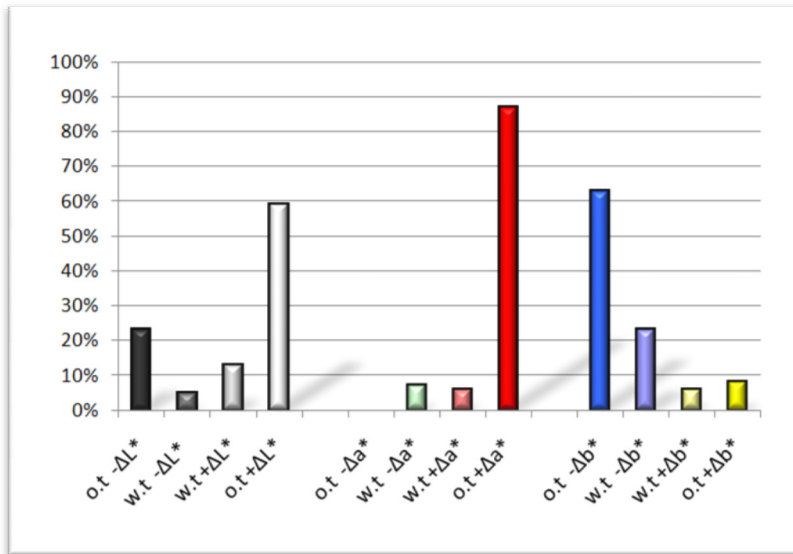
A complete compilation of the measurements from this part of the project can be found in appendix I - Colour of competitors' machines. However, the brand or model of the machines are not revealed in this appendix due to secrecy. All colour measurements are given as Δ -values, because it was of interest to investigate how the competitors' colours are compared to the ASKO-white colour. As mentioned earlier, the spectrophotometer is set with a target colour that is $L^* = 92,2$; $a^* = -1,88$; $b^* = 0,85$, with this information the absolute colour of the measured machines can easily be calculated if it is desired.

To make the compilation of the data from the different measurements and the analysis of it easier to grasp some abbreviations have frequently been used; WM = washing machine, TD = tumble dryer, DC = drying cabinet and DW = dish washer. The measured colours are categorized by if it contains little or much more of a certain hue, the basis for this is the tolerance limits used in production today. If nothing else is noted in the protocol of the measurements the panels are made of some kind of polymeric material. The colouring of the cells containing the data in the appendix might not be the most beautiful seen but its main purpose is to quickly give the reader an overview of the measured colour. Some of the panels were covered with a thin layer of a transparent polymer, for these panels especially the measurement of ΔL^* is not correct because of the spectrophotometer's difficulties to measure correctly.

The analysis will be presented for different groups to see possibly interesting trends and the number of measured machines or surfaces will be given in brackets in the headings above the diagrams. The results will also be presented separately for varnished metal surfaces and surfaces of polymeric parts. This analysis of the competitors can be useful in understanding which white colours are available at the market and what is considered to be a suitable colour by other companies.

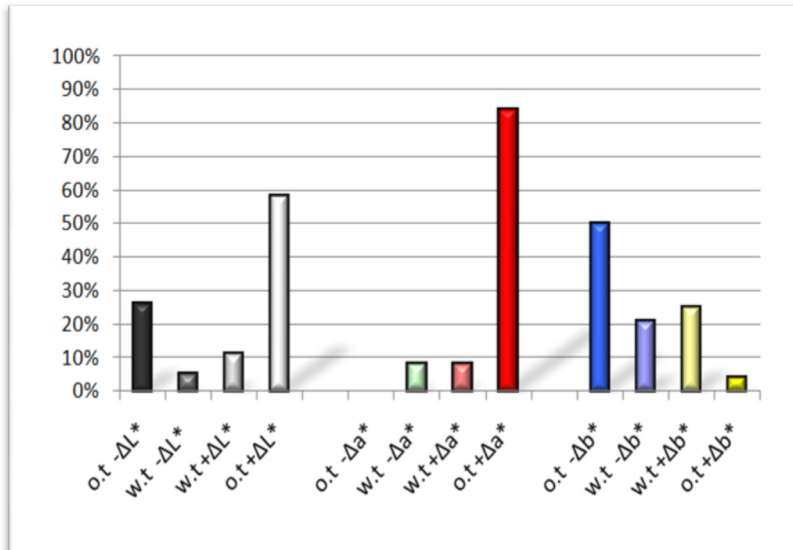
For each of the groups, diagrams present how many percentages of the measured machines that relates to the ASKO-white colour in a certain way. Also some basic statistics have been calculated, such as mean, standard deviation, median and also which colour these statistics represent in absolute values. The abbreviations *o.t* and *w.t* on the x-axis stands for *out of tolerances* respectively *within tolerances*. The bars in the diagrams are also colour coded in the same way as the data in the corresponding appendix to better visualize which relative hue a certain bar corresponds to.

- **All of the machines (29)**
Varnished metal (83)



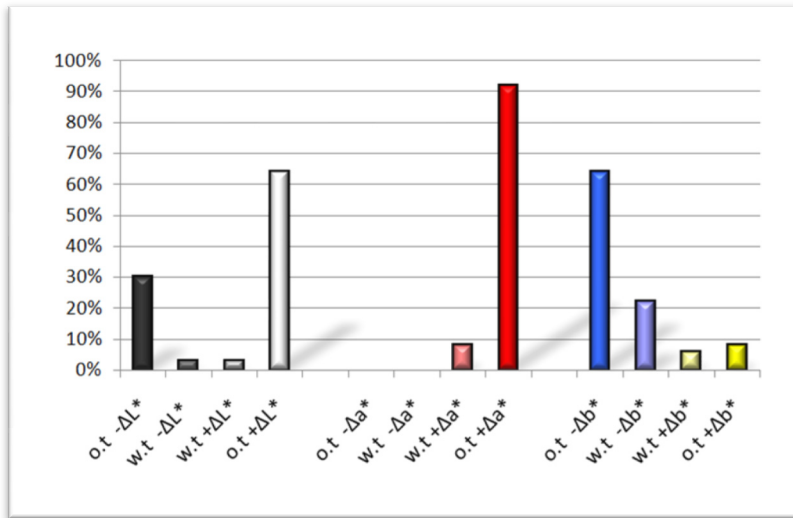
Mean values; $\Delta L^* = 0,83$ $\Delta a^* = 0,71$ $\Delta b^* = -0,84$
Standard deviations; $s_{\Delta L^*} = 1,54$ $s_{\Delta a^*} = 0,37$ $s_{\Delta b^*} = 1,08$
Medians; $\Delta L^* = 1,03$ $\Delta a^* = 0,77$ $\Delta b^* = -0,98$
The presented Δ -values result in a mean respectively median colour which are;
 $L^* = 93,03$ $a^* = -1,17$ $b^* = 0,01$
 $L^* = 93,23$ $a^* = -1,11$ $b^* = -0,13$

Polymeric parts (24)



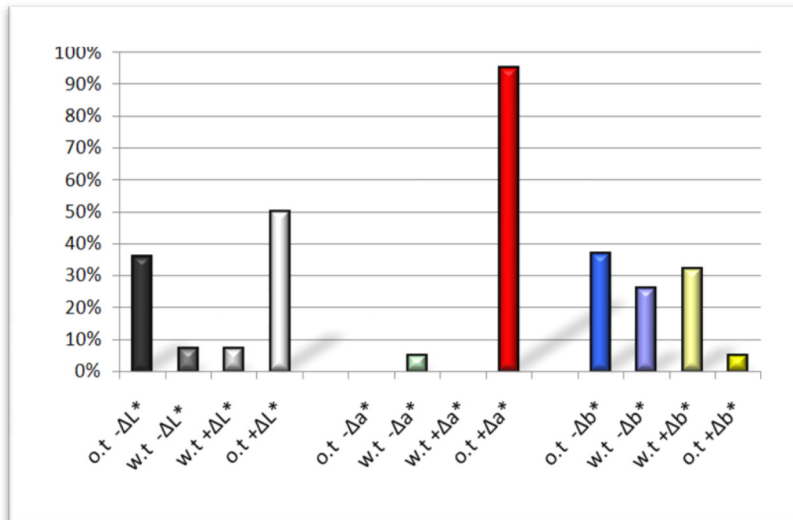
Mean values; $\Delta L^* = 0,64$ $\Delta a^* = 0,87$ $\Delta b^* = -0,65$
Standard deviations; $s_{\Delta L^*} = 1,60$ $s_{\Delta a^*} = 0,59$ $s_{\Delta b^*} = 0,94$
Medians; $\Delta L^* = 0,89$ $\Delta a^* = 0,95$ $\Delta b^* = -0,75$
The presented Δ -values result in a mean respectively median colour which are;
 $L^* = 92,84$ $a^* = -1,01$ $b^* = 0,20$
 $L^* = 93,09$ $a^* = -0,93$ $b^* = 0,10$

- **All of the machines except ASKO, Cylanda and UPO (21)**
Varnished metal (64)



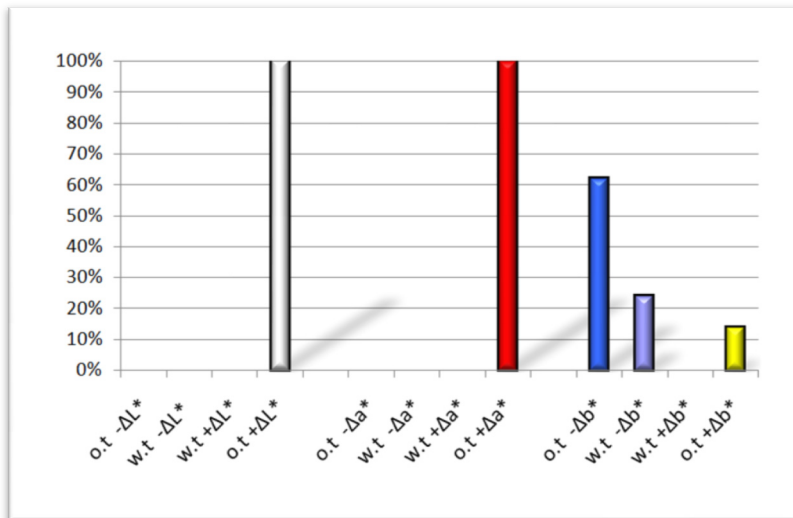
Mean values; $\Delta L^* = 0,77$ $\Delta a^* = 0,80$ $\Delta b^* = -0,86$
Standard deviations; $s_{\Delta L^*} = 1,63$ $s_{\Delta a^*} = 0,29$ $s_{\Delta b^*} = 1,11$
Medians; $\Delta L^* = 1,12$ $\Delta a^* = 0,84$ $\Delta b^* = -1,02$
The presented Δ -values result in a mean respectively median colour which are;
 $L^* = 92,97$ $a^* = -1,08$ $b^* = -0,01$
 $L^* = 93,32$ $a^* = -1,04$ $b^* = 0,17$

Polymeric parts (19)



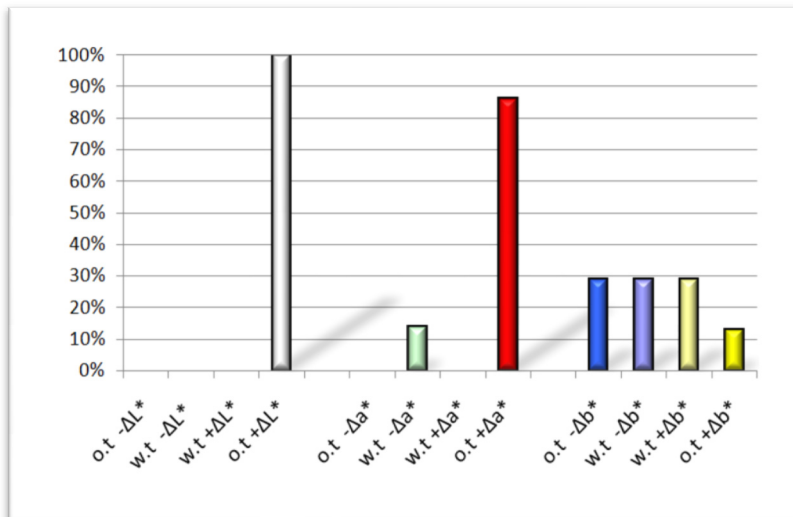
Mean values; $\Delta L^* = 0,33$ $\Delta a^* = 1,01$ $\Delta b^* = -0,50$
Standard deviations; $s_{\Delta L^*} = 1,68$ $s_{\Delta a^*} = 0,53$ $s_{\Delta b^*} = 1,00$
Medians; $\Delta L^* = 0,78$ $\Delta a^* = 1,00$ $\Delta b^* = -0,55$
The presented Δ -values result in a mean respectively median colour which are;
 $L^* = 92,53$ $a^* = -0,87$ $b^* = 0,35$
 $L^* = 92,98$ $a^* = -0,88$ $b^* = 0,30$

- **One of the main competitors (7)**
Varnished metal (21)



Mean values; $\Delta L^* = 1,88$ $\Delta a^* = 0,88$ $\Delta b^* = -0,50$
 Standard deviations; $s_{\Delta L^*} = 0,51$ $s_{\Delta a^*} = 0,16$ $s_{\Delta b^*} = 0,91$
 Medians; $\Delta L^* = 1,90$ $\Delta a^* = 0,90$ $\Delta b^* = -0,95$
 The presented Δ -values result in a mean respectively median colour which are;
 $L^* = 94,08$ $a^* = -1,00$ $b^* = 0,35$
 $L^* = 94,10$ $a^* = -0,98$ $b^* = -0,10$

Polymeric parts (7)



Mean values; $\Delta L^* = 1,97$ $\Delta a^* = 1,14$ $\Delta b^* = -0,37$
 Standard deviations; $s_{\Delta L^*} = 0,28$ $s_{\Delta a^*} = 0,80$ $s_{\Delta b^*} = 1,18$
 Medians; $\Delta L^* = 1,96$ $\Delta a^* = 1,54$ $\Delta b^* = -0,17$
 The presented Δ -values result in a mean respectively median colour which are;
 $L^* = 94,17$ $a^* = -0,74$ $b^* = 0,48$
 $L^* = 94,16$ $a^* = -0,34$ $b^* = 0,68$

5.1.2 Summarizing remarks; competitors' colours

According to these measurements there is a noticeable deviation in colour between ASKO and other brands. This is just a competitor survey of modest scale but it can anyway be used as an indication of in which direction the competitors' colours are. Significant deviations are found for all three colour parameters and many mean and medians of the Δ -values are around 1. In general the colours are brighter (positive ΔL^*), less green (positive Δa^*) and more blue (negative Δb^*). When analyzing these Δ -values it is important to remember ASKO's target colour. For example, the target value for a^* is -1,88 which means as long as the positive Δa^* -values are not larger than 1,88 the colour is only less green instead of red. For all the groups it is obvious that the less green colour is one of the clearest deviations. For the main competitor's machines in the survey 100% of the surfaces are also much brighter than the ASKO colour, both for the varnished and polymeric components.

5.2 Customer inquiry

In this section of the report will the results from the customer inquiry be presented. The results are both concerning white colour and surface finish.

5.2.1 Research concerning the white colour

To enhance the understanding of this section the colour coding of the demonstration objects that also is described in section 4.2.5 is displayed below in figure 28. As also mentioned earlier, the machines are coloured according to their Δb^* -value, and not their absolute colour value since it is the difference compared to the target colour of ASKO today that is interesting.

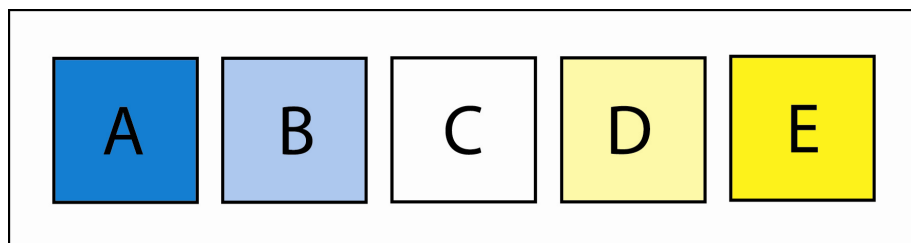


Figure 28: The colour coding of the demonstration objects denoted A-E that are used in the research concerning white colour. The colour coding is based on Δb^* -values.

In the following section, the results of the interviews and observations are presented for the different questions. The number that is presented is the total from arrangement 1 and 2. However, the separate results for the two arrangements are presented in brackets as (1:x) and (2:x) to reveal possible differences induced by the rearrangement and the different distance between the machines.

- **Summary of results from arrangement 1 and 2**

1. Which of the five machines have the most neutral/unblended white colour? In other words, which colour contains the least quantity of different hues other than white?

A: 40 persons	55,6 %	(1: 53,8 %)	(2: 60 %)
B: 22 persons	30,5 %	(1: 30,8 %)	(2: 30 %)
C: 9 persons	12,5 %	(1: 13,5 %)	(2: 10 %)
D: 1 person	1,4 %	(1: 1,9 %)	(2: 0 %)
E: none	0 %	(1: 0 %)	(2: 0 %)

2. Which of the colours do the customer perceive as the most attractive? If the customer would order a machine today which colour would she/he select?

A: 26 persons	36,1 %	(1: 32,7 %)	(2: 45 %)
B: 24 persons	33,3 %	(1: 40,4 %)	(2: 15 %)
C: 18 persons	25 %	(1: 19,2 %)	(2: 40 %)
D: 3 persons	4,2 %	(1: 5,8 %)	(2: 0 %)
E: 1 person	1,4 %	(1: 1,9 %)	(2: 0 %)

27 persons (37,5 %) (1: 40,4 %) (2: 30 %) selected the same colour as they perceived as the most neutral white colour.

3. When purchasing a new dish washer, how important is it that the white colour on the machine matches with/is the same as the colour of other white surfaces in the kitchen? (1 = not important at all, 5 = conclusive for the selection of machine)

1: 1 person	1,4 %	(1: 1,9 %)	(2: 0 %)
2: 3 persons	4,2 %	(1: 5,8 %)	(2: 0 %)
3: 19 persons	26,4 %	(1: 26,9 %)	(2: 25 %)
4: 35 persons	48,6 %	(1: 46,2 %)	(2: 55 %)
5: 14 persons	19,4 %	(1: 19,2 %)	(2: 20 %)

This data gives a mean value equal to 3,81 (1: 3,75) (2: 3,95) and a median equal to 4 (1: 4) (2: 4).

4. When purchasing a new washing machine/tumble dryer, how important is it that the white colour on the machine matches with/is the same as the colour of other white surfaces in the bathroom/laundry room? (1 = not important at all, 5 = conclusive for the selection of machine)

1: 14 persons	19,4 %	(1: 21,2 %)	(2: 15 %)
2: 17 persons	23,6 %	(1: 19,2 %)	(2: 35 %)
3: 26 persons	36,1 %	(1: 36,6 %)	(2: 35 %)
4: 13 persons	18,1 %	(1: 19,2 %)	(2: 15 %)
5: 2 persons	2,8 %	(1: 3,8 %)	(2: 0 %)

This data gives a mean value equal to 2,6 (1: 2,65) (2: 2,5) and a median equal to 3 (1: 3) (2: 2,5).

5. The customer is about to purchase a new dish washer and has found a model which has the desired functions and design but an obvious difference in the white colour compared to the white colour in the customer's kitchen*. If the customer then finds an identical machine but which has the right colour and is 2000 SEK more expensive, which one does the customer select?

The cheaper:	32 persons	44,4 %	(1: 38,5 %)	(2: 60 %)
The more expensive:	40 persons	55,6 %	(1: 61,5 %)	(2: 40 %)

* When answering this question the participants assume that their kitchen is rather modern and/or maintained in a good condition.

6. In general, how important does the customer think it is to match colours of the furnishing? Are colours a major factor when selecting which furnishing to purchase or how it should be arranged?
(1 = not important at all, 5 = conclusive for the selection of fixtures and furniture)

1: none	0 %	(1: 0 %)	(2: 0 %)
2: 1 person	1,4 %	(1: 1,9 %)	(2: 0 %)
3: 13 persons	18,0 %	(1: 15,4 %)	(2: 25 %)
4: 37 persons	51,4 %	(1: 50 %)	(2: 55 %)
5: 21 persons	29,2 %	(1: 32,7 %)	(2: 20 %)

This data gives a mean value equal to 4,08 (1: 4,13) (2: 3,95) and a median equal to 4 (1: 4) (2: 4).

While the participants were active in the inquiry they did also give many spontaneous comments and shared their general opinions about the actual topic, a compilation of the comments can be found in appendix III – Comments from customers during inquiry; arrangement 1 & 2.

However, in general about the test and the comments;

- At least two men with defect colour vision participated in the test. However, they did not have clearly deviating opinions about the white colours than other participants.
- The majority of the comments were concerning yellow and blue hues, some comments were about grey hues and only few of the comments were concerning green hues.
- In the test when using arrangement 2 most of the participants first walked around in the room between the machines, then they stopped between machine A and B and focused alternating on these two machines and after a while they made their decision about the most attractive colour.
- The white colours which contain a clearly noticeable amount of yellow (D and especially E) are experienced to express second-hand and high age. Machines/surfaces with this colour does not look fresh or clean. These colours are therefore seldom perceived as attractive.

In the following section the results of the interviews and observations are presented for the different questions. The number that is presented is the total from arrangement 3 and 4. However, the separate results for the two arrangements are presented in brackets as (3:x) and (4:x) to reveal eventual differences induced by the rearrangement and by the change of weather. The day when arrangement 3 was used was a sunny day with strong and warm light from the window. The next day, when arrangement 4 was used it was cloudy and the sunlight was perceived as not as strong and with a cooler colour.

- **Summary of results from arrangement 3 and 4**

1. Which of the five machines have the most neutral/unblended white colour? In other words, which colour contains the least quantity of different hues other than white?

A: 15 persons	48,4 %	(3: 58,9 %)	(4: 35,7 %)
B: 7 persons	22,6 %	(3: 17,6 %)	(4: 28,6 %)
C: 8 persons	25,8 %	(3: 23,5 %)	(4: 28,6 %)
D: none	0 %	(3: 0 %)	(4: 0 %)
E: 1 person	3,2 %	(3: 0 %)	(4: 7,1 %)

2. Which of the colours do the customer perceive as the most attractive? If the customer would order a machine today which colour would she/he select?

A: 14 persons	45,2 %	(3: 64,8 %)	(4: 21,5 %)
B: 4 persons	12,9 %	(3: 17,6 %)	(4: 7,1 %)
C: 12 persons	38,7 %	(3: 17,6 %)	(4: 64,3 %)
D: none	0 %	(3: 0 %)	(4: 0 %)
E: 1 person	3,2 %	(3: 0 %)	(4: 7,1 %)

15 persons (48,4 %) (3: 52,9 %) (4: 42,9 %) selected the same colour as they perceived as the most neutral white colour.

3. Which of the five machines have the white colour that contains the greatest quantity of grey? In other words, which colour is perceived as the darkest one on a scale from black to white?

A: 10 persons	32,3 %	(3: 23,5 %)	(4: 42,9 %)
B: none	0 %	(3: 0 %)	(4: 0 %)
C: 9 persons	29,0 %	(3: 35,3 %)	(4: 21,4 %)
D: 11 persons	35,5 %	(3: 41,2 %)	(4: 28,6 %)
E: 1 person	3,2 %	(3: 0 %)	(4: 7,1 %)

4. On which of the five machines do the customer perceive the most distinct difference in white hue between two adjacent surfaces? Where on the machine is this difference noticed?

A: 1 person	3,2 % (3: 0 %)	(between panel and front sheet) (4: 7,1 %)
B: none	0 % (3: 0 %)	(4: 0 %)
C: 1 person	3,2 % (3: 0 %)	(between handle cover and front sheet) (4: 7,1 %)
D: 2 persons	6,5 % (3: 0 %)	(between panel and front sheet) (4: 14,3 %)
E: 5 persons	16,1 % (3: 11,8 %)	(between panel and front sheet) (4: 21,4 %)
F:* 3 persons	9,7 % (3: 0 %)	(between displays and front sheet) (4: 21,4 %)
G:* 19 persons	61,3 % (3: 88,2 %)	(between panel and front sheet/top sheet/(the buttons and knob)) (4: 28,7 %)

* Machine F and G were used in the inquiry about the finish but were also included in this question. Machine F was a DW of type ASKO DW90.1 and G was a WM of type ASKO WM70.1. Machine F had approximately the same colour as machine C while machine G had a noticeable low Δb^* -value for all varnished surfaces but it was approximately -1,95 for the polymeric panel. The panel had a colour that was very similar to NCS S 0502-B. These colour differences are difficult to document in a true way with photographs but an attempt to do it is displayed below in figure 29.



Figure 29: A photograph of the top sheet and panel of machine G in the tests in ASKO Showroom.

5. Did the customer notice this difference in white hue before she/he was asked about it?

Yes: 25 persons	80,6 %	(3: 71,4 %)	(4: 88,2 %)
No: 6 persons	19,4 %	(3: 28,6 %)	(4: 11,8 %)

6. How is the identified difference in hue perceived by the customer if it is found on a dishwasher?

- It is okay, it is neither conspicuous nor annoying:
1 person 3,2 % (3: 7,1 %) (4: 0 %)
- It is noticeable but it is not important, the customer will get used to it:
12 persons 38,7 % (3: 42,9 %) (4: 35,3 %)
- It is very conspicuous, the customer prefer not to purchase a machine with a difference in hue of this magnitude; it is annoying:
18 persons **58,1 %** (3: **50 %**) (4: **64,7 %**)

Also during these tests did the participants share many valuable comments and opinions, they are all collected and categorized in appendix IV – Comments from customers during inquiry; arrangement 3 & 4.

However, in general about the test and the comments;

- At least one man with defect colour vision participated in the test. However, he did not have clearly deviating opinions about the white colours in the test.
- The majority of the comments are concerning yellow and blue hues, some comments are about grey hues and few of the comments are concerning red hues.
- A clear majority of the participants is choosing between machine A and C when they are searching for the machine with the most attractive white colour.
- The white colours which contain a clearly noticeable amount of yellow are experienced to express second-hand and high age. Machines/surfaces with this colour does not look fresh or clean. These colours are therefore seldom perceived as attractive.

5.2.2 Summarizing remarks; white colour

When the test was performed in the examination room, it was found that the proximity between surfaces clearly affects which machine that is perceived to have the most attractive colour. It was also revealed that it is more important how the colour is perceived on dishwashers than on laundry appliances. For the assessment in the ordinary room, there is a clear difference between the tests about which colour that is perceived as the most attractive and which that is perceived to be the darkest one. This is with high certainty a result of the different weathers and therefore also the correlated colour temperature of the light in the room. The results concerning the most attractive colour did also spread less than compared to the tests in the examination room. The sunny day did a clear majority prefer the bluest machine (A) probably because the warm light made it less glaring. The cloudy day did all colours look less yellow because of the cold light and therefore was yellow hues less noticeable, the ASKO machine (C) did then receive a clear majority for having the most attractive colour.

5.2.3 Research concerning surface finish

In this section will the results of the research concerning surface finish be presented. The different arrangements of the demonstration objects as well as the objects themselves are further described in section 4.2.6.

- **Results from arrangement A**

The defects that were noticed by the participants:

α. 1: 4 persons	9,8 %	(press marks)
α. 2: 1 person	2,4 %	(orange peel)
α. 3: 9 persons	22,0 %	(scratches)
β. 1: 6 persons	14,6 %	(dot)
β. 2: 7 persons	17,1 %	(orange peel)
γ. 1: 18 persons	43,9 %	(striped orange peel)
γ. 2: 10 persons	24,4 %	(scratches)
δ. 1: 10 persons	18,5 %	(paint run)
δ. 2: 1 person	1,9 %	(display edge)
δ. 3: 2 persons	3,7 %	(dots)
δ. 4: none	0 %	(white display detail)
δ. 5: 4 persons	7,4 %	(fitting of panel)
ε. 1: none	0 %	(thin paint layer)
ε. 2: 4 persons	16,7 %	(orange peel)
ε. 3: 1 person	4,2 %	(scratches)

How the customers examined the surfaces:

Alternative 1: 9 persons	22,0 %	(visually, some wipes)
Alternative 2: 15 persons	36,6 %	(visually from 1m)
Alternative 3: 12 persons	29,2 %	(careful wiping)
Alternative 4: 5 persons	12,2 %	(touching, visually)

The complete compilation of the customers' comments is presented in appendix V – Comments from customers during inquiry; arrangement A.

As for the earlier results are the individual results from arrangements B and C presented in brackets in the section below.

- **Summary of results from arrangement B and C**

The defects that were noticed by the participants:

α. 1: 21 persons	67,7 % (B: 58,8 %) (C: 78,6 %)	(press marks)
α. 2: 9 persons	29,0 % (B: 35,3 %) (C: 21,4 %)	(orange peel)
α. 3: 7 persons	22,6 % (B: 23,5 %) (C: 21,4 %)	(scratches)
β. 1: 3 persons	9,7 % (B: 5,9 %) (C: 14,3 %)	(dot)
β. 2: 10 person	32,3 % (B: 52,9 %) (C: 7,1 %)	(orange peel)
γ. 1: 18 persons	58,1 % (B: 52,9 %) (C: 64,3 %)	(striped orange peel)
γ. 2: 9 persons	29,0 % (B: 29,4 %) (C: 28,6 %)	(scratches)
δ. 1: 3 persons	9,7 % (B: 5,8 %) (C: 14,3 %)	(paint run)
δ. 2: 2 persons	6,5 % (B: 5,8 %) (C: 7,1 %)	(display edge)
δ. 3: 1 person	3,2 % (B: 5,8 %) (C: 0 %)	(dots)
δ. 4: 2 persons	6,5 % (B: 5,8 %) (C: 7,1 %)	(white display detail)
δ. 5: 1 person	3,2 % (B: 0 %) (C: 7,1 %)	(fitting of panel)
ε. 1: none	0 % (B: 0 %) (C: 0 %)	(thin paint layer)
ε. 2: 11 persons	35,5 % (B: 23,5 %) (C: 50 %)	(orange peel)
ε. 3: 2 persons	6,5 % (B: 5,8 %) (C: 7,1 %)	(scratches)

How the customers examined the surface:

Alternative 1: 5 persons	16,1 %	(visually, some wipes)
	(B: 11,8 %)	(C: 21,4 %)
Alternative 2: 12 persons	38,7 %	(visually from 1m)
	(B: 58,8 %)	(C: 14,3 %)
Alternative 3: 3 persons	9,7 %	(careful wiping)
	(B: 11,8 %)	(C: 7,1 %)
Alternative 4: 11 persons	35,5 %	(touching, visually)
	(B: 17,6 %)	(C: 57,2 %)

The comments from this part of the inquiry are found in appendix VI – Comments from customers during inquiry; arrangement B & C.

5.2.4 Summarizing remarks; surface finish

It could be seen that the participants who examined the surfaces quickly mostly focused on the upper, left and right edge of the front sheet, the panel and the part of the top sheet closest to the customer. Another interesting observation was that when the participant found her/his first defect she/he started to examine the remaining surfaces more carefully and with more enthusiasm. The surfaces that already had been examined were also examined once more with the new carefulness. When the first defect had been found the participant became more critical in her/his judgement and was more aware of what to look for at the specimens. Probably does this also reflect the reality; if a customer finds a finish defect on her/his new machine she/he will probably examine the rest of the machine more careful to see if there are other defects on the object. It was also perceived that it was much easier to see finish defects when the surfaces were placed higher up (on chairs) than directly on the floor. The surfaces with an apparent orange peel texture, such as at specimen γ and perhaps also ϵ , were perceived as unattractive and they did look as if they were not professionally manufactured.

If the finish inquiry from the examination room is compared with the one from ASKO Showroom it can be seen that deviations that is clearly more visible in different types of directional light and gleam such as press marks and orange peel structure were detected by a significantly higher percentage of the participants in the showroom. This is an important remark since these kinds of defects are rather common and users do very seldom use their appliances in rooms without windows and only perfectly diffuse illumination. Neither does a common environment in a store has a similar environment and lighting compared to the examination room.

5.3 Examination of surface waviness and microstructure

In this section will the results concerning waviness and microstructure of the varnish, found during the analysis with optical microscope and SEM, be presented.

5.3.1 Assessment of surface waviness of varnished components

One of the parameters that was found to be most important for a mathematical characterization of a surface with potential orange peel structure was the skewness or the symmetry around the centre line, Wsk . It was found to almost always have a negative value for surfaces with orange peel structure and positive for surfaces that were perceived as smooth. The mean value of Wsk was for the measurements $-0,16$ for surfaces with orange peel structure and $0,07$ for smoother surfaces. It is however difficult to isolate one parameter totally from the other ones because

often several parameters together present the appearance of a surface in the most descriptive way. The high spot count HSC was also found to be a useful measure; if the value is equal to or less than 2 for an assessment length of 1300 μm the surface is most certainly perceived as smooth. The mean value of HSC was for the measurements 3,5 for surfaces with orange peel structure and 1,5 for smoother surfaces.

A smooth surface can have significantly higher values of the amplitude parameters such as W_a , W_q , W_v , W_p and W_t than a rough surface, as long as the values of the spacing parameters are significantly lower. Therefore, the amplitude parameters are not satisfactory to use alone for this specific purpose. The local peak count parameter P_c was found to be almost as useful as HSC. A low value of P_c indicates a smooth surface. However, since the calculation of P_c is slightly more demanding than of HSC while it at the same time is a little bit less accurate the recommendation is to use HSC instead of P_c . It is rather the total number of peaks of the waviness curve that is relevant instead of the mean spacing between the profiles and especially when it is defined as for W_{Sm} . Smooth surfaces do also seem to have lower values of W_{ku} than rough surfaces. The transmission point between what is considered to be a low respectively high value of W_{ku} has not been definitely found but it is around 2,35. The mean value of W_{ku} was for the measurements 2,5 for surfaces with orange peel structure and 2,2 for smoother surfaces.

Since, the different parameters cannot be used with full satisfaction separate from each other the combination of the useful height distribution parameter W_{sk} and the spacing parameter HSC can be a preferable choice. The amplitude parameters are not useful for this purpose. It is however then assumed that the surfaces that is being examined is smooth or in the worst case has a clear orange peel structure, no surface deviations with even rougher surfaces have been considered when making this recommendation.

5.3.2 SEM micrographs; microstructure of the varnish

Micrographs of the orange peel structured varnish layer, showing most of the interesting observed features and details will be presented with descriptions in this section. Some additional micrographs can also be found in appendix VII - Additional SEM micrographs. Some important information is included in each figure such as the actual magnification, which detector that is used, date and time. EHT as well as WD is also given, EHT is an abbreviation for extra high tension (the accelerating voltage) and WD stands for working distance. To see what the varnish looks like at very high magnification could generate further understanding of the behaviour of the powder in the process and the resulting colour and texture of the surfaces.

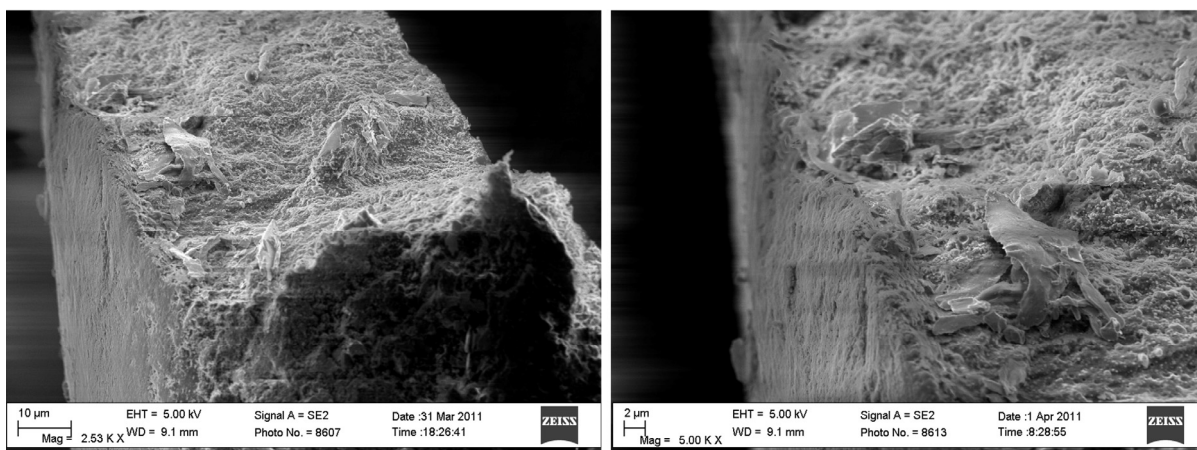


Figure 30 and 31: SEM micrographs of the coating layer. Figure 30; the cross-section of the varnished layer showing the roughness of its outer surface (the vertical surface to the left). Figure 31; a further magnification of the outer edge showing the different appearance of the thin absolute outermost layer of the varnish (to the left).

In figure 30 is the layer of varnish displayed with rather high magnification. The rough surface of the cut of the upper part can be seen as well as the somewhat striped structure of the surface that is visual for the customer on a product (to the left in the picture). The roughness of the cut is expected because it is a result of the sectioning of the sample. The roughness of the normally visible surface is more interesting, but as can be seen the furrows are very small and shallow which make them difficult to detect at an ocular examination. However, the vertically orientated furrows in this figure was vertically orientated as well when the former sheet was placed on the hanger and passed the curing furnace. The orange peel structure of the surface was however horizontally orientated. In figure 31 is the outermost part of the horizontal edge further magnified. It can be seen that there is a noticeable different appearance of the absolute outermost layer with a thickness of approximately 4-5 μm . This layer seems to be slightly denser but especially more uniform in its structure than the inner layer where particles of different shape and size are easily detected.

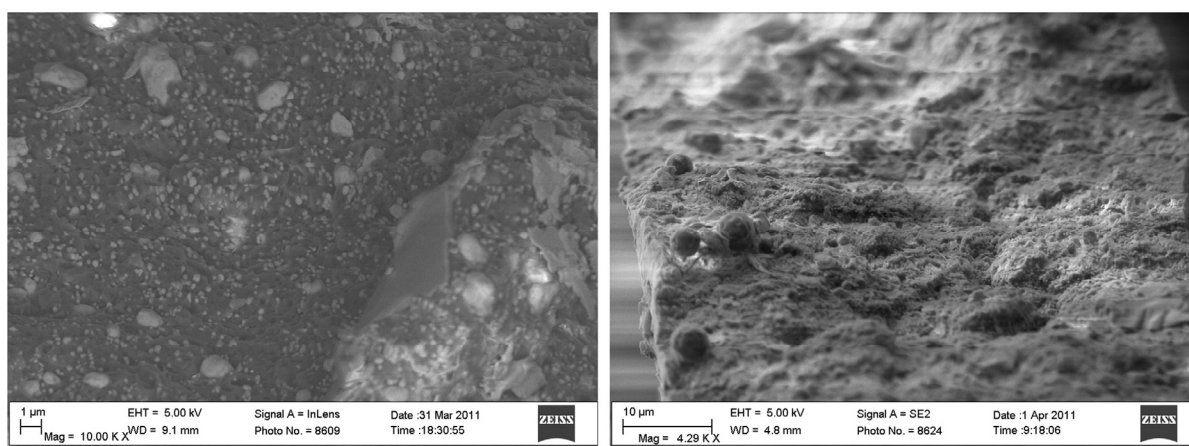


Figure 32 and 33: SEM micrographs of the coating layer. Figure 32; the white colour pigments embedded in the darker polymeric matrix. Figure 33; showing five spherical polymeric particles positioned close to the outermost layer of the varnish (to the left).

Figure 32 shows also the upper surface of the cut. The brighter particles that are embedded in the darker matrix are the white colour pigments, the titanium dioxide. It can be seen that the size of the TiO_2 particles vary quite much and the diameter of them seems to range from only a fraction of a μm to approximately at least 3 μm .

Figure 33 is quite interesting, it shows four perfectly spherical balls and one fifth in the upper part of the image which is slightly flattened. All the balls of this type that were found in the sample, except one, were found close to the outermost layer but not as close as they could be seen from the outer surface. It can be seen from the figure that the balls are almost perfectly spherical and are not completely mixed with the rest of the matrix. The perfect round shape indicates that the particles are not dust or dirt and the fact that they are placed a small distance below the outermost surface layer indicates that it is something that has come from the coating powder. The balls are relatively large, approximately 4 μm in diameter. When these balls were examined in even higher magnification it was found that there are some small particles attached to the surface of the balls, when they are compared to the rest of the material it is found that it is small TiO_2 particles that are attached to the balls. A difference in colour between these particles and the balls gives the information that they consist of something else than TiO_2 .

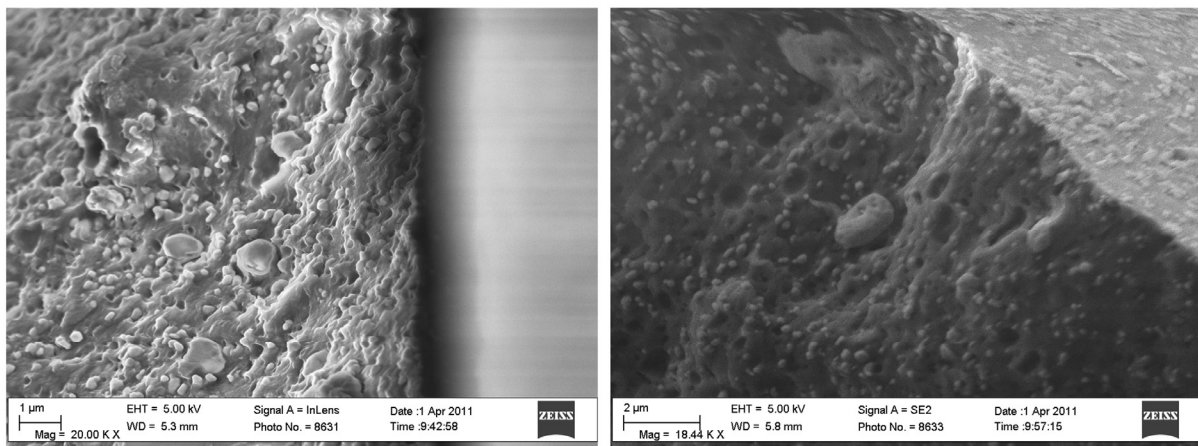


Figure 34 and 35: SEM micrographs of the coating layer. Figure 34; showing the zone where the varnish layer (to the left) is attached to the metallic component (to the right). Figure 35; the white pigments embedded in the matrix (down to the left) and some residuals of zinc from the galvanized layer (up to the right).

Figure 34 shows the zone where the powder coating (to the left) is attached to the galvanized layer of the metal sheet (to the right). The zinc layer is blurry in these pictures, the focus is instead on the varnished layer. The dark zone between the varnish and the metal is caused by the detachment of the layers from each other; a highly probable cause to this is the sectioning of the samples. It can be seen in the picture that there is plenty of both smaller and bigger holes in the cut surface. The size of these holes corresponds well to the size of the TiO_2 particles. When the surface is analyzed it can be seen that besides the holes where TiO_2 particles were positioned before the sectioning the structure of the varnished layer is rather dense and naturally contains almost no porosity. Figure 35 is a magnification of the upper edge of a flake of varnish that is still attached to the edge of the sample. The surface that is positioned upwards in the pictures was earlier attached to the galvanized layer and it can be seen that some zinc particles still are attached to the surface. Particles with higher molecular weight have a brighter colour in this picture. The TiO_2 particles embedded in the polymeric matrix are also clearly displayed in the figure.

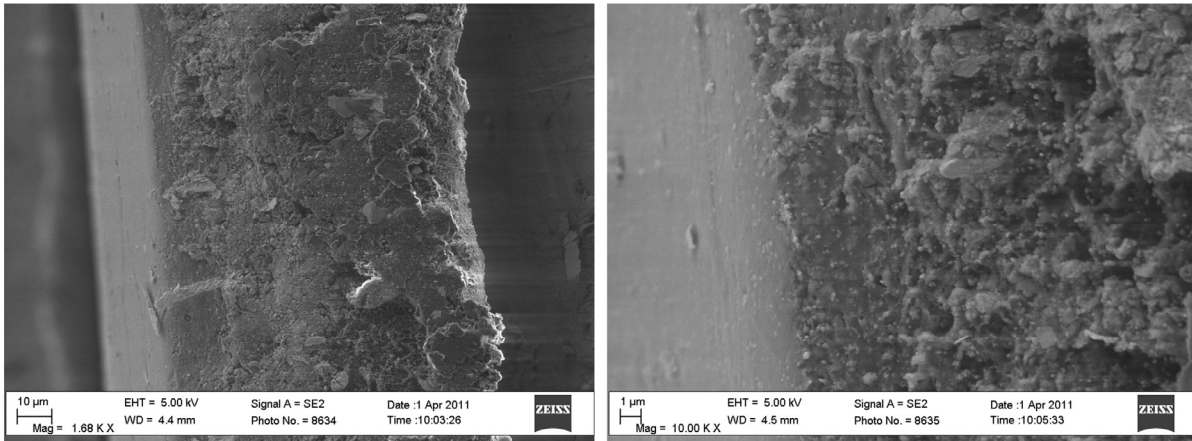


Figure 36 and 37: SEM micrographs of the coating layer. Both figures show the difference in appearance between the outer (to the left) and inner zone of the varnished layer.

In figure 36 the varnish layer is shown more directly from the side than before and the difference between the outer and inner section of it is even more clearly visualized. Where these pictures are taken the thickness of the outer layer is just above 10µm. Figure 37 is a further magnification of the area where the two different sections meet each other. No definite explanation can be given to this observation. A possible reason can be that the varnish layer is not completely cured all the way down to the metallic substrate. It can also be that the outermost layer is affected by a factor from the outside during curing that not penetrates deep into the powder. A third possible reason is that this appearance is caused by deformations during the sectioning process.

5.3.3 Chemical analysis

When the appearance of the material was examined visually through the SEM micrographs the sample that was standing in its sample holder was also examined with a smaller chemical analysis through EDX. The accelerating voltage was then increased to 20kV which made it possible to analyse X-rays emitted from a larger volume of the sample's topmost layer. Because of the fact that some elements have EDX spectrum peaks that resembles each other much, some manual sorting and judgement was needed before the real result was elucidated.

However, the EDX analysis presented in this section gives only a rough indication of which elements that are present in the sample. If a more detailed analysis would have been requested the sample would have needed to be prepared with high carefulness to achieve a totally smooth and flat surface. The instrument would also have needed to be calibrated before the analysis. Since the SEM micrographs were of major interest during the SEM examination the sample was examined in this state as well during this chemical analysis. This rough chemical analysis can however be seen as a shorter demonstration of the possibilities with EDX, which possibly can be beneficial in the future for Asko.

The area displayed in figure 38 was first analyzed. The presence of different elements was firstly mapped, the following elements were found; carbon (C), oxygen (O), magnesium (Mg), aluminium (Al), silicon (Si), sulphur (S), calcium (Ca), titanium (Ti), chromium (Cr), iron (Fe), nickel (Ni) and zinc (Zn). Maps showing the distribution of the elements revealed that particle marked with the thin white circle is made of stainless steel because of its high concentrations of

iron, chromium and nickel. The particle marked with the thicker white line has a high concentration of magnesium and oxygen. The two almost perfectly spherical balls on each side of the particle marked with green does not have totally different chemical composition than the rest of the area however they contain less titanium and sulphur than the surrounding area. They have a high concentration of carbon which makes it highly probable that they are made of a polymeric material. The other elements that were found in this picture were quite evenly dispersed.

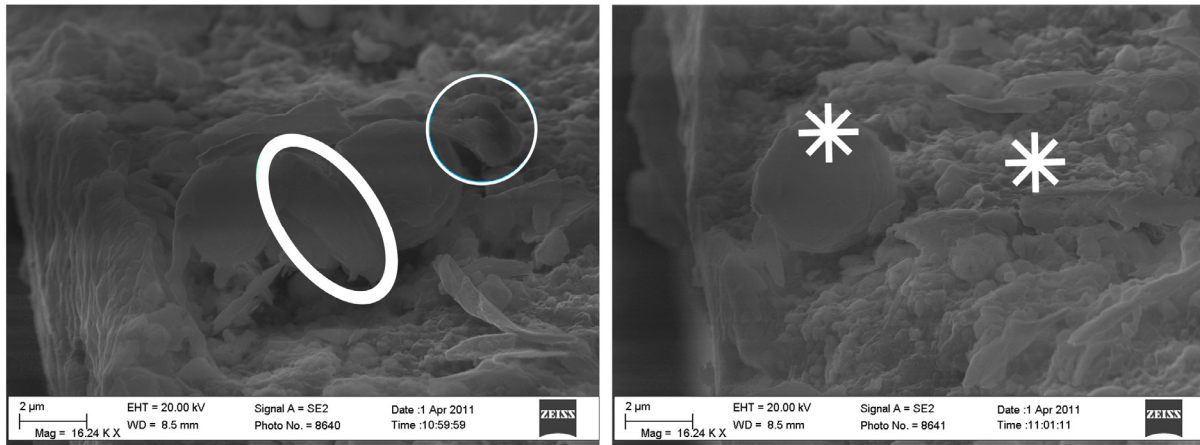


Figure 38 and 39: SEM micrographs of the coating layer.

The view in figure 39 was the next to be analyzed; it is the same ball as can be seen in figure 33. This ball has the same composition as the two in the earlier figure. The mapping of the present elements showed that the same elements were found as in figure 38. There are some small flakes randomly distributed in the picture that has a high concentration of iron, these flakes are most certainly from the sectioning and does not represent the real composition of the powder. In this figure, the outermost layer (to the left in the picture) seems to have a slightly higher concentration of chromium than the rest of the material.

The chemical spectrum was analyzed for the positions of the two white stars in figure 39. These spectrum analyses omit elements if only traces of them are found. For both points carbon and oxygen was present with the highest atomic%. The amount of titanium was much less than of carbon and oxygen but it was the element with the third highest representation in the spectrum. Small but clearly noticeable amounts of sulphur, zinc and iron was also found. In the point to the right some aluminium was found as well.

The better understand where the elements originally come from and why they are found in the sample a short reflection will be made about this. Carbon is one of the main constituents in the polymers that the coating powder is made of. Oxygen is also a part of the polymers and it is included in the white pigments of TiO_2 as well as titanium. Sulphur is included in the coating powder in the form of barium sulphate that is a part of one of the pigments. It could also be the case that some sulphur is resulting from the combustion of the LPG that contains ethyl mercaptan, this has however not been investigated further. The found zinc is with high certainty from the galvanized layer of the metal sheet and the iron is probably also flakes form the sheet.

The aluminium as well as the stainless steel particles (iron, chromium and nickel) can be impurities possibly from the sectioning tool. According to Thomas Jacobson at DuPont (2011) the silicon is explained by that some amorphous silicon dioxide is an additive in the powder. Neither magnesium nor calcium is added to the powder but it is likely that some of the raw material can contain small amounts of these elements. No hydrogen (H) or nitrogen (N) was found with the chemical analysis. Hydrogen is an important constituent in the polymers and nitrogen is assumed to affect the colour of the outermost layer of the coating during curing.

5.3.4 Summarizing remarks; waviness and microstructure

It was found that it is possible to assess orange peel structure through measurements of surface waviness, but it was also found that the selection of parameters for this assessment is crucial for the usefulness of the method. The height distribution parameter Wsk and the spacing parameter HSC was found to be a preferable choice. The knowledge of how the varnish looks like in high magnification together with the results from the brief chemical analysis can be useful for deeper understanding of the process performance and behaviour of the materials.

5.4 Analysis of the varnishing process

Discoloration of white varnish has earlier been a rather common problem in processes where LPG furnaces have been used for curing of the powder coating. Nowadays it is not a problem to the same extent; the reasons are that the powder manufacturers usually adapt or customize the powder to the ordering company's furnace and that the combustion chambers in newer furnaces are designed in a different way (Axelsson 2003).

To be able to control the varnishing process the factors that influence the result must be identified and understood. Also since the competitors' colours deviate from Asko's it can be beneficial from an OEM's point of view to be able to steer the output of the process more explicitly. Also the research about the users' preferences show that higher customer satisfaction could be reached with a better controlled process.

5.4.1 Historical colour measurements from production

The results of the analysis of the historical data from the varnishing process will be presented in this section. In figure 40, box plots of ΔL^* , Δa^* and Δb^* are displayed for 2008, 2009, 2010 and the beginning of 2011. When ANOVAS were made for the different colour parameters versus the different years it was found that the P-value for all three analyses was equal to 0. This value that is clearly less than $\alpha=0,05$ indicates that the factor of year is significant. In other words, there is a clear statistical difference between the colours for the different years. ΔL^* has for 2008-2009 a median value close to 0 and for 2010-2011 a median that is approximately 0,1. The variance is however rather equal for all years ($\approx 0,037$) but for 2010 there is noticeable many outliers. Also for Δa^* is the median values lower for the first two years. For 2010 it is slightly higher; just below 0 and for 2011 it is just above 0. The variance for Δa^* is much lower than for ΔL^* and is rather constant for 2008-2010 ($\approx 0,008$) but is higher for the beginning of 2011. The variance for Δb^* is also rather equal the first three years ($\approx 0,045$) and significantly higher for the beginning of 2011. The median value of Δb^* is close to -0,10 for 2008-2009 and between 0,10 and 0,20 the later years.

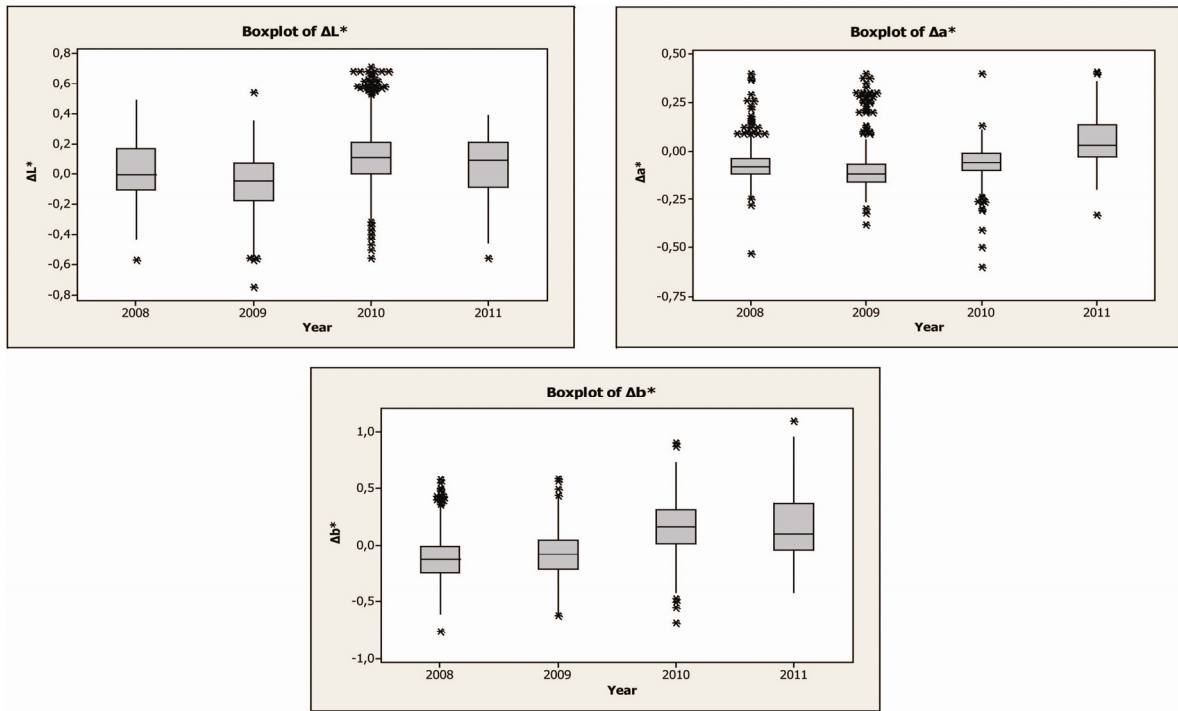


Figure 40: Box plots of ΔL^* , Δa^* and Δb^* presented separately for 2008, 2009, 2010 and the beginning of 2011. The figures show the shift of the median values for the data collected these years.

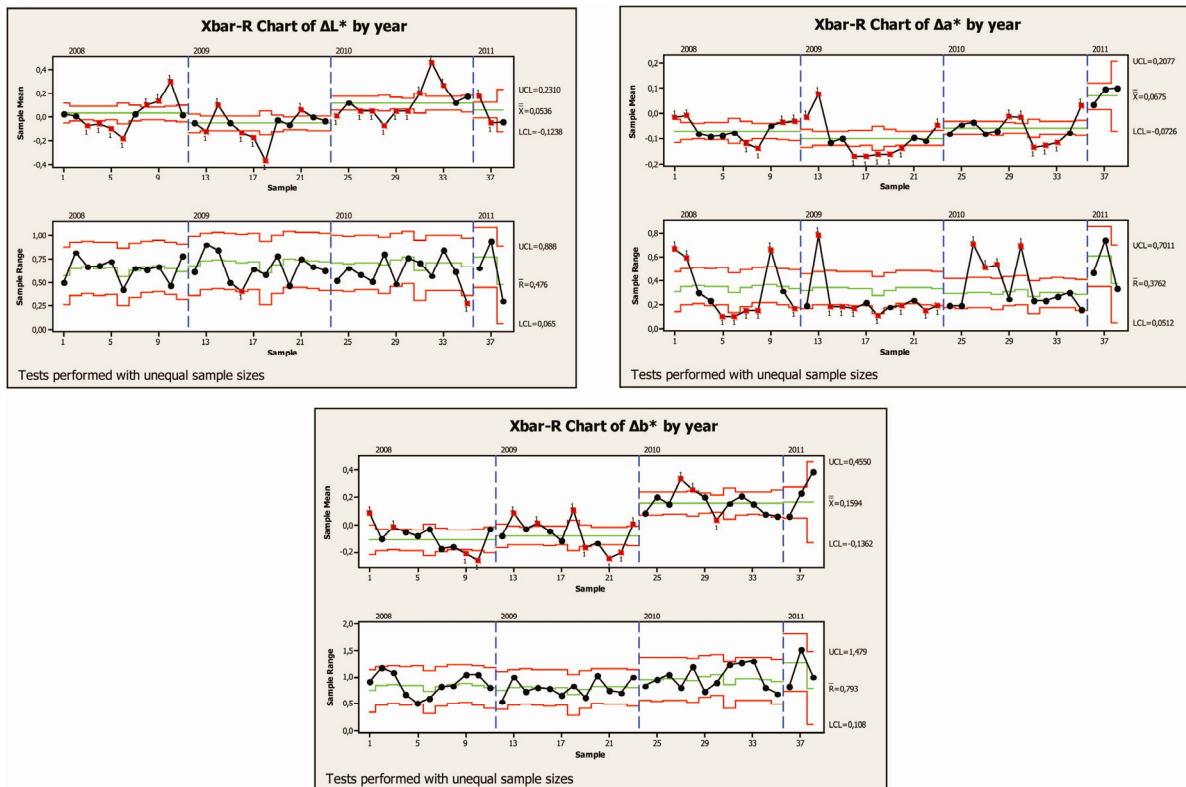


Figure 41: Xbar-R charts of ΔL^* , Δa^* and Δb^* for each month during the analyzed period. The shift of the centre line in the turn of the year 2009-2010 for Δb^* is clearly visualized in the chart in the bottom of the figure.

When the data for each month is plotted in an Xbar-R chart as in figure 41 the shift of the centre line in the turn of the year 2009-2010 for Δb^* is even more clearly visualized. These plots visualize the stability of the analyzed process. For ΔL^* and Δb^* there are few respectively no warnings for the process range which indicates that the warnings of out-of-control process in the plot of the mean are probably true (Minitab 2011). For Δa^* the warnings for the mean values cannot be interpreted as strictly as for the other two colour components. However, according to the plots the process is somewhat out of control for all the three parameters. For Δb^* there can be a cyclic trend each year, with higher values in the beginning of the year that decreases towards the end of the year.

In figure 42, the process capability of ΔL^* , Δa^* and Δb^* are displayed. It can be seen that none of the different measurements of the overall capability, which is what actually is experienced by the customer, exceeds the recommended value of 1,33. ΔL^* and Δb^* are rather centred around the target values but Δa^* is shifted towards lower values. If the shift and drift are removed at least ΔL^* can reach an almost acceptable process according to the potential capability. The PPM identifies the number of “nonconforming parts out of a million parts” (Minitab 2011). The abbreviations LSL and USL stand for lower and upper specification limit and they are set equal to the tolerance limits used in the production process today.

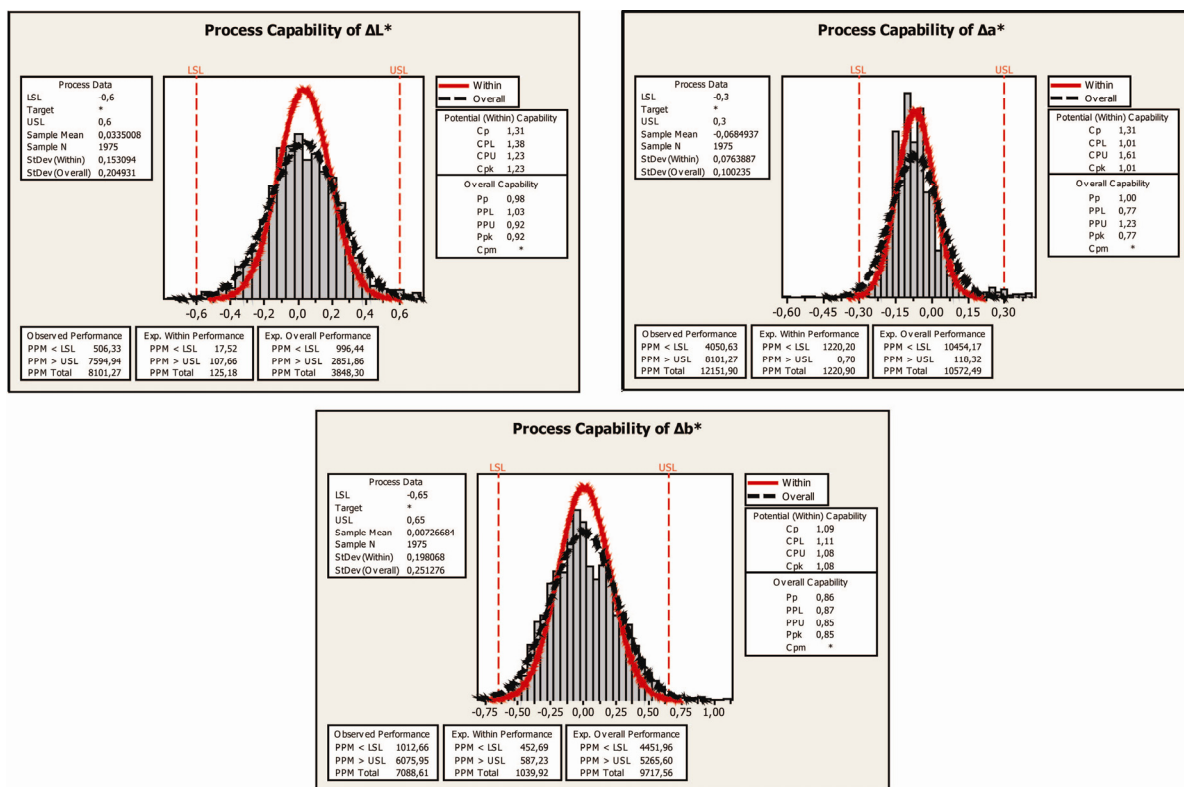


Figure 42: The process capability of ΔL^* , Δa^* and Δb^* during the analyzed period. ΔL^* and Δb^* are centred around the target values while Δa^* is shifted towards lower values.

5.4.2 Factors and their corresponding effects that should be investigated

In the initial stage of the six sigma project, during the define phase, a process map was made and Key Process Input Variables (KPIV) as well as Key Process Output Variables (KPOV) were identified. Based on the process map and on the analyzed possibilities to vary certain

parameters the following list of factors and questions that preferably should be analyzed during the project was produced.

How do the following process characteristics affect the resulting white colour?

- The thickness of varnish layer (TVL).
- Time in curing furnace.
- Material temperature during curing.
- Type of curing furnace; LPG vs. electric.
- The material thickness of the varnished components.
- Different powder batches.
- Number of times a component passes the process; 1 vs.2.
- Number of components on a hanger; 2 large vs. 4 large.
- The sheets' position on the hanger.
- Local positions of different sections of a sheet.
- Position in the curing furnace during break or stop.

The collection of data and analysis in the further phases of the project was then based on these decisions of characteristics of interest and possibilities to investigate them further.

5.4.3 Research about changes in the process or of raw material

To find out what possibly could have caused the shifting of mainly the Δb^* values around the turn of the year 2009-2010 and the other visible fluctuations in the measured colour, an investigation about changes in or around the process was made. The main outcome of this investigation is that basically nothing seems to have changed. Reports about maintenance of the equipment in the spray painting shop have been studied, operators have been interviewed, routines have been investigated but noting that is remarkable compared to what is usual has been found. Also the manufacturer of the powder has been interviewed and neither have they made any significant changes in their process or recipe. Although, it can be possible that for example subcontractors have made changes that the manufacturer is not aware of or detects with the current test methods. In the same way it can be possible that other subcontractors to Asko have changed something that could cause variation in the varnishing process.

The only difference or noticeable adjustment made of equipment related to the process around the actual period is that the spectrophotometer that is used in the paint shop was calibrated in January 2010. During this calibration a wavelength adjustment of the magnitude 1,4nm was made. According to Martin Lindbom (Konica Minolta Sensing Europe B.V., 2011) this adjustment was unusually large compared to what is normal during a calibration ($\approx 0,6\text{nm}$). The need of adjusting the measurement of wavelengths can occur for example if the instrument has been dropped on to the floor. However, Martin Lindbom does also remark that the result of such an adjustment depends on which colour that is being measured because of their different shapes of the reflection curves. For a clean white colour this curve is horizontal and the colour measurement should not be much affected by an adjustment. In conclusion, it is after all not possible to definitely state that it was this calibration that caused the shift of the curve.

The possible cyclic trend for Δb^* with higher values in the beginning of each year that decreases towards the end of the year, was also briefly examined. One possible explanation could be that

the outdoor temperature influences the temperature in the process in some way and by that cause these variations. Another, maybe rather far-fetched explanation can be due to the variation with the seasons of the concentration of air pollutants. In general the concentration is higher during the winter, the reason to this is higher emissions and that the dilution is prohibited by the stratification that the combination of colder and warmer air causes. The concentration of ambient ozone is however higher during the warmer seasons (Umeå Kommun 2010).

Thomas Jacobsson at DuPont (2011) has also given information about that a sudden increase in yellowness can be the result of a remaining problem with the ventilation in the furnace. The ventilation in the furnace is crucial for preventing the colour to become too yellow. If the ventilation does not function properly considerable amounts of for example NO_x-gases will stay in the furnace and can cause reactions that make the colour more yellow.

5.4.4 Examination of the result of different colour batches

To reveal if there are any colour differences between different batches representatives from the powder manufacturer performed tests where samples painted with powder from five different saved batches were cured on the same hanger in the curing furnace at Asko. No obvious difference between the tested batches was then found. Samples varnished with powder from different batches were also cured during the 10 respectively 20 minutes break. The behaviour was observed to be similar between the batches when the time was increased and the colour of the samples became uniformly more yellow. First when the samples were cured during the 20 min break values of Δb^* exceeded the tolerance limits. Also the behaviour of ΔL^* and Δa^* were similar for the different batches. This test implies further that there has to be some other factors that have the major impact on the output of this process, since the results of the measurements in the daily process contain more extreme values especially of Δb^* than what was found in this test.

5.4.5 Analysis of the collected data

Due to the extensive collection of data that has been made during this project several appendices have been needed to hold all the data and more complete collections of results from the statistical analysis with Minitab. The appendices that belong to this section of the report are appendix VIII-XXIV. Some appendices are more relevant for the analysis than others but it is anyway important to have the whole background of the analysis clear to enhance comprehension of it. However, in this section the content of the data and its analysis will be elucidated and related to the circumstances in the varnishing process. The data have been collected in different sets with respect to different factors and will be analysed in that order as well.

- **Measurement A-B; Effects of changes of temperature, time and TVL in electric convection oven**

In the first part of the measure phase, data was collected according to a DOE plan of Taguchi Orthogonal Array Design. This plan was prepared by the six sigma team and is attached in appendix VIII – Design of experiment (DOE). According to this plan the experiment should be performed as 3³ which means 9 runs per experiment. Two different experiments were made

with the electric convection oven; one experiment with normal thin thickness of the sheets and one with thicker components. An identical test with normal sheet thickness would have been desirable to perform with the LPG furnace. Due to difficulties to adjust the parameters of the process at all or without disturbing the production too much this was not possible. Therefore, tests with curing in the LPG furnace were performed later and with other designs. The 3^3 notation means that in each experiment 3 factors were tested at respectively 3 levels. Here the temperature was altered between 160, 180 and 200°C. The time in the curing furnace altered between 13, 18 and 28 min and the thickness of varnish layer (TVL) varied between “thin”, “normal” and “thick”. These levels were determined based on recommendations for the curing of the actual coating powder and the lowest level for each factor is denoted as level 1.

Measurements of both colour and TVL were made on different spots in areas not too close to the edge of the surfaces. A mean value of the measurements was then calculated and used in the statistical analysis. During each run 5 thin respectively 3 thick sheets were measured. The resulting measurements are found in appendix IX – Colour measurements resulting from the design of experiment (DOE), and complete figures and plots from the analysis with Minitab are found in appendix X – Analysis of data from measurements A-B.

To elucidate the effects that changes in temperature, time and TVL have on the measured colour, mean of means are plotted for the different levels of the three factors. This relation was calculated in Minitab and based on the measurements that the DOE resulted in. These calculations were performed according to an algorithm defined by the Taguchi DOE method in Minitab therefore the values on the y-axis are not important in themselves; it is instead the shape of the graph that is relevant. In figure 43 these plots for the samples with thin sheet thickness are displayed. From these plots it can be seen that the temperature has a rather modest effect on ΔL^* and Δa^* but a significant effect on Δb^* ; the colour becomes noticeably more yellow when the samples are cured at higher temperatures. In total temperature is the factor that has the second most significant effect on the colour.

For the time it is interesting to see that it seems to almost have no effect at all on ΔL^* and Δa^* . However, for shorter times an increase in time has a clear tendency to make the colour more yellow. This trend does though cease above approximately 18 minutes and instead discretely decrease instead. According to the graphs the TVL seems to have the most significant impact of all factors. This can however be rather misleading because at smaller TVL the surface of the varnish can be smooth and attractive but anyway so thin that it lets through some of the colour of the metal. Therefore, my opinion is that the effect of TVL between level 1 and 2 is not solely depending on the colour of the coating powder and the curing. In total it can though be seen that Δb^* is the colour parameter that is most affected when the factors in the experiment are changed.

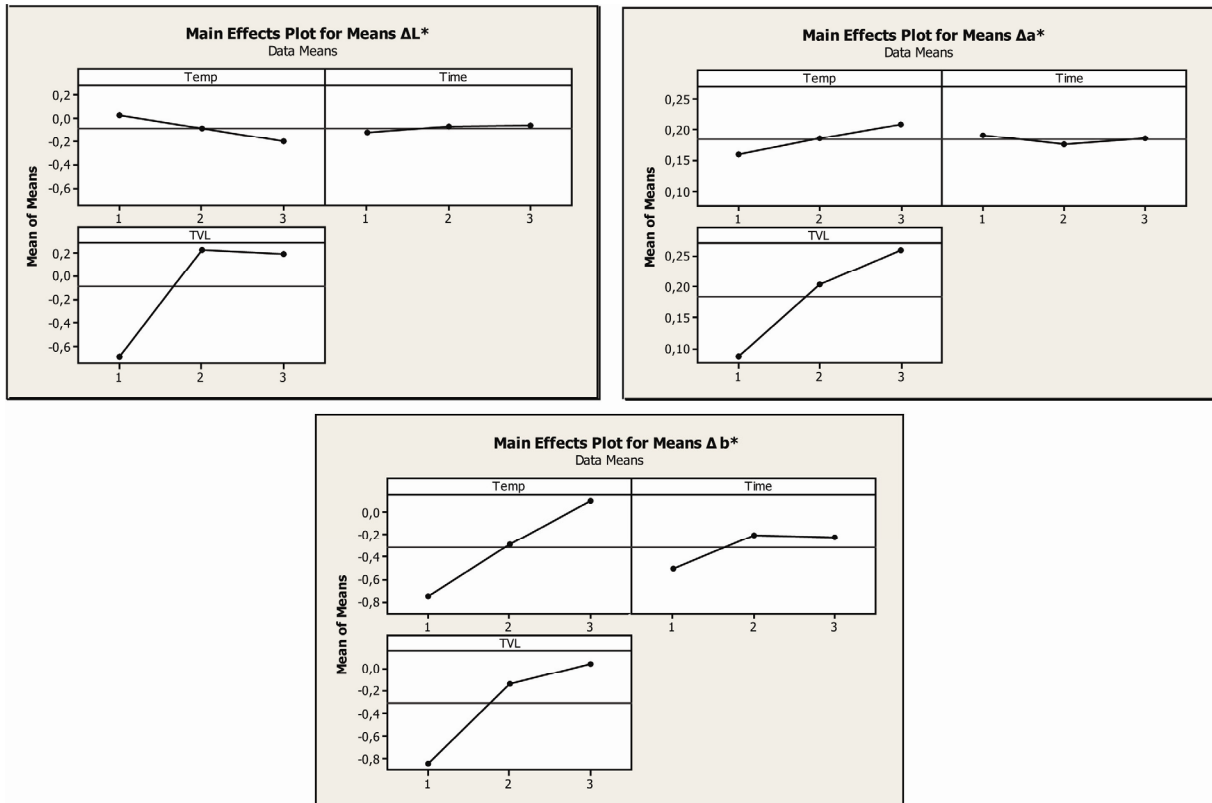


Figure 43: Plots of mean of means for ΔL^* , Δa^* and Δb^* from the analysis of the DOE for thin sheet thickness. It can for example be seen that the time has a small effect on the colour parameters.

From the analyses of the Signal to Noise (SN) ratios it can be seen that the ratios for Δa^* are the highest. It can also be seen that the ratios are rather equal for the different levels of the factors for respectively colour parameter for time and especially for the temperature. The SN ratio is calculated through an algorithm in Minitab and it gives information about the power of the signal that is desired to be analyzed relative to the power of disturbing noise. An SN ratio higher than 1 indicates that the signal is stronger than the noise. The SN ratio is therefore interesting because it gives information about how strongly the signals are corrupted by different noises.

In figure 44 the plots of mean of means for the experiment with the thicker samples are displayed. These plots look somewhat different than for the thin samples. The thick samples have a sheet thickness that is approximately 4,6 times the thickness of the thin samples, which means that the difference is relatively large. For the temperature the end points of the graphs have a rather similar positioning relative to each other compared to for the thin samples. On all the three graphs there is though a significant bend of the curve in the middle that makes the result more difficult to interpret. The temperature has the second most significant effect for both ΔL^* and Δb^* , for Δa^* it has the least significant effect.

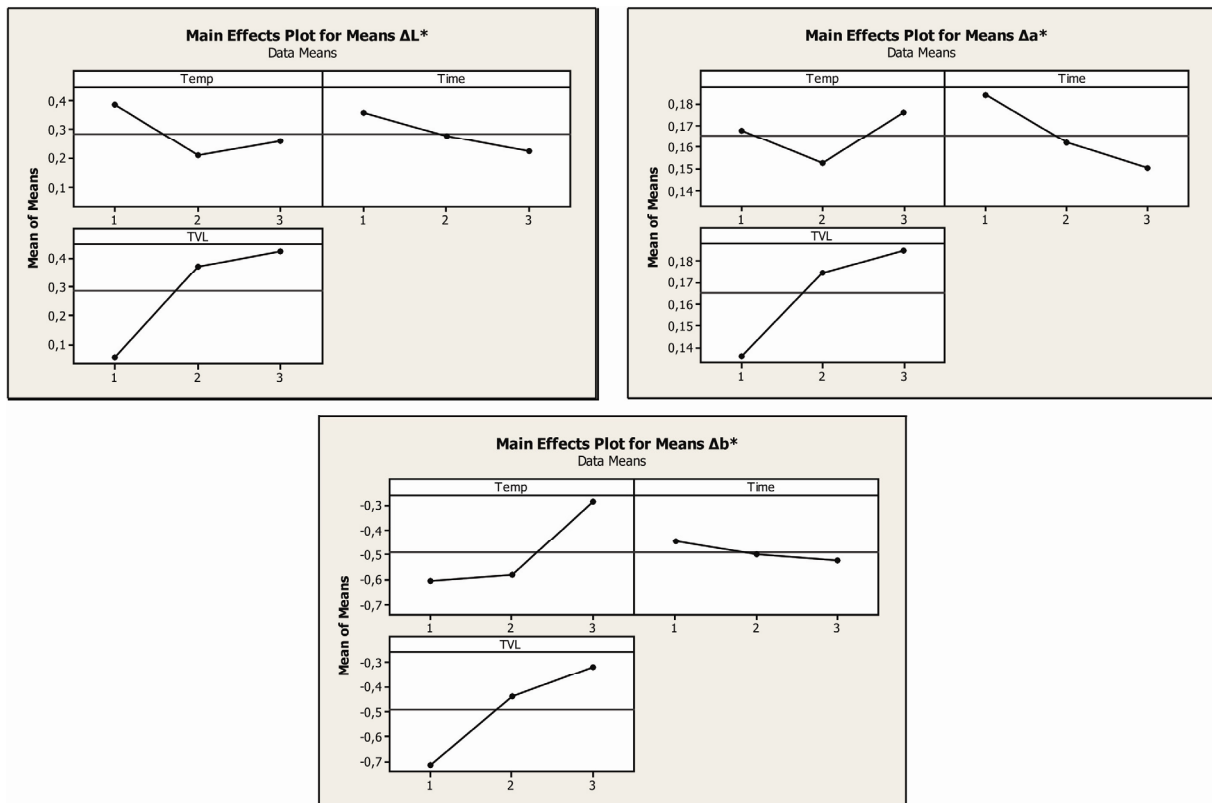


Figure 44: Plots of mean of means for ΔL^* , Δa^* and Δb^* from the analysis of the DOE for thick sheet thickness. The graphs show a slightly different behaviour for the thicker samples compared to the thinner ones.

The effect of changing the time is highly interesting, for all colour parameters they decrease noticeable with increased time. The decrease is most obvious for ΔL^* . This is the opposite to the reaction for the thin samples and the result is also clearly more significant for these samples. The graph for TVL has approximately the same appearance as for the thin samples. In conclusion, from the comparison of these two experiments there is a difference in the resulting colour when samples of different thickness are cured, especially in the behaviour when the time is changed.

The SN ratios behave fairly similar to the ones for the earlier experiment. The most noticeable difference is that the ratio strongly decreases with increased temperature for Δa^* .

- **Measurement C; difference between LPG and electric furnace**

Measurement C contains data of colour measurements performed on samples varnished on the same hanger but cured in different furnaces; the normal LPG furnace or an electric convection oven. The time and temperature of the convection oven was set to be as similar as possible to the conditions of the LPG furnace. The data is presented in appendix XI – Colour measurements of samples from electric convection oven vs. LPG furnace, and the complete data from the analysis in Minitab is found in appendix XII – Analysis of data from measurement C.

In figure 45, box plots of ΔL^* , Δa^* and Δb^* for the two methods of curing are displayed. It can be seen from these plots that curing in the LPG furnace made the samples slightly darker, significantly greener and yellower. Also the p-values indicate this difference between the

methods, in other words $H_0: \mu_1 - \mu_2 = \Delta_0$ is rejected. The smallest variance is found for Δa^* and the greatest for Δb^* . Even though the data is collected from samples from the same hanger there is a noticeable difference in TVL after curing. For this experiment the samples from the electric convection oven has greater TVL than those from the LPG furnace. The difference between the mean values is $12,79 \mu\text{m}$ but both of the means are above the recommended minimum level. It is interesting to see that $\Delta b^*(E)$ is significantly lower than $\Delta b^*(G)$ in spite of the fact of a thicker TVL for the samples from the electric oven.

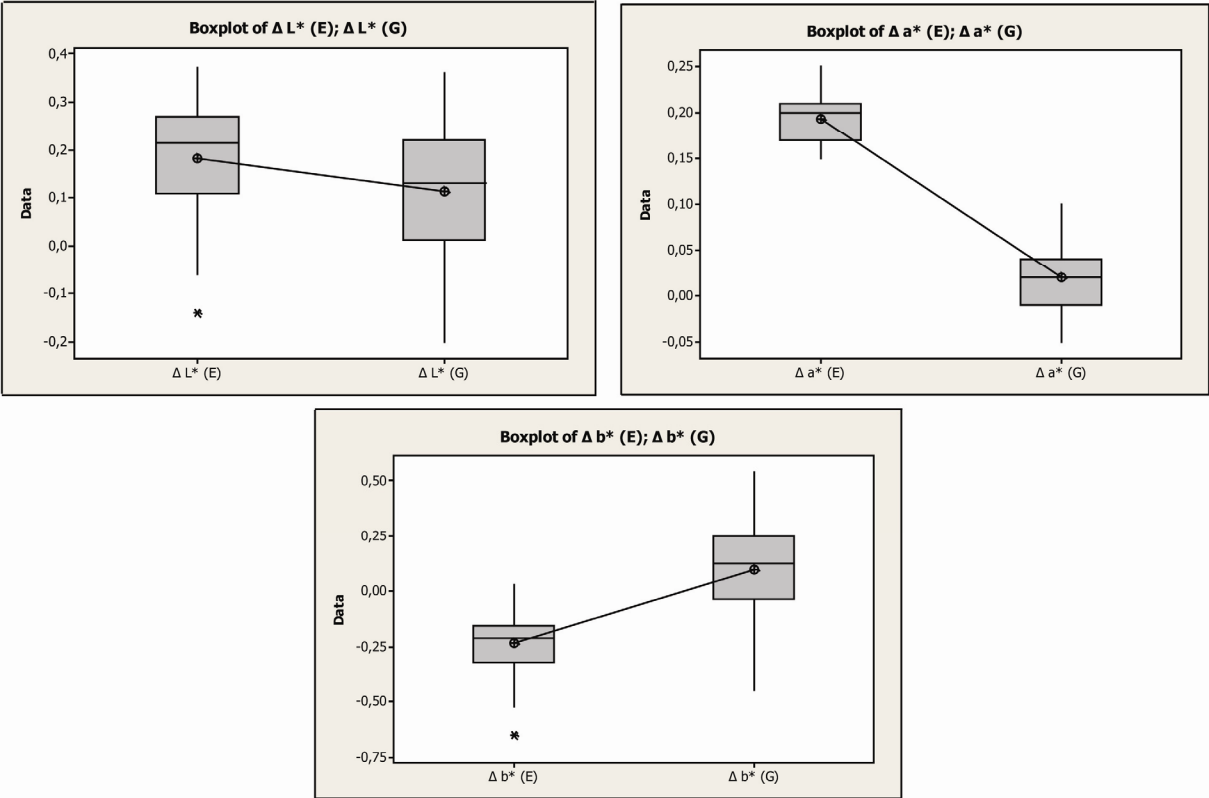


Figure 45: Box plots of ΔL^* , Δa^* and Δb^* for electric convection oven (E) versus LPG furnace (G), showing that the type of curing method significantly affects the resulting colour.

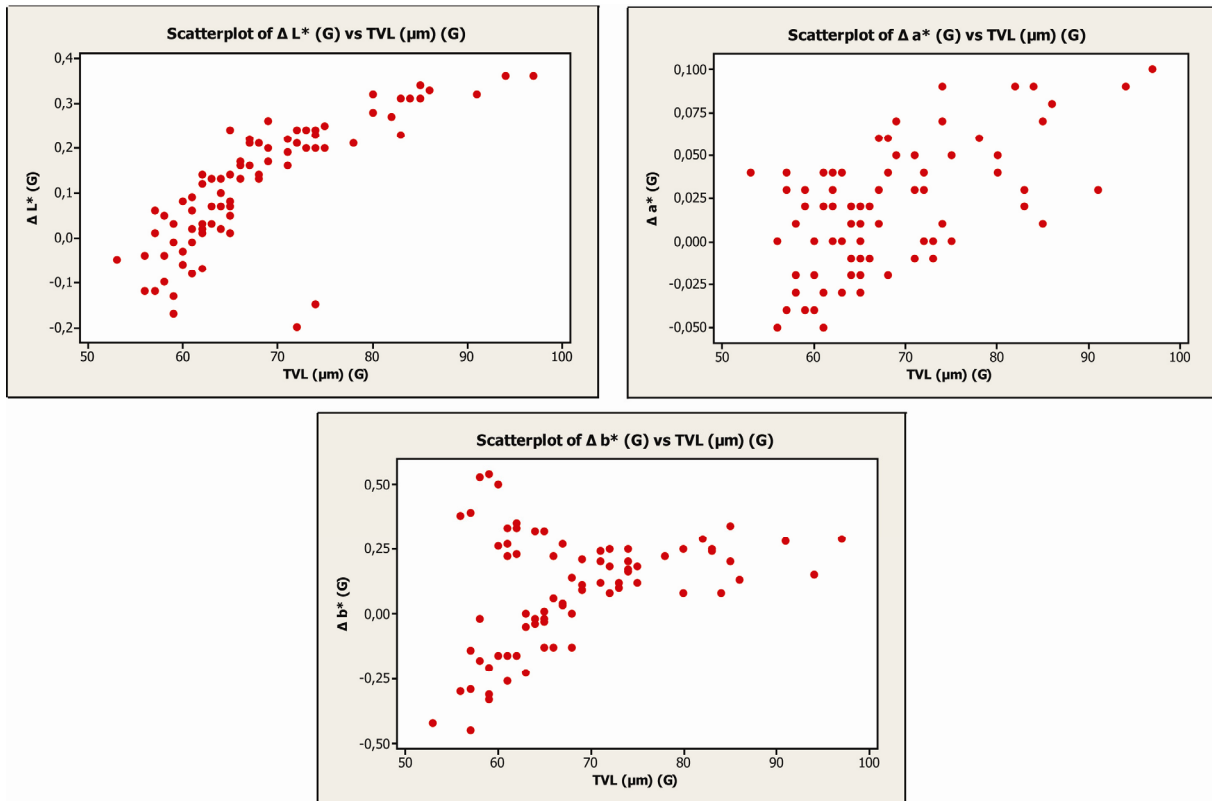


Figure 46: Scatter plots of $\Delta L^*(G)$, $\Delta a^*(G)$ and $\Delta b^*(G)$ versus TVL, showing an increase for the colour parameters at thinner TVLs.

In figure 46 scatter plots of the colour parameters versus TVL for the LPG furnace are displayed. For $\Delta L^*(G)$ there seems to be an increase for increasing TVL. However, the rate of increase ceases at around $75\mu\text{m}$. For $\Delta a^*(G)$ it would not be correct to declare that there is a clear trend because the width of the band of plotted points is too large. The appearance of the plot for $\Delta b^*(G)$ is interesting because the data displays almost the same pattern as for $\Delta L^*(G)$ but with the exception that it has an outgrowth up in the left corner. When the points forming this outgrowth were analyzed it was found that they belong to a group of samples collected at the same time. No obvious reason for this is found since all the data were collected from samples varnished with the same batch of powder during the same period of time.

The scatter plots of $\Delta L^*(E)$, $\Delta a^*(E)$ and $\Delta b^*(E)$ versus TVL display equal or less obvious trends compared to for the LPG furnace. The sample sizes for the different curing methods were not equal but anyway it seems like the influence on the colour of TVL is greater for the samples cured in LPG furnace.

- **Measurement D-E; the effect of revarnishing**

A common idea among the staff working with the varnishing process is that all revarnishing makes the colour more yellow. Sheets are revarnished for different reasons but mostly because there is some kind of surface defects in the first layer of varnish. The collected data from this experiment is found in appendix XIII – Colour measurements of samples varnished and cured one respectively two times, and the complete data from the analysis in Minitab is found in appendix XIV – Analysis of data from measurements D-E. These measurements were performed in two sets. In the first set the samples were cured the first time on position 2 of a hanger and in

the second set they were cured the first time on position 4 instead. The second layer was cured while the sheets were hanging on position 2 or 4. These different sets of the experiment resulted in 4 different constellations called 2:2, 2:4, 4:2 and 4:4. The variations of position for the different measurements were made because the objective was to determine if it was the revarnishing or other factors that affect the colour.

For the 2:2 constellation, both ΔL^* and especially Δa^* are significantly higher after the second layer of varnish. For Δb^* the P-value is 0,292 which means that the mean values before respectively after the second treatment is not significantly different. The variance for Δa^* is relatively small and constant for both the measurement groups. The variance of ΔL^* decreases clearly and is at the same level as for Δa^* after the second layer has been applied. By far, the largest variance is found for Δb^* (layer 1) and the smallest for Δb^* (layer 2). For this constellation in this test the revarnishing of the samples decreases the spread of Δb^* without actually changing the mean value.

For the 2:4 constellation, displayed in figure 47, there is a statistical difference between the layers for all the colour parameters even though it is not large for Δa^* . The estimate of difference between the layers is the largest for Δb^* . In other words, the differences are not at all similar to the ones for the 2:2 case. There is a slight decrease in variance with the revarnishing for all three colour parameters. However, the variance is largest for Δb^* both for layer 1 and 2.

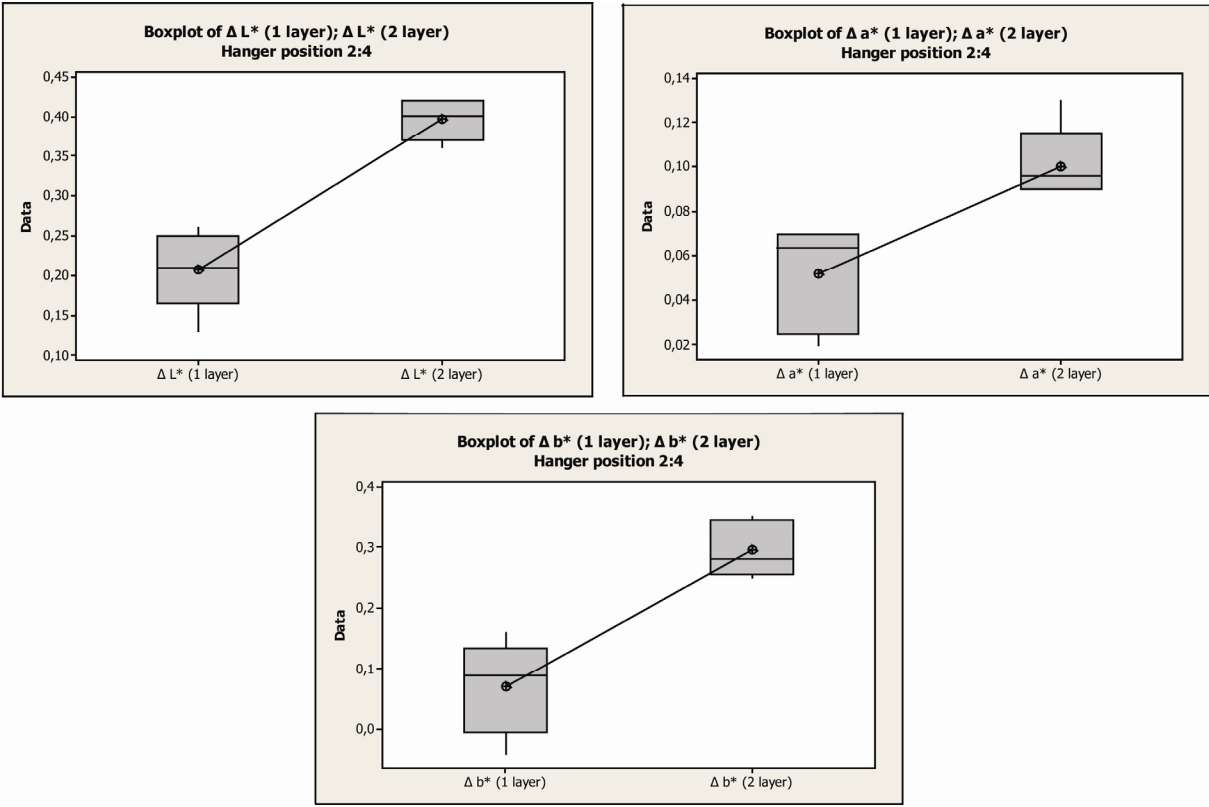


Figure 47: Box plots of ΔL^* , Δa^* and Δb^* for 1 versus 2 layers of varnish. The first curing they hung on position 2 and the second curing they hung on position 4 instead. This test the samples became for example more yellow when they were revarnished.

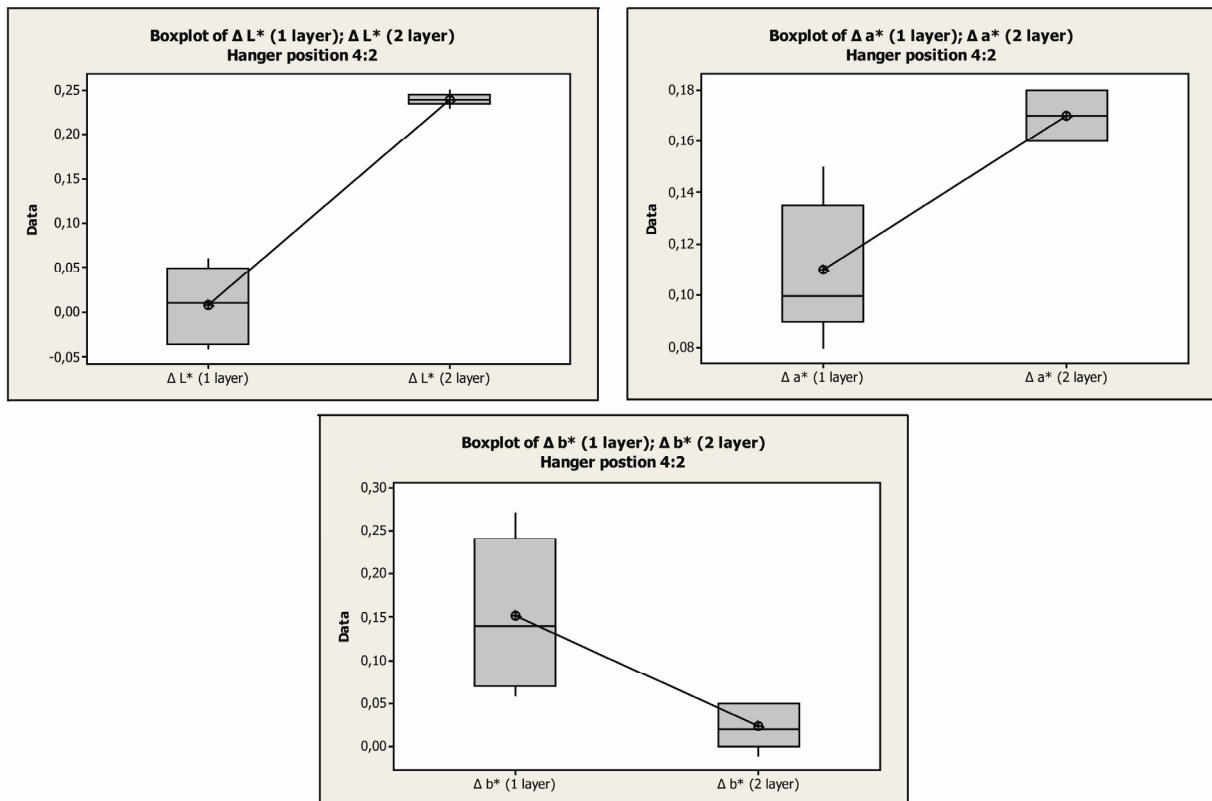


Figure 48: Box plots of ΔL^* , Δa^* and Δb^* for 1 versus 2 layers of varnish. The first curing they hung on position 4 and the second curing they hung on position 2 instead. This test the samples became for example less yellow when they were revarnished.

In figure 48, the box plots of the constellation 4:2 are shown. There is a statistical difference for all colour parameters but the most interesting observation is that Δb^* decreases when the samples are revarnished. The hypothesis that revarnishing always makes the samples more yellow is thereby falsified. Compared to the tests 2:2 and 2:4 the only difference for test 4:2 and the coming 4:4 is that in the two later the different layers are varnished with powder from different batches. However, no change has been made in the powder recipe neither have any difference in its performance been noticed in the daily inspections in the spray painting shop. This difference is therefore not probable to cause the decrease of Δb^* . The variance decrease as well with the revarnishing, a drastic difference is found for ΔL^* .

Finally for 4:4, the differences between the sets of varnish are quite similar to 4:2 also in this test the decrease of Δb^* is found. Also for the variance the behaviour of the two tests are similar. The most extreme decrease in variance is found for ΔL^* .

The mean value of the TVL for the sheets varnished one time is 79 μm and 153 μm after the second layer is applied. The two individual layers are in other words of approximately the same thickness. If the analyses of these data are compared with the plots in figure 46 showing $\Delta L^*(G)$, $\Delta a^*(G)$ and $\Delta b^*(G)$ versus TVL it can be seen that the influence of TVL on the colour cannot be determined uniformly discarding the influence of the number of curing process that the samples have been subjected to.

- **Measurement F-H; variation between positions on hanger during normal operation**

Measurement F-H contains data collected during normal operation in the varnishing process. The samples' position on the hanger has been important to note in this experiment as well, the reason to this measurement was to investigate if there is any difference between the four positions. The collected data is found in appendix XV – Colour measurements during normal operation, and the complete output from the statistical analysis is found in appendix XVI – Analysis of data from measurements F-H. Only measurements from top sheets have been analyzed to avoid bias that different types of components could possible result in.

In figure 49 box plots where the different positions are compared can be seen. The P-value is 0 respectively 0,001 for Δb^* and ΔL^* which means that H_0 , that there are no difference between the positions immediately can be rejected. For Δa^* the H_0 cannot be rejected, the P-value is just slightly above 0,05. The variance is also smallest for Δa^* , for ΔL^* and Δb^* the variances are rather equal. For both ΔL^* and Δb^* it can be observed that the highest values are found on position 4, followed by position 1 and at position 2 and 3 the lowest values are found. The difference between the mean values of the different positions was analyzed for Δb^* , the difference in mean between position 4 and 3 is 0,25. This difference is rather large considering that the data has been collected during normal operation and from the same hangers. The difference in mean between position 1 and 3 for Δb^* is 0,13. In other words it is position 4 that prominently deviates from the other positions. It is also only for position 4 that outliers are found among the collected data. The difference in colour between the four positions is likely to be caused by differences in temperature between the different positions, the results of the temperature measurements are presented later in this section.

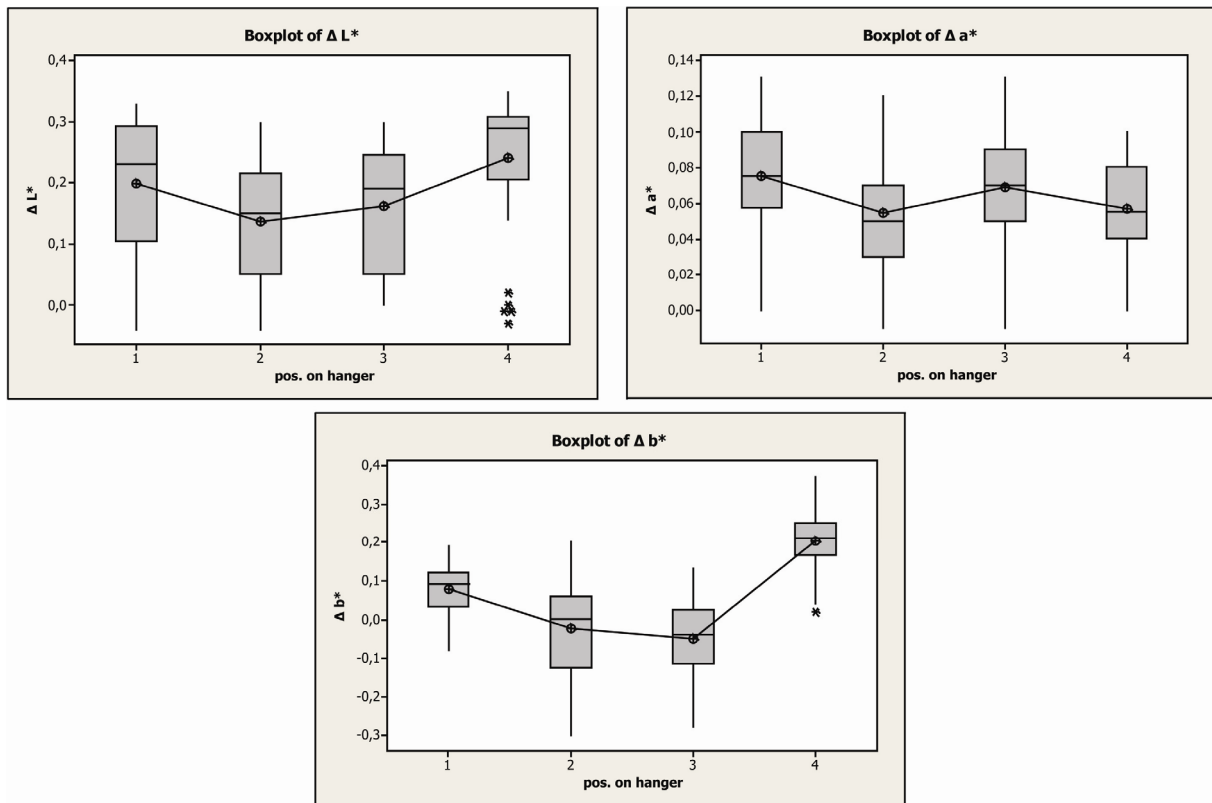


Figure 49: Box plots of ΔL^* , Δa^* and Δb^* for the different positions of a hanger. The deviating behaviour of position 4 can for example be seen in these plots.

There are only very few measurements available from other components than top sheets. However, for those four hangers that have been measured with front doors to WM/TD the mean values of Δb^* and ΔL^* seems to be slightly higher than those for top sheets. There are too little data available for other components to make a scientific statement about this but the possibility that the shape and/or size of components can influence the colour is interesting.

- **Measurement I-J; effects of 10 minutes increase of time**

To analyze the effect of increased time on the colour, data was collected from sheets that were positioned in the furnace during the 10 minutes long afternoon break, this data can be found in appendix XVII – Colour measurements after 10 min break. The graphs from the analysis in Minitab are shown in figure 50 and 51. To not get any bias from the position on the hanger all these analyzed data are from position 1. Since the design of the furnace is not identical all along the conveyor's way though it, the order of the hangers has been noted. This is to see if there are any differences in the resulting colour depending on the hanger's position when the conveyor stops during the break.

In the plots the mean values for an experiment performed during normal operation are also found, as well as the mean of the data collected in this experiment. It can be seen that Δb^* differs the most when time is increased. The difference between the mean values is approximately 0,4. After a 10 minutes conveyor stop the colour becomes brighter, greener and yellower. Interesting is to observe that the value for Δa^* is closer to the target colour after this 10 minutes break than after normal operation. It can also be seen that where the hangers stop in the furnace probably

has an impact on the colour, this is because there are great variations in colour between sheets that has been placed on hangers rather close to each other on the conveyor. This could imply that there are differences in for example heat, circulation of air or ventilation of exhaust gases.

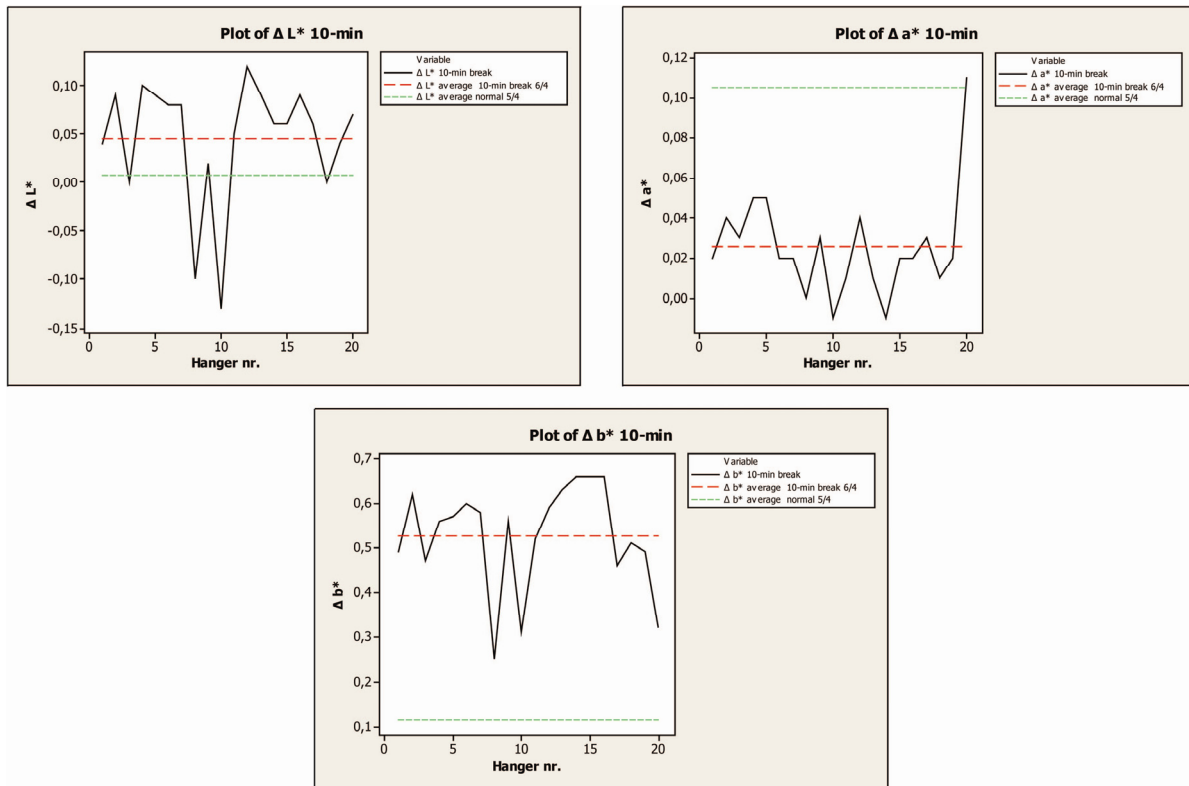


Figure 50: Plots of ΔL^* , Δa^* and Δb^* from position 1 after 10 minutes extra in the curing furnace. The mean values of the experiment are also plotted as well as from an experiment performed under normal operation.

To determine more explicitly if the irregular shape of the graphs is just caused by natural variation or if the process is out of control the data was plotted in I charts as well, see figure 51. The plots of ΔL^* and Δa^* show one warning each and Δb^* does not show any warning. However, just a very small change of one of the data points will lead to a warning for Δb^* as well. In this analysis it is the 20 individual positions in the furnace and not a process in normal operation that is considered. Therefore the warnings indicate that depending on where the hanger stops during a break colour that spread more than what is normally expected can be measured which means that the position in the furnace can have a significant effect on the result.

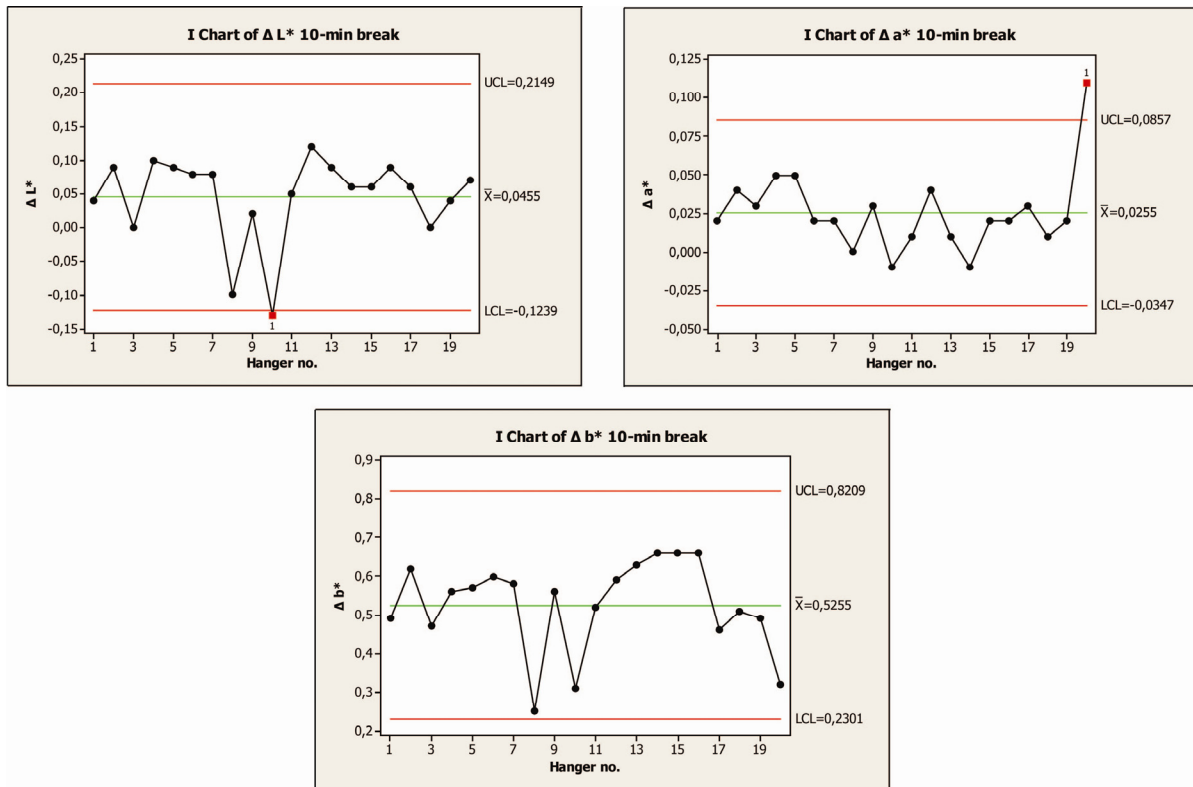


Figure 51: I Charts of ΔL^* , Δa^* and Δb^* from position 1 after 10 minutes extra in the curing furnace, showing some statistical warnings.

- **Measurement K; effects of 45 minutes increase of time**

Data has also been collected after an accidental conveyor stop of approximately 45 minutes, this data is gathered in appendix XVIII – Colour measurements after 45 min conveyor stop, and the graphs from the analysis in Minitab are shown in figure 52 and in appendix XIX – Analysis of data from measurement K. The principle of these plots is quite similar to those for the 10 minutes break in figure 50, but here graphs are displayed for all four positions of a hanger. Because of the fact that every second hanger has two respectively four sheets on it, the data from position 1 and 3 are not as extensive as for position 2 and 4. The limits marked with bold black lines indicate the tolerance limits that are being used today.

It can be seen from these graphs that the long stay in the furnace appears to have a decreasing effect on ΔL^* . This is the opposite to what was observed after the 10 minutes break. The graphs for the different positions follow each other quite well and only the graphs for position 2 and 3 are under the lower tolerance limit for some hangers. Also on Δa^* does the stop seems to have a lowering effect, even though this effect is very discrete. This is consistent with the results of the analysis after the 10 minutes break. The graphs for the different positions follow each other extremely well and they are never out of the tolerance limits for this test.

The most interesting graph is the one for Δb^* ; here an enormous increase in yellowness can be found. This is also consistent with the earlier analysis. Only the data for the sheets on the hangers that were placed the closest to the furnace's opening during the stop are within the tolerance limits. Otherwise the most of the data is more than a tolerance range (1,3) above the upper limit. It is also for Δb^* that the lines for the different positions seem to diverge the most.

The line for position 4 is often the one on top and the line for position 1 seems to be smoother than the other ones. The data collected under these very extreme circumstances gives information about what happens when among others factors such as the time is exaggerated.

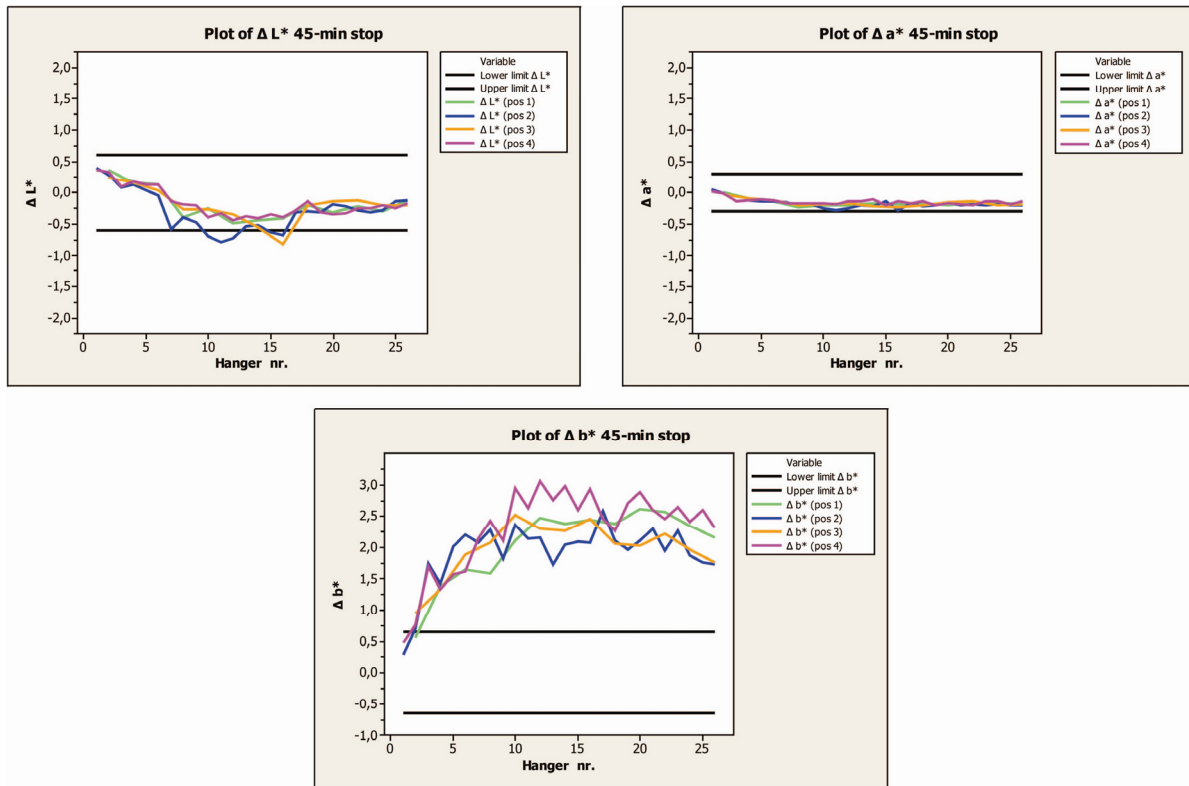


Figure 52: Plots of ΔL^* , Δa^* and Δb^* from different positions on the hanger after a 45 minutes long conveyor stop. The tolerance limits that are used today are also marked in the graphs.

Also these data were analysed with I charts, the two first data points are displayed in the plots but are omitted from the calculation of the LCL and UCL because these two hangers were placed too close to the opening of the furnace during the stop. Especially the plots for ΔL^* show warnings, also some are visible for Δb^* . Position 2 and 4 seems to be the positions with most warnings, but as exactly as for the analysis of the data from the 10 minutes break the data points analyzed represents individual positions in the furnace during the stop. Therefore, the same conclusion can be drawn; variations that cannot be explained by normal variations can be caused by the position at which the hanger is positioned during the stop.

- **Measurement L-N; effect of the number of sheets on a hanger**

The six sigma team was also interested in if the number of sheets on the hangers can influence the colour. To not get any bias from other factors only data from top sheets were analyzed. During normal operation every second hanger with this kind of components has two respectively four sheets hanging on it. The complete collection of data from these measurements is shown in appendix XX – Colour measurements on samples from hangers with two vs. four sheets, and the complete information from the statistics and probability analysis is found in appendix XXI – Analysis of data from measurements L-N.

In figure 53 the results are displayed in total for the hangers with two versus four sheets hanging on them. The P-value for ΔL^* and Δb^* are both close to 0,05. However, H_0 for ΔL^* can with a slight margin be accepted and rejected for Δb^* . The only parameter for which it is a significant difference is Δa^* and it increases when 4 sheets are placed on the same hanger instead of 2. The variance for Δa^* is quite constant between the different constellations. For the other two parameters the variance is larger for hangers with four sheets on.

When the data only for position 2 was analyzed it was also found that, H_0 only could be rejected for Δa^* even though it was with a slight margin. The P-value was once again highest for Δa^* , but this time it was as high as 0,758 which indicates a very high similarity between the data collected from the hangers with two versus four sheets on. Also the increase of the variance is similar to the former test; it increases for the hangers with four sheets on and it increases only discretely for Δa^* .

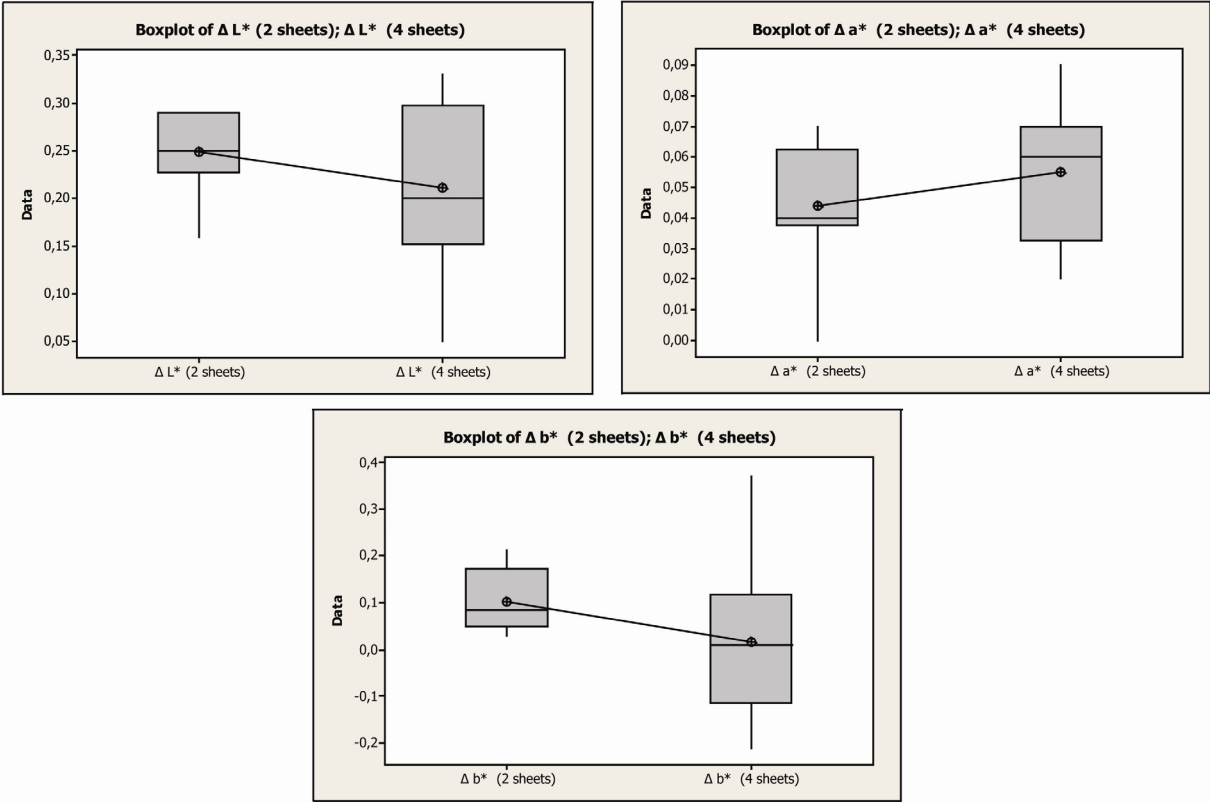


Figure 53: Box plots of ΔL^* , Δa^* and Δb^* for hangers with 2 respectively 4 sheets on, showing only a smaller difference in colour.

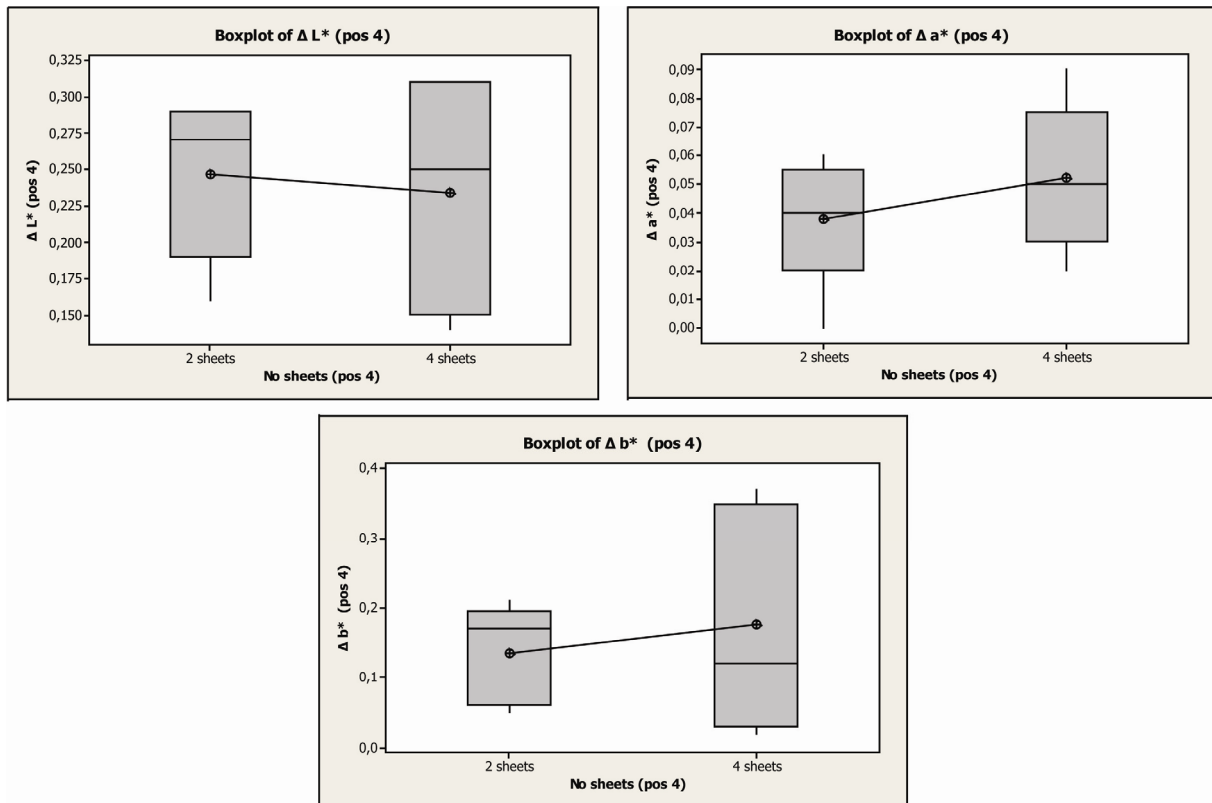


Figure 54: Box plots of ΔL^* , Δa^* and Δb^* for hangers with 2 respectively 4 sheets on, measured from position 4.

Above, in figure 54 the results from a similar analysis but for position 4 instead can be seen. For position 4 all P-values can be regarded as high and therefore none of the null hypothesis can be rejected. Also the variances increases more or less when 4 sheets are hanged on the hangers instead, this is consistent with the earlier analyses. One of the more obvious differences from the earlier analysis of this experiment is that the mean value of Δb^* increases slightly for four sheets.

- **Measurement O-R; variations in colour along sheets**

To investigate if there are any colour variations along the surfaces of the individual sheets, measurements along certain lines along each sheet were performed. The lines along which data was collected are displayed in figure 55. The data from these collections can be found in appendix XXII – Colour measurements of sheets along line A, B, C and D. The most extensive analyses have been performed with data from position 2 and 4 because due to practical circumstances it was more convenient to measure on sheets from these positions. All this analyses are based on measurements during normal operation of the process and measurements of top sheets. Along each of the lines 5 measurements were most often made. The calculations that this analysis is based on is found in appendix XXIII – Analysis of data from measurements O-R.

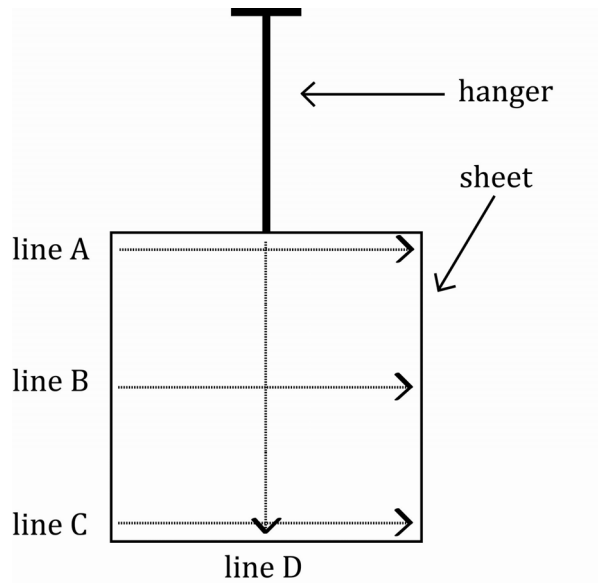


Figure 55: The four different lines along which the colour has been measured.

For ΔL^* on position 2 the mean of the differences between max and min along a line was around 0,1 for all lines. The variance seems to increase closer to the bottom of the sheet and was the highest with a RSD on 65% for line D. The maximum difference between two measurements was found for line D and was equal to 0,25. There can be a slight tendency that the sheets are a little bit brighter close to the bottom. If ΔL^* is considered for position 4 instead, the mean of the difference between max and min was higher for line A and D, around 0,3. The variance did not behave in the same way as for position 2, here the smallest variances with a RSD on 0,20-0,33 were found for line A and D. The maximum difference between two measurements was found for line B and D and was approximately 0,4. The tendency that the sheets are a little bit brighter close to the bottom is even more visible on position 4. However, none of the results of the analysis of ΔL^* are very significant therefore they are difficult to display in a clear visual way.

When Δa^* was analyzed for position 2 and 4, it could be seen that the mean of the difference between max and min along a line was between 0,4 – 0,9 for all lines. The variance was also rather equal and modest for all lines. The RSD varied between 14 and 52%, but since the mean difference was very small my opinion is that this measure is not really suitable in this situation. The maximum difference between two measurements along the same line varied between 0,06 and 0,16. These differences are not very significant in this analysis. These variations along the surfaces are even more modest than for ΔL^* , therefore they are not either illustrated in a visual way.

The differences in the measured value of Δb^* was though more interesting than the other two. The differences and variations were even so clear that they have been illustrated and are shown in figure 56. The basis for these illustrations are the calculated median values for the measured samples. Since there were great differences between different hangers my assumption was that it was more correct to use the median value than the mean value. The colour swatches display how the saturation of the colour in the figure should be interpreted. The illustrations have been produced so that $\Delta b^* = 0,65$ equals 100% of Yellow in the CMYK colour system. In appendix XXIV

– Illustrations of colour measurements along line A, B, C and D, these illustrations can also be found with included graphs that elucidate the colour variation along the lines even more clearly.

For sheets on position 2, the mean value of the difference between max and min along a line was between 0,07 and 0,27. The difference was largest for line D, where one individual difference even was as large as 0,52. The variance was rather equal for all lines and the RSD was around 45%. Besides the value for line D the maximum difference between two measurements along the same line was rather equal and around 0,20. When the mean and median values for the different lines are compared it can be found that the sheets are more yellow close to the left and right edge and especially close to the bottom of the sheet.

The position that drastically diverges from the other ones is position 4. The mean value of the difference between max and min along a line varied between 0,18 and 0,43. The difference was largest for line A and D with 0,71 respectively 0,63. Also for the other two lines the differences were larger than for the other measurements analyzed earlier in this section. The variance was rather high for all lines except line D with a RSD on 28,3 %. There is a very clear trend that the sheets are more yellow close to the left and right edge, especially in the top of the sheets. Along D the most significant result is found and that is that the sheet gets gradually much more yellow down along line D.

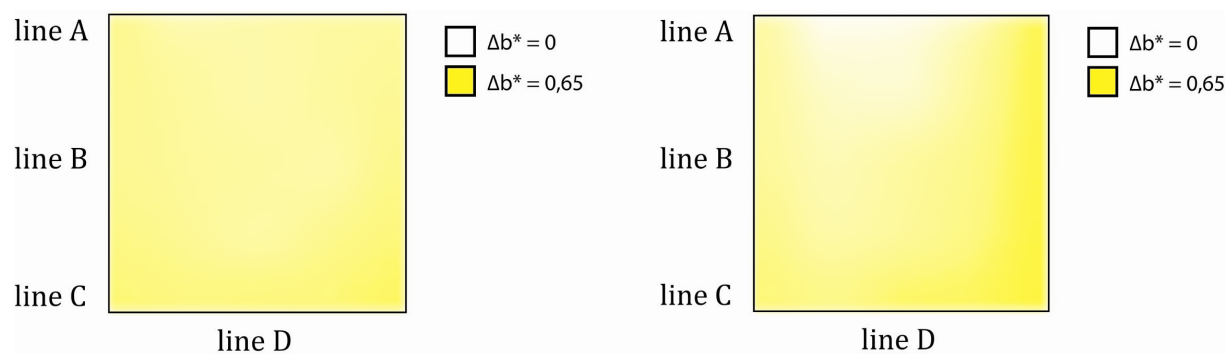


Figure 56: Schematic illustration of how Δb^* varies along the sheets on position 2 (to the left) and 4 (to the right) of a hanger.

5.4.6 Differences in temperature in curing furnace

A couple of times each year the powder coating producer measures the temperature in the curing furnace at Asko. This is made to ensure that the temperature is high or low enough to fulfil the requirements for the curing of the powder. The temperature data is collected by measuring instruments that are attached to the hanger and sheets directly before the hanger enters the furnace and that are removed directly after it has exit. During each run of measurements four different temperatures are measured simultaneously. The air temperature is always measured by a gauge attached in the middle of the hanger in the top, close to the strut that is attached to the conveyor. However, the other three temperatures which are material temperatures are measured in a less standardized way; for example the side of the hanger is randomly selected and not noted in the measurement protocol. Therefore, these protocols give some information but are not a completely reliable basis for the analysis of the temperature in the furnace. The material temperature is though always measured on the unvarnished back of the components.

Four measurement protocols have been analyzed in this project, they were from the following dates; 2008-12-10, 2009-12-02, 2010-09-15 and 2011-03-01. The passage through the furnace takes approximately 18 minutes. The shape of the graph for the air temperature is similar for the three latest measurements; with a steep upward slope in the beginning, a steep downward slope in the end and in the middle of the curve a dip at the higher temperatures. This dip of the curve produces two local maximums at approximately 6-6,5 and 13-14 minutes after entrance. The difference in air temperature between the peaks and the bottom of this dip is approximately 15°C. The second local maximum is somewhat higher than the first one for these curves. The graph from 2008 does not have the dip in the middle but otherwise the same appearance, in other words the point for the first local maximum is here instead a saddle point. The shape of the graphs though indicates some kind of uneven temperature in the furnace that can be of interest for the result.

The graphs for the material temperature show a similar shape but a delay of approximately 2,5-3,5 minutes. This delay indicates the time it takes for the material to be heated. In the three first protocols the material temperatures for the top, middle and bottom of a sheet can be found. These temperatures have been measured along a line in the middle of the sheet but it has not been noted on which side of the hanger it has been measured. However, it can be found that the temperature in the bottom of the sheets is around 5 °C higher than in the top, and in the middle it lies just slightly above the temperature in the top. This observation with the temperature being higher in the bottom of the sheets I found a little bit surprising at first. However, according to Thomas Jacobsson at DuPont (2011) this is a common observation in curing furnaces caused by that fans press down the hot air in channels in the walls to the bottom of the furnace and when the hot air then rise it cools off.

When the registered temperatures versus time are analyzed it can be seen that for 2008 and 2009 the results are rather similar. When they are compared with the measurements from 2010 it can be seen that in 2010 both the peak material temperatures as well as the temperature registered for a certain fraction of the time in the furnace is significantly higher (≈ 5 °C). When this is compared with the plots in figure 41 it can be seen that the Δb^* -value follows the same pattern. Since the temperature measurements are performed very seldom a correct conclusion cannot be drawn from this observation, only a guess that the raised temperature can be a cause to the more yellow colour after the turn of the year 2009-2010 can be made.

In the measurements from 2011, the material temperature was measured in the middle of the sheets on position 2 and 4 of a hanger. It was then found that the temperature at that time was 3 °C higher at position 4 than 2. Position 2 is closer to the LPG burners in the furnace; this temperature difference is though also possibly explained by the circulation of the hot air in the furnace. It is however very interesting to observe the temperature difference and compare them with the observed colour differences.

It can also be seen from the material temperature measurements that the time at 180 °C are considerably lower than the recommended 10 minutes, this is explained by the powder manufacturer as that the process is close to the lower limit for what is tolerable but as it is today the process should anyway result in a satisfying result. The material temperature which is held for 10 minutes or just above is around 160 – 175 °C.

To receive even better understanding of the uneven temperature in the curing furnace, additional temperature measurements were performed during the project. The result of the temperature measurement is displayed in figure 57 below. The bigger circles in the figure indicate the measurements on the front of the sheets and the smaller circles represent the measurements on the back. It can therefore directly be seen that for the positions where the temperature was measured on both sides it was the same. This was expected since the sheets are thin but it was however important to show with facts. The sheets on the hanger are illustrated as if their positions at the top edge were constant and the bottom edge was bent upwards. This model was selected to show the relation between the temperature and the position in the furnace in the clearest way. In the figure photographs of the labels are also displayed and it can be seen that the two different top temperatures that was measured was 182 respectively 188 °C.

It can clearly be seen that the path of the conveyor indicates the boundary between the temperature areas. Position 4 and the half sides of position1 and 3 that are closest to position 4 have higher temperatures. Position 2 and the remains of position 1 and 3 have a lower temperature. This temperature difference agrees with what was expected based on the measurements made by the powder producer. The difference between the temperatures in the top and bottom of the sheets which has been clearly indicated by earlier measurements is not clearly visible. It can only be seen that side 2 that has a uniform low temperature has one point in the bottom where the higher temperature has been recorded.

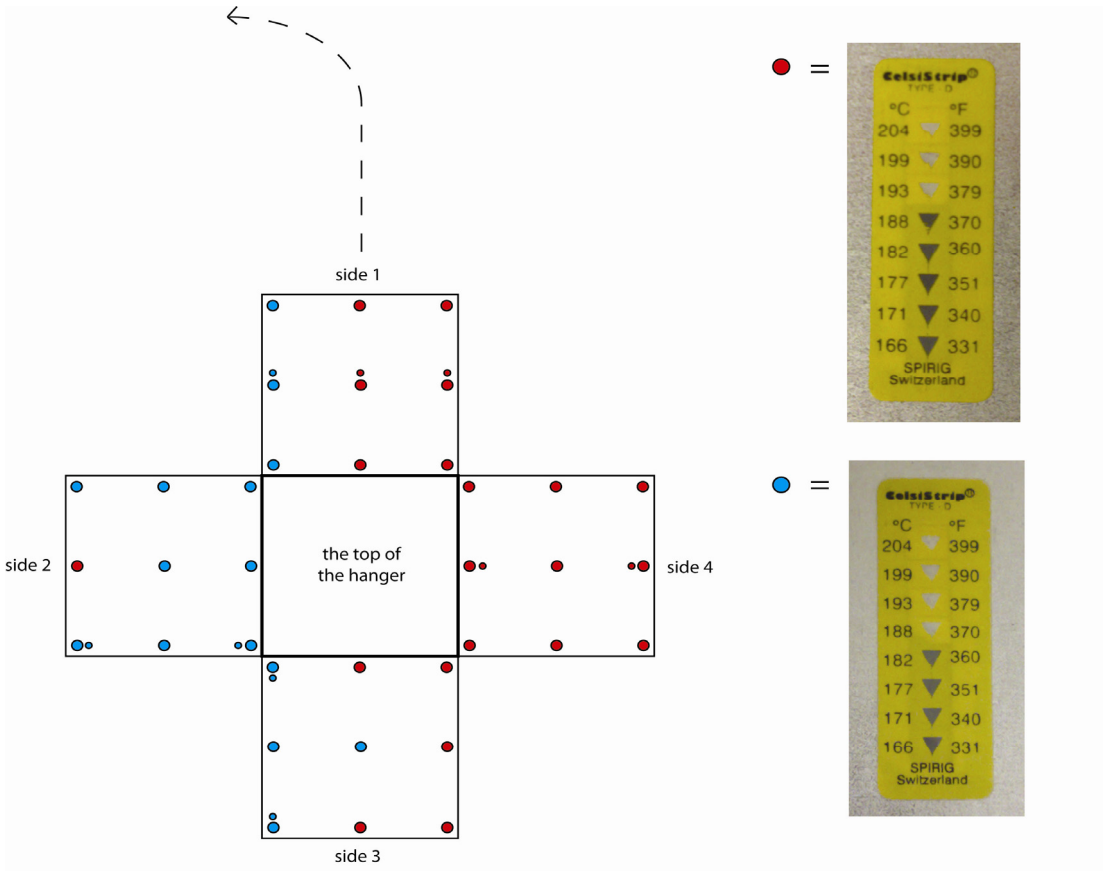


Figure 57: Schematic illustration of how the maximum material temperature varies along the surface of the four different sides of a hanger. The blue dots indicate a lower temperature and the red dots indicate a higher temperature.

If the red and blue dots in the figure are counted it can be seen that side 4 has nine red dots, side 1 has six red dots, side 3 has five red dots and side 2 has only one red dot. When this is compared to the colour measurements during normal operation in figure 49, it can be seen that the ranking of position 4, 1, 3 and 2 is the same as for ΔL^* , where ΔL^* is highest for position 4. It can also be seen that it is also almost the same order as for Δb^* . The only difference for Δb^* is that position 2 and 3 change place in the ranking, also for Δb^* has position 4 the definitely highest value. In this temperature measurement with the labels, it is not very significant if the results for position 1 and 3 if the colour is the same or just slightly different since the temperatures and their distribution is similar but just mirrored. This indicates that the temperature probably has a significant importance for the resulting colour.

The differences between the specified temperatures on the labels are 5 or 6° C, which is rather large considering the context. This makes the fact that differences were measured even more interesting but also introduces some uncertainty in the measurements, for example at a point where the indicator for 182 °C has turned black this indicates that the highest material temperature has been somewhere between 182 and 187 °C.

5.4.7 Summarizing remarks; analysis of varnishing process

During the analysis of the varnishing process much new knowledge was generated. It was found that the three colour parameters L^* , a^* and b^* often have different sensitivity to changes in the process. It was also found that the combination of different process factors most often causes discoloration of the varnish. However, some factors have a major impact on the process, for example the time, temperature and the chemical environment in the furnace. It is also revealed that there are rather large temperature differences between different positions in the curing furnace, this is an important discovery for the further development of the process and equipment at Asko.

6. Discussion

In this chapter both methods and results will be discussed. Also the overall layout of the project and its influence of the results will be considered.

6.1 Reflections on methods and project organization

This project has been wide and has included many different aspects of white colour and surface finish. A natural consequence of the width of the project has been that some of the different parts has not received as much time and weight as they could have been assigned if the project would have been less inclusive. However, the extensive scale of the project has resulted in a rather complete picture of how the manufacturing process and the surface quality and colour that the customers perceive are related to each other. My intention with this report has been to communicate the different results that have been found during the project but also to elucidate the system that the relation between customers and their perception form together with manufacturing companies and their production processes.

The systematic approach to problems and questions that has been an important tool from the university has been interesting to combine with methodology commonly used in the working life such as six sigma for example. One of the main characteristics of working with problems is the uncertainty of the final result and how it will be achieved, but with good planning and usage of suitable methods and tools the project will move forward and generate new knowledge that in different ways can be benefited in the future. This is what makes problem solving and inquiries both difficult and interesting. Even though some of the conclusions of this project have been expected it has been important to verify these assumptions with facts and analysis so no ambiguousness remains about these questions.

The market survey, a short introductory part of the project where colour of the competitors' machines was measured was a good start because it included important activities that would return later in the project but then more extensive; planning of experiment, colour measurements, brand identity and so on. Benchmarking is commonly used in other areas in industry. Therefore, why not use it for comparison of colour as well?

The examination of the surface waviness was one of the most difficult parts because of the great need to all the time evaluate the results and through instant analyses find out if the measurements performed with the actual settings could be rewarding or if the experimental of the measurements needed to be adjusted. This resulted however in a good understanding for both the instruments used and different waviness parameters. This part of the project ran parallel with the analysis of the varnishing process and as it became more obvious that the powder coating possibly could be discoloured by elements in the exhaust gases from the combustion of the LPG, a chemical analysis was suddenly of high interest. Therefore the study with the SEM and EDX can be seen as an important demonstration of a very useful tools.

The customer inquiry was primarily made to generate understanding of how customers perceive different hues of white and surface defects. It was added like an interesting additional feature to briefly examine as well how the environment affected the results of these studies, an addition that was found to be rewarding.

The benefits with being able to control the output of the varnishing process are many. It is necessary to understand the relation between the different affecting factors to be able to steer the process to make it work with inherent events such as breaks, conveyor stops, temperature changes in the production facilities and variations of the coating powder. The fact that Asko is an

OEM for some other brand makes it even more interesting and profitable to be able to explicitly control the process.

As the analysis of the varnishing process started some inherent features in the process that made the analysis more difficult were identified. For example that there are great practical difficulties with changing certain parameters such as the time by changing the speed of the conveyor. There are also great economical risks with changing some parameters such as the temperature during normal production. Therefore all of the experiments were not conducted in an optimal way for the project. However, the conclusion that the system is difficult to control and adjust completely as desired is also important. If the limitations of the system is fully identified the possibilities are as well identified.

6.2 Reflections on the results of the project

The results from the market survey cannot be said to present a complete picture of the truth because of the small scale of the study, but it gives important indications about the colours on the market. Especially since a clear deviation was found for all three colour parameters the results can be used as inspiration or important input in a process when a new target colour should be found.

During the analysis with EDX, the sulphur that was found in the sample was first assumed to be an indication of the discoloration caused by the LPG in the process. However, since the powder from the beginning contains some sulphur this hypothesis could not be justified by the analysis. When the waviness was analyzed the relation between the different parameters became clearer and it was understood that only one parameter is not enough to use if a feature such as orange peel structure should be analyzed and assessed. If the somewhat complex relationship between the individual waviness measurements is understood the method can be of value because it makes it possible to measure subjective perception in a numerical way.

As the project proceeded and the customer inquiry was performed it became clearer that the perception of colours can never be made without being influenced by the surrounding context. All the colours that have been investigated in this project can be perceived as perfectly neutral white if it is placed in the right context. It is when colours of adjacent surfaces and/or surfaces in the vicinity affect each other a user can perceive a difference in hue.

It was also found that Hering's opponent colour theory was of importance for especially the perception of white hues which all contain very modest amounts of the chromatic elementary colours. As long as two white colours contain the same hue the difference is perceived as less noticeable and annoying as if the white hues contain different hues. For example, two white colours that contain different amounts of yellow can be perceived as more harmonious together than two white colours where one of them contains some yellow and the other one some blue, even if the measured difference (ΔE) for the later pair is smaller.

The perception of the surface defects was also found to vary between different environments but the most influencing factor for that was the light, especially differences in light intensity and

direction of the light. The behaviour of the customers when they examined the demonstration objects was also interesting. It was obvious that if a defect was not found rather directly the customer showed less interest for examination of the rest of the surfaces with a high carefulness and accuracy. It was almost like the customer then supposed that the finish is good and that there are no defects to be found.

The fact that more defects and especially the rather common defects as orange peel structure and press marks are more easily detected in environments with directional light is important for the situation when the machines are displayed in stores for customers. Directional light and glare are always a part of the window-dressing in stores even though the correlated colour temperature can vary quite much between different stores and lighting equipment. This is therefore a strong argument for focusing on the surface finish especially at surfaces that the customers pays the most attention to. In the situation in a store the machines must look attractive; otherwise the customers will select a machine from a competitor.

Both the white colour and surface finish can be considered to be details compared to other features such as functionality and usefulness of the machines. However, during this study it was assumed that all basic requirements are fulfilled and the focus was instead on the latent needs; the features that makes the machine competitive against other premium machines on the market. It might not be likely that customers often make a complaint of the colour or finish of a purchased machine if it is not satisfactory. However, the customers remember it the next time they are about to purchase appliances and they talk with friends and neighbors about the purchased machine. Therefore, it is important that also the details of a premium machine are coherent with the rest of the premium feeling of the machine.

One of the problems that was observed during the customer inquiry; it is perceived as disturbing and express low quality when the white colour of adjacent surfaces do not match. This is probably caused by the difference between the NCS and NCS S colour systems. Since the NCS S system is national standard and standard constituents for manufacturing processes such as pigments and polymeric granules are most often produced according to valid standards there is a big risk with specifying a target colour according to the old NCS system today. Therefore, several problems will probably disappear if a new colour defined according to the NCS S system is selected instead.

The analysis and the investigation of the varnishing process revealed several different important results and facts. The factors that influence the output of the process were mostly in focus. But it was also found that it is important that all procedures that is related to the process are standardized to for example enhance further analyses and follow-up in the future of the output from the process. During the analysis of how the output can be controlled it was found that several different factors affect the colour but also that the real primary causes are relatively few. The extensive part of the project which concerned the varnishing process resulted in more focus on this process in general at the company. The effect was extra obvious because persons from different departments and with different competences participated in the six sigma project that dealt with the process. Therefore the resulting new awareness and increased control of the process were important results of the project as well.

If the results from the analysis of the varnishing process are summarized it is found that the colour parameter that was most sensitive to changes of the process was b^* . This is interesting because it was the b^* -value that the customers reacted most strongly to as well. This colour parameter seems to have the major impact on how the quality of a machine is perceived. In other words, variations of b^* directly influence the customers' experience of the machine and therefore it is highly important to be able to control the varnishing process in a satisfactory way.

7. Conclusions

Finally, in this chapter the conclusions from this master's thesis will be presented. Recommendations for the future work with the analysed process and phenomena will also be given.

7.1 Conclusions from the project

The objective of this project has been to;

“... determine how the output of the varnishing process can be controlled and give recommendations about how the process can be improved. It is also to give recommendations about the white target colour and its tolerance limits based on the customers inquiry and partly also on the competitors' colours. The objective is as well to provide a foundation for a possible update of the appearance-specification based on how customers in reality and natural context perceive surface defects. Finally, it should be determined if measurements of surface waviness can be a useful tool for judgement of surfaces with orange peel structure.”

The most important conclusions will be presented in this section in a bulleted list sorted according to the four different parts of the project, to enhance the readability and the comprehension;

7.1.1 Conclusions; competitors' colours

- The colour of the competitors' machines is in general brighter (positive ΔL^*), less green (positive Δa^*) and more blue (negative Δb^*) than ASKO's target colour.

7.1.2 Conclusions; white colour and surface finish

- Colour can never be perceived without the customer being influenced by the surrounding context. It is when colours of adjacent surfaces and/or surfaces in the vicinity affect each other that a customer can perceive hue differences.
- As long as two white colours contain the same hue the difference is perceived as less noticeable and annoying as if the white colours contain different hues.
- The possibility to assess colours and surface finish in a standardized environment is highly preferable because of the repeatability it results in, but the differences compared to the natural environment of usage must be remembered.
- The correlated colour temperature of the light in which the colours are judged is critical for the assessment.
- The colour of the lighting in the examination room is perceived as slightly cold which can result in an assessment of colour that falsely favours especially hues that contain yellow such as ASKO's target colour.
- The surface defect that was found as the most critical and that was most often identified was in total orange peel structure.
- Some of the most common and the most critical surface defects as orange peel structure and press marks are without doubt more easily found in environments with some directional light and gleam than in diffuse lighting.
- How different colours are perceived and appreciated is subjective but there seems to be some kind of inherent association that yellow hues represent high age, second-hand and dirtiness. Therefore the colour yellow must be handled with high caution when designing a new white colour.
- Customers prefer colours that in the actual environment are perceived as clean, fresh and neutral white. In most of the possible situations and environments this means a

colour that contains considerable amounts of blue ($b^* \approx -1$). A high lightness was also found desirable ($L^* \approx 93$) as well as a modest amount of green ($a^* \approx -0,75$).

- The fact that ASKO is a premium brand increase the customers' expectations on colour and surface finish of the products. The visual impression of the product is often the first contact between a potential customer and a product and is therefore crucial.
- The tolerance limits today are satisfying; if all parameters deviates maximal within the tolerance limits the resulting ΔE value is 0,93 which means that the difference is difficult to perceive for the human eye.
- A skewed tolerance range could be proposed based on the CIEDE2000 but this would probably not improve the customers experience of the products since the actual colour has very low saturation.
- With a small majority most of the customers prefer to examine the surface finish visually standing not too close to the demonstration objects.

7.1.3 Conclusions; surface waviness

- The combination of the skewness of the surface waviness Wsk and the high spot count HSC is recommended if the surface structure with orange peel appearance should be judged or classified mathematically.
- Surfaces that are perceived as smooth and attractive were found to have positive values of Wsk and HSC was found to be less than or equal to 2 if an assessment length of $1300\mu m$ was used for the same surfaces. It must though be remembered that there is a small range of values between a smooth and a orange peel structured surface that can be difficult to classify by surface measurements.
- Amplitude parameters are not satisfactory to use alone for characterisation of surfaces that possibly can be perceived to have orange peel structure.

7.1.4 Conclusions; the varnishing process

- When the positions of the hangers are analyzed; position 4 has a prominently deviating behaviour compared to the others.
- In conclusion, the b^* parameter was most sensitive to changes of the varnishing process. The next most sensitive parameter was L^* , and a^* was least sensitive. Individual differences are though found for individual parts of the extensive analysis.
- The features of the process which effects were analysed can be rated as follows, were 1 has the highest influence. The process parameters affect the colour parameters very different sometimes and therefore this list is primarily based on the b^* -values, because of the conclusion in the bullet above. Since correct DOE has not been possible to follow there are some factors on the same level and the ranking is **roughly** assumed to be like this;
 1. Time in curing furnace.
 2. Type of curing furnace during normal operation; LPG vs. electric.
 3. The sheets' position on the hanger.
 3. Material temperature during curing.
 4. Local positions of different sections of a sheet.

5. The thickness of varnish layer (TVL).
 6. Position in the curing furnace during break or stop.
 7. The material thickness of the varnished components.
 8. Number of times a component passes the process; 1 vs.2.
 8. Number of components on a hanger; 2 large vs. 4 large.
 8. Different powder batches.
- As can be seen above the primary factors that mostly affect the b^* value are;
 - The time during which the powder is in contact with the environment in the furnace.
 - The elements or factors that are significant for furnaces heated with LPG burners.
 - The temperature where the individual sheet or part of component is placed due to the uneven temperature distribution. Possibly this bullet can also include the concentration of different exhaust gases.

7.2 Recommended further work

Some possible solutions or ideas to work further with will now be presented. They are categorized according to how much resources it demands to implement the changes or make the recommended further work relative to the gain for the process and customer experience.

7.2.1 Effective and not expensive

- To make the examination room suitable for assessment of colours the lighting should be changed. The slightly cold colour of the lighting should preferably be changes to a slightly warm colour instead.
- The colour of the fixtures and walls in the examination room should preferably be changed to a neutral colour, in other words a colour that contains less yellow than today.
- There should be only one system to denote the sides of the hangers. The strong recommendation from this project is to use the denotation that is described in section 3.1 and illustrated in figure 25.
- There should be specified from which sides of the hangers the samples that are being measured in the daily controls of the varnishing process should be collected from. Position 4 can be used as a critical position; if the sheets from this position is below the upper tolerance limit the rest of the sheets on the same hanger are that as well. Position 1 can be used to represent the mean value of the hanger in a rather fair way. If both position 3 and 4 are used the resulting measurements presents the range of hues on that hanger.
- The part of the components that is placed furthest away from the top of the front door of a machine should be positioned closer to the bottom on the hangers. Since the colour deviates the most in the bottom of the hanger these deviations are then positioned in areas where the customer pay little attention on the complete machine.

- If there are difficulties to receive exactly the same colour on components from the varnishing process and components ordered from subcontractors; the measured colour difference (ΔE) is less visible for the customer if the different white colours contain the same hue (e.g. yellow and yellow) compared to two different (e.g. yellow and blue). This should be remembered when designing new colours and/or working with subcontractor quality.
- The target colour and colour tolerances should be equal for all white components; varnished as well as polymeric from subcontractors. They must also be clearly specified on every drafting so no misunderstands can come up.
- If some hangers have been positioned in the furnace during a conveyor stop the knowledge about the different hues on the different sides can be benefited so that only the sheets from position 4 needs to pass the process one more time, while the other sheets probably are within tolerances if the stop was not too long.
- When the temperature is measured in the furnace with the control instrument it would be beneficial to standardize the positions of measurements further as well as making notations of which sides of the hanger that were being measured. This will provide even more useful information for the future than today.

7.2.2 Demand a slightly greater effort

- Develop a new white target colour that is specified according to the NCS S system. This colour should preferably contain greater amounts of blue, less green and be brighter than the actual target colour.
- Try to make the powder somewhat less yellow from the beginning. This will probably result in improved performance especially during breaks and stops.
- It would be beneficial to investigate the circulation of heat and exhaust gases in the furnace further and through that achieve the possibility to control it.
- Increased ventilation of the exhaust gases will most certainly decrease the discolouring of the white powder coated surfaces.
- An additional lighting system can also be installed in the examination room. Such a system should then have a considerably warmer colour to better simulate the colour of the lighting in a room a sunny day or if light bulbs are used for illumination. The second system is then not optimised for assessment of absolute colour values but instead for simulation of the reality in many common environments of usage.
- For a more realistic assessment of surface finish some directional light sources could be installed in the examination room as well.
- The settings of the spectrophotometer are rather easy to destroy therefore it would be preferable to calibrate the instrument once a year to prevent the programmed target value to drift too much from what is desired.
- In a perfect production process the varnishing process should not contain any stops at all.

7.2.3 More demanding work

- If the hangers could be rotated during their tour through the furnace the colour would be more even between the different sides of the hangers.
- Perform EDX and SEM analyses of samples that have been cured in some type of electric furnace and the present LPG furnace to elucidate if there are some chemical differences. This could preferably be done in cooperation with the powder manufacturer since the result might be of mutual interest.
- A solution that would solve basically all the problems related to colour deviations resulting from the varnishing process would be to heat the furnace electrically instead. Only the colour is now being considered and other aspects may be investigated separately from this project.
- Another and not as drastic solution would be to isolate the burners from the tunnel where the hangers pass and instead transfer the heat with heat exchangers.

8. List of references

To enhance further investigation of sections that the reader finds interesting and to ensure the quality of the information in this report the references are presented in this chapter. The references are sorted in three subgroups; electronic documents, literature and verbal references.

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9. Appendices

In this final chapter all the appendices that have been referred to through the report will be presented. Together they present a more detailed picture of for example collected data and statistical analyses.

Appendix I - Colour of competitors' machines

Appendix II - Description of show machines in colour inquiry

Appendix III – Comments from customers during inquiry; arrangement 1 & 2

Appendix IV – Comments from customers during inquiry; arrangement 3 & 4

Appendix V – Comments from customers during inquiry; arrangement A

Appendix VI – Comments from customers during inquiry; arrangement B & C

Appendix VII – Additional SEM micrographs

Appendix VIII – Design of experiment (DOE)

Appendix IX – Colour measurements resulting from the design of experiment (DOE)

Appendix X – Analysis of data from measurements A-B

Appendix XI – Colour measurements of samples from electric convection oven vs. LPG furnace

Appendix XII – Analysis of data from measurement C

Appendix XIII – Colour measurements of samples varnished and cured one respectively two times

Appendix XIV – Analysis of data from measurements D-E

Appendix XV – Colour measurements during normal operation

Appendix XVI – Analysis of data from measurements F-H

Appendix XVII – Colour measurements after 10 min break

Appendix XVIII – Colour measurements after 45 min conveyor stop

Appendix XIX – Analysis of data from measurement K

Appendix XX – Colour measurements on samples from hangers with two vs. four sheets

Appendix XXI – Analysis of data from measurements L-N

Appendix XXII – Colour measurements of sheets along line A,B,C and D

Appendix XXIII – Analysis of data from measurements O-R

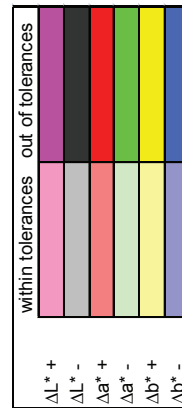
Appendix XXIV – Illustrations of colour measurements along line A,B,C and D

Appendix I; Colour of competitors' machines

ID	Brand	Model	Machine	Left side			Right side			Front			Top			Panel			Notes	
				ΔL^*	Δa^*	Δb^*	ΔE^*	ΔL^*	Δa^*	Δb^*	ΔE^*	ΔL^*	Δa^*	Δb^*	ΔE^*	ΔL^*	Δa^*	Δb^*		ΔE^*
Is3	Brand 1	XXX	WM	0.95	0.65	1.33	1.76	1.16	0.61	1.42	1.93	1.62	0.85	1.79	2.50	P	19.20	1.54	1.40	19.40*
Is4	Brand 1	XXX	WM	1.82	0.88	-0.96	2.24	1.90	0.91	-0.95	2.31	1.64	0.85	-0.98	2.08	P	1.96	0.56	-0.64	2.13
Is5	Brand 1	XXX	WM	2.42	0.78	-0.95	2.72	2.62	0.77	-1.15	2.96	2.66	1.08	-0.04	2.87	P	2.25	0.81	-1.39	2.77
Is10	Brand 1	XXX	WM	1.30	0.97	-1.04	1.93	1.20	0.90	-0.91	1.75	1.44	0.95	-0.87	1.94	P	-19.00	1.64	0.13	19.10*
Is11	Brand 1	XXX	WM	1.53	1.13	-0.49	1.97	2.29	0.94	-0.34	2.59	1.66	0.83	-0.50	1.92	P	-17.80	1.77	-0.17	17.90*
Is13	Brand 1	XXX	WM	2.07	1.12	-1.16	2.62	2.22	1.02	-1.13	2.69	1.95	0.91	-1.06	2.40	P	-17.60	1.94	0.29	17.70*
Is26	Brand 1	XXX	WM	2.22	0.74	-1.28	2.67	2.33	0.74	-1.10	2.88	2.45	1.11	-0.15	2.70	P	1.70	-0.25	-2.21	2.79**
Is12	Brand 2	XXX	WM	3.03	0.87	-1.35	3.43	2.63	0.80	-1.48	3.12	3.16	0.89	-1.47	3.60	P	2.66	0.97	-1.40	3.16
Is21	Brand 2	XXX	DW	N.M	N.M	N.M	N.M	N.M	N.M	N.M	N.M	-0.54	-0.05	-0.03	0.54	N.M	0.89	0.04	-1.45	1.70
Is14	Brand 2	XXX	WM	1.24	0.74	-2.35	2.76	1.06	0.84	-2.37	2.37	0.18	1.00	-1.95	2.19	P	0.55	1.22	-1.95	2.37
Is24	Brand 3	XXX	WM	0.61	0.95	-2.11	2.39	0.56	0.94	-2.10	2.37	0.94	1.06	-2.09	2.53	P	-0.11	0.96	-1.76	2.01
Is27	Brand 3	XXX	DW	N.M	N.M	N.M	N.M	N.M	N.M	N.M	N.M	-1.00	0.88	-0.02	1.34	N.M	-1.59	1.05	-0.15	1.91
Is29	Brand 3	XXX	DW	N.M	N.M	N.M	N.M	N.M	N.M	N.M	N.M	-0.72	0.96	0.03	1.20	N.M	-1.34	1.28	0.20	1.86
Is16	Brand 4	XXX	WM	1.91	0.22	-1.02	2.18	1.74	0.25	-1.01	2.02	-0.46	0.23	-0.58	0.78	P	-8.14	1.38	0.61	8.28*
Is28	Brand 4	XXX	WM	0.96	0.97	0.22	1.38	-3.99	1.43	0.84	4.32	1.08	0.74	-0.04	1.31	P	1.01	0.41	-0.55	1.22
Is20	Brand 5	XXX	DW	N.M	N.M	N.M	N.M	N.M	N.M	N.M	N.M	0.28	-0.07	0.24	0.38	N.M	0.71	0.02	-1.45	1.62
Is22	Brand 5	XXX	DW	N.M	N.M	N.M	N.M	N.M	N.M	N.M	N.M	0.36	0.33	-0.23	0.54	N.M	N.M	N.M	N.M	N.M
Is23	Brand 5	XXX	DW	N.M	N.M	N.M	N.M	N.M	N.M	N.M	N.M	0.21	0.49	0.68	0.86	N.M	0.55	-0.18	-0.86	1.04
Is2	Brand 6	XXX	WM	2.37	0.94	-0.93	2.72													
Is9	Brand 6	XXX	WM	0.94	0.34	-0.48	1.11	1.03	0.31	0.10	1.09	1.21	0.42	-0.20	1.29	P	1.11	0.50	-0.56	1.34
Is6	Brand 7	XXX	TD	1.55	0.52	-0.53	1.72	1.41	0.51	-0.47	1.57	0.66	0.57	-0.48	0.99	P	2.67	0.83	-1.01	2.97
Is17	Brand 7	XXX	DC	0.07	0.72	-0.93	1.18	0.37	-0.10	-1.99	2.02	0.52	-0.16	-1.71	1.80	N.M				***
Is18	Brand 7	XXX	DC	0.59	-0.13	-2.15	2.24	0.53	-0.18	-1.92	2.00	0.56	-0.17	1.72	1.82	N.M				
Is7	Brand 8	XXX	TD	-0.81	0.80	-1.64	1.99	-0.90	0.98	-1.99	2.39	-1.00	0.97	-1.54	2.08	N.M				
Is8	Brand 8	XXX	WM	-1.32	0.74	-1.99	2.50	-1.09	0.70	-2.05	2.43	-1.25	0.79	-1.97	2.47	N.M				
Is1	Brand 9	XXX	WM	3.26	0.84	-1.21	3.58	2.99	0.69	-1.60	3.46	3.20	0.73	-1.21	3.50	P	3.18	0.72	-1.36	3.53
Is15	Brand 10	XXX	WM	-2.17	0.37	-1.71	2.79	-2.26	0.36	-1.70	2.84	-1.93	0.08	-0.22	1.94	P	-3.25	0.47	0.57	3.34
Is19	Brand 11	XXX	TD/DC	-0.74	0.70	-2.34	2.55	-0.90	0.64	-2.29	2.54	-1.03	0.72	-1.75	2.15	N.M				
Is25	Brand 12	XXX	DW	3.02	0.81	0.50	3.16	1.77	0.62	-0.55	1.95	2.10	0.67	-0.07	2.21	N.M				

P = Patterned -> the hue is not measurable.
 N.M = Not Measurable i.e. because there is no white or separate surface to measure.

* polymeric panel covered with another layer of a transparent polymer.
 ** the polymeric lid was measured instead of the panel
 *** this is a measurement of the polymeric lower part of the front



Tolerances today;
 $\Delta L^* = \pm 0.6$
 $\Delta a^* = \pm 0.3$
 $\Delta b^* = \pm 0.65$

Appendix II; Description of show machines in colour inquiry

Machine A, Brand: Brand 3, Model: XXX, Type of machine: washing machine

	L*	ΔL^*	a*	Δa^*	b*	Δb^*	ΔE^*	panel material
left side	93,44	1,24	-1,14	0,74	-1,50	-2,35	2,76	
right side	93,26	1,06	-1,04	0,84	-1,52	-2,37	2,37	
front	92,38	0,18	-0,88	1	-1,1	-1,95	2,19	
top	P	P	P	P	P	P	P	
panel	92,75	0,55	-0,66	1,22	-1,1	-1,95	2,37	polymer
mean value:	92,96	0,76	-0,93	0,95	-1,31	-2,16	2,42	
median:	93,01	0,81	-0,96	0,92	-1,30	-2,15	2,37	

Machine B, Brand: Brand 7, Model: XXX, Type of machine: tumble dryer

	L*	ΔL^*	a*	Δa^*	b*	Δb^*	ΔE^*	(panel) material
left side	93,75	1,55	-1,36	0,52	0,32	-0,53	1,72	
right side	93,61	1,41	-1,37	0,51	0,38	-0,47	1,57	
front lid	92,86	0,66	-1,31	0,57	0,37	-0,48	0,99	
front	94,32	2,12	-1,16	0,72	0,04	-0,81	2,38	polymer
top	91,65	-0,55	-0,82	1,06	-0,22	-1,07	1,60	
panel	94,87	2,67	-1,05	0,83	-0,16	-1,01	2,97	polymer
mean value:	93,51	1,31	-1,18	0,7	0,12	-0,73	1,87	
median:	93,68	1,48	-1,24	0,65	0,18	-0,67	1,66	

Machine C, Brand: ASKO, Model: DW90.1, Type of machine: dish washer

	L*	ΔL^*	a*	Δa^*	b*	Δb^*	ΔE^*	panel material
left side	N.M	N.M	N.M	N.M	N.M	N.M	N.M	
right side	N.M	N.M	N.M	N.M	N.M	N.M	N.M	
front	92,39	0,19	-1,89	-0,01	0,88	0,03	0,20	
top	N.M	N.M	N.M	N.M	N.M	N.M	N.M	
panel	92,49	0,29	-1,85	0,03	0,79	-0,06	0,30	polymer
mean value:	92,44	0,24	-1,87	0,01	0,84	-0,02	0,25	
median:	92,44	0,24	-1,87	0,01	0,84	-0,02	0,25	

Machine D, Brand: Brand 5, Model: XXX, Type of machine: tumble dryer

	L*	ΔL^*	a*	Δa^*	b*	Δb^*	ΔE^*	panel material
left side	91,94	-0,26	-2,20	-0,32	1,59	0,74	0,85	
right side	92,13	-0,07	-2,07	-0,19	1,15	0,3	0,36	
front	91,92	-0,28	-2,09	-0,21	1,36	0,51	0,63	
top	92,13	-0,07	-2,11	-0,23	1,03	0,18	0,30	
panel	92,23	0,03	-2,07	-0,19	2,02	1,17	1,19	polymer
mean value:	92,07	-0,13	-2,11	-0,23	1,43	0,58	0,67	
median:	92,13	-0,07	-2,09	-0,21	1,36	0,51	0,63	

Machine E, Brand: Brand 1, Model: XXX, Type of machine: washing machine

	L*	ΔL^*	a*	Δa^*	b*	Δb^*	ΔE^*	panel material
left side	93,15	0,95	-1,23	0,65	2,18	1,33	1,76	
right side	93,36	1,16	-1,27	0,61	2,27	1,42	1,93	
front	93,82	1,62	-1,23	0,65	2,64	1,79	2,50	
top	P	P	P	P	P	P	P	
panel	.(73,00)	(-19,2)	-0,34	1,54	2,25	1,4	.(19,4)	polymer covered with transparent polymer layer
mean value:	93,44	1,24	-1,02	0,86	2,34	1,49	2,06	
median:	93,36	1,16	-1,23	0,65	2,26	1,41	1,93	

A
B
C
D
E

	within tolerances	out of tolerances
$\Delta L^* +$		
$\Delta L^* -$		
$\Delta a^* +$		
$\Delta a^* -$		
$\Delta b^* +$		
$\Delta b^* -$		

Appendix III; Comments from customers during inquiry; arrangement 1 & 2

Frequently occurring (49-72 persons):

- It is very important that washing machine and tumble dryer match well with each other.
- The white colours which contain a clearly noticeable amount of yellow (D and especially E) are experienced to express second-hand and high age. Machines/surfaces with this colour does not look fresh or clean. These colours are therefore seldom perceived as attractive.
- It is confusing and disturbing that machine B's front lid has a different white colour especially compared to the rest of the machine's front. It renders difficulties to perceive the machine as one coherent unit. (The difference in lightness is approximately 2 and in blue hue it is around 0,50).
- It is decisive for the importance of matching the white hues if the consumer has the washing machine and tumble dryer in the bathroom or in a laundry room. If the machines are placed in the bathroom the importance of matching the colours is as high as or just little lower than in the kitchen. If the machines are placed in a laundry room it is not very important that the white colours match with the rest of the furnishing.
- The colour of machine A is perceived as the most neutral/unblended white colour.
- If purchasing a new dishwasher to an old kitchen the matching of the white colours is not worth to pay much extra for. However, if the kitchen is being renovated and everything is new it is definitely worth to pay extra to receive the desired result concerning the colours.
- The colour difference between the panel and the rest of machine G is noticed and commented.

Rather frequently occurring (25-48 persons):

- It is disturbing that machine B's front lid has a different white colour compared to the rest of the machine. A machine with such a large component in a deviating colour looks unprofessional.
- The colour of machine A is perceived as the most clinically clean and thereby cold and not very tempting or attractive colour.
- The colour of machine A is perceived to have too high lightness. The colour is too bright to be comfortable to look at.
- The colour of machine A looks fresh, clean and new and is therefore the most attractive one.
- The fact that the colour of machine A is very bright makes it very spirited and vivid.
- The colour of machine B is perceived as the most attractive. The reason for this is that it does look fresh and new like A but without being too bright or glaring.
- If there would have been a colour between the ones on machine A and B the customer would have selected that one as the most attractive.
- It is important that the colour change over time is not very different on the different components of the machine.
- A new kitchen is/can be very expensive and therefore it is worth 2000 SEK extra to receive a dish washer in a matching white colour.
- The customer thinks that she/he is not aware of a potential difference in the white colour between a dish washer and the kitchen when being in the shop. However, after installing the dish washer in the kitchen a noticeable difference in colour (when the

white colours contain different colours compared to each other) would be annoying and not appreciated.

- The price of the machines influences how careful the customers examine the products and how high the expectations are on them. When buying a machine of a premium brand the consumer considers having the right to demand high quality and exactness in its appearance, even in details that the consumer normally would not pay much attention to.
- The customer thinks that 2000 SEK is much money and is not sure that it is worth that large amount to receive a machine in the right white colour. However, the customer thinks that it can be worth to pay some more money for a matching machine.
- The colour difference between the white details on the round displays and the rest of the front of machine F is noticed and commented.
- The colour difference between the panel and the rest of machine G lowers the perceived quality of the machine when the customer sees it in the store and is perceived as annoying.

Not frequently occurring (0-24 persons):

- Even though some men declare that they are not very interested in design and colours, they apprehend it as annoying when colours of the furnishing are not matching at all.
- The colour of machine A looks too white, it is probably difficult to keep the machine clean.
- The colour of machine B contains some amounts of blue, A looks more neutral.
- A colour difference between the panel and the rest of the machine can be approved as long as the panel does not look yellowish.
- If the furnishing of the kitchen should be fully matched, this cannot be achieved as long as the machine is not fully integrated. When it is fully integrated the white colour of its components is not crucial.
- It is important that the washing machine and tumble dryer matches with the furnishing even though they are placed in a laundry room. Several products in the room are often white, such as ironing board, laundry baskets and so on.
- If there would have been a colour between the ones on machine A and C the customer would have selected that one as the most attractive.
- The fact that the colours of the surfaces will change over time makes it less important that the colour and matching are perfect from the beginning.
- It is more important that the white colour does not change over time than that it has the exactly correct hue from the beginning.
- The fact that the colours of the surfaces will change over time makes it not worth to pay much extra for a certain hue of white on the machine.
- If the fixtures in the kitchen are white it would be worth to pay rather much extra to receive a white dish washer that matches well with the other white colours.
- The colour of machine C feels greyish.
- Green hues does not feel fresh, therefore the colour of machine D is not attractive.
- It is confusing and disturbing that the parts of machine D have different white colours. It renders difficulties to perceive the machine as one coherent unit.
- If there are differences in colour between the parts of the machine the consumer gets used to this and therefore it is not a problem.
- The price of a machine or product is always a more decisive factor than for example colour and design.
- It is evident that the customer will pay 2000 SEK extra for a dish washer in a matching white hue. Otherwise she/he will be annoyed about the difference in colour and regret the selection of machine.

Appendix IV; Comments from customers during inquiry; arrangement 3 & 4

Frequently occurring (21-31 persons):

- The white colours which contain a clearly noticeable amount of yellow are experienced to express second-hand and high age. Machines/surfaces with this colour do not look fresh or clean. These colours are therefore seldom perceived as attractive.
- It is difficult to distinguish the different white hues from each other and see which colours they contain in the light in which the test was performed.
- The colour of machine D is very unattractive. It is very dull and yellow, it almost looks beige.
- It is perceived as easy to find the yellow nuances in the white colours.
- When answering question number 6 the participants comment that the colour difference would have been less important if the machine would have been a washing machine or tumble dryer instead. For a washing machine/tumble dryer its functions are clearly superior to its appearance.

Rather frequently occurring (11-20 persons):

- All machines except A looks yellowish.
- The colour of machine B and C is perceived to be rather similar.
- The white colour of machine C, D and E are perceived to contain some amounts of yellow and are therefore not selected as the most attractive one.
- The price and the brand of the machines influence how high the expectations are on them. When buying a machine of a premium brand the consumer considers having the right to demand high quality and exactness in its appearance, especially in such a basic factor as uniformity of the colour.
- The participant thinks that there possibly can be a difference in colour between the front lid and the rest of the machine's front on machine B.
- It is difficult to distinguish between greyish and bluish nuances.
- If the surface with a deviating white hue has such great dimensions as the panel of machine G, the difference in colour is clearly perceived as annoying when it has been noticed.
- The participants who have not selected machine G when they were asked about the greatest colour difference between two adjacent surfaces do however comment it for this machine when they later on in the test are wiping the surfaces and searching for defects.
- The colour difference between the panel and the other surfaces of machine G makes the varnished surfaces look even more yellow than with a uniformly coloured panel. Therefore, the colour difference decreases the attractiveness of this machine.
- Even though the colour difference between the panel and the front sheet of machine E is not perceived as the most palpable it is commented and noticed.
- It is confusing and disturbing with colour differences of great magnitude on adjacent surfaces. It renders difficulties to perceive the machine as one coherent unit.
- The colour difference between the different plastic details such as buttons and knobs relative to the rest of the panel of machine G is observed and commented.
- The colour difference between the white details on the round displays and the rest of the front of machine F is noticed and commented.

Not frequently occurring (0-10 persons):

- The white components of machine F looks more homogenously coloured than on machine C.
- Machine A looks pink or red, this is not perceived as attractive.
- In a kitchen there is much other fixture and furniture, therefore a difference in white hue between two adjacent surfaces on a dishwasher is not important.
- Machine B has a slightly yellowish colour.
- The colour of machine C contains a very small amount of blue.
- The colour of machine C is not fresh; it looks too dull and yellow.
- The exact white hue is not important as long as it is perceived as some variant of white.
- It is confusing and disturbing that machine B's front lid has a different white colour especially compared to the rest of the machine's front. It renders difficulties to perceive the machine as one coherent unit. (The difference in lightness is approximately 2 and in blue hue it is around 0,50).
- The colour of machine D looks greenish, which is not perceived as attractive.
- If the fixture in the kitchen is white it is important that the dishwasher has a uniform colour over all visible white surfaces.
- The participant has experienced to have a machine with different white colours by having an old machine which panel has become yellowish over time. This is not at all appreciated by the participant.
- The colour of the panel of machine G is the most attractive.
- The colour of machine A and B is very similar, but the one on B looks just a little bit warmer than the other one.
- A machine can look attractive with a panel in a deviating (white) colour, but then the difference has to be clear enough to make it look like a conscious design choice instead of a mistake.
- The colour differences between different white surfaces of machine G is probably not noticed in the store when purchasing the machine, but it will be noticed and perceived as annoying when it has been installed in the home.
- The panel of machine G will become more yellow over time and therefore the initial colour difference is not a big concern.
- It is more difficult to distinguish the white hues from each other when some of the surfaces flare up in the light from the lamps or the sun.
- The panel of machine G looks greenish.

Appendix V; Comments from customers during inquiry; arrangement A

Frequently occurring (37-54 persons):

- When the participant has found her/his first defect she/he starts to examine the remaining surfaces more carefully and with more enthusiasm. The surfaces that already have been examined are also examined once more with the new carefulness. When the first defect has been found the participant becomes more critical in her/his judgement and is more aware of what to look for at the specimens.

Rather frequently occurring (19-36 persons):

- The surface of machine δ looks smooth and nice.
- The texture of the surface is important. Preferably it should not be such that it collects dirt and it should also be easy to clean.
- Once a defect is noticed the customer will not forget it and will from time to time think of it and maybe be annoyed of it.
- The participant does not understand for what purpose she/he should use the cloth and wipe the surfaces. She/he prefers to use her/his hands and fingers to examine the texture of the surfaces instead.

Not frequently occurring (0-18 persons):

- The price and the brand of the machines influence how high the expectations are on them. When buying a machine of a premium brand the consumer considers having the right to demand high quality and exactness in its appearance, even in details that the consumer normally would not pay much attention to.
- When the orange peel is perceived as discrete and not very conspicuous, which can be the case for specimen α and β , it is acceptable and not annoying.
- Some orange peel texture is acceptable on a washing machine such as machine ϵ .
- The marks from the stamping are maybe not perceived as annoying because they are so small.
- The surface of machine ϵ looks smooth and nice.
- The dot of dried paint on machine β is not annoying because it is on the lower edge of the sheet.

Appendix VI; Comments from customers during inquiry; arrangement B & C

Frequently occurring (21-31 persons):

- It is perceived that it is much easier to see finish defects when the surfaces are placed higher up (on the chairs) than directly on the floor.
- The participant do not understand for what purpose she/he should use the cloth and wipe the surfaces. She/he prefers to use her/his hands and fingers to examine the texture of the surfaces instead.
- The surfaces with an apparent orange peel texture, such as at specimen γ and perhaps also ϵ , are perceived as unattractive and they look not professionally manufactured.
- When the participant has found her/his first defect she/he starts to examine the remaining surfaces more carefully and with more enthusiasm. The surfaces that already have been examined are also examined once more with the new carefulness. When the first defect has been found the participant becomes more critical in her/his judgement and is more aware of what to look for at the specimens.

Rather frequently occurring (11-20 persons):

- The price and the brand of the machines influence how high the expectations are on them. When buying a machine of a premium brand the consumer considers having the right to demand high quality and exactness in its appearance, even in details that the consumer normally would not pay much attention to.
- The scratches on specimen α and γ are easy to detect and they would have been noticed in a store in a situation where a customer is searching for a machine to purchase.
- The surface of machine δ looks smooth and nice.

Not frequently occurring (0-10 persons):

- The texture of the surface is important. Preferably it should not be such that it collects dirt and it should also be easy to clean.
- When the customer is in a store and searching for a new machine to purchase she/he is very meticulous and observant on quality and the finish of the machines.
- Scratches on machines that handle water are not acceptable, because of the risk for corrosion.
- When the orange peel is perceived as discrete and not very conspicuous, which can be the case for specimen α and β , it is acceptable and nor annoying.
- Some orange peel texture is acceptable on a washing machine such as machine ϵ .
- Some orange peel texture is acceptable if the texture is the same or similar at all the surfaces of the machine.
- The marks from the press are not perceived as annoying as long as the user does not see them when the sun shines at them so they flare up.
- The surface of machine ϵ looks smooth and nice.

Appendix VII; Additional SEM micrographs

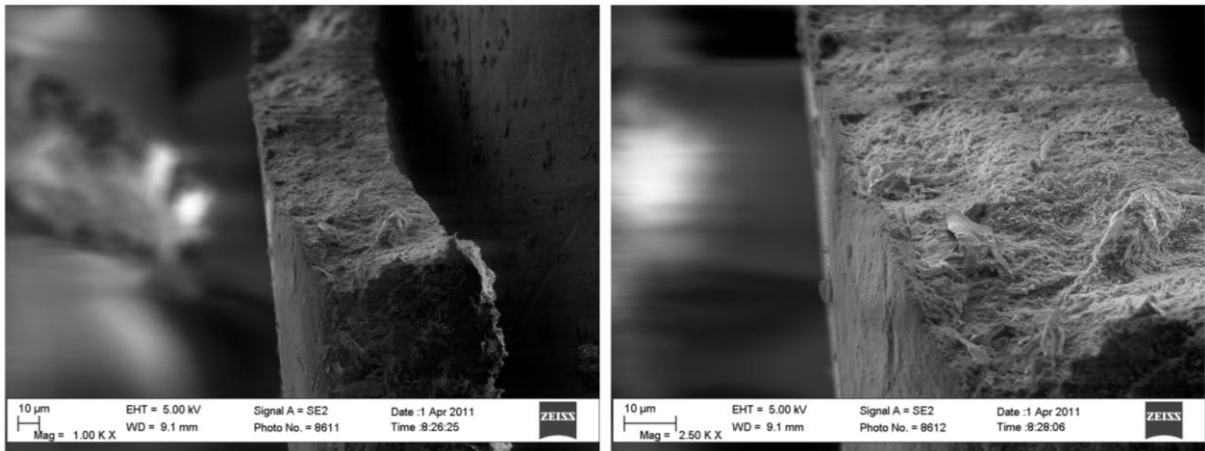


Figure VII.1: The layer of varnish that is slightly detached from the metal component (to the right) along the edge of the cut.

Figure VII.2: The horizontal part of the cut varnish layer showing the rough topography. Also the absolute outermost layer with a different appearance and structure is visible.

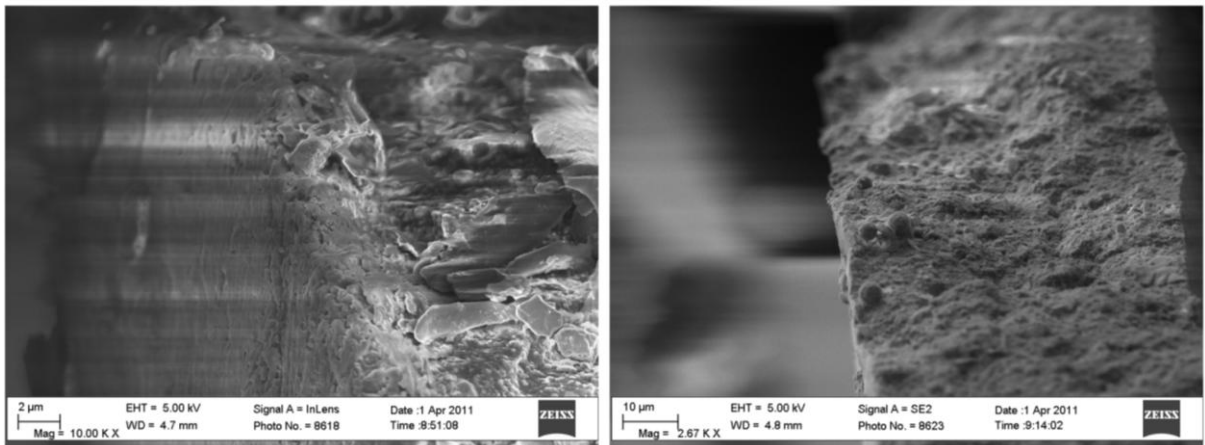


Figure VII.3: The more uniform outermost surface layer without noticeable TiO_2 particles.

Figure VII.4: A group of four of the perfectly spherical balls that were found close to the outermost layer.

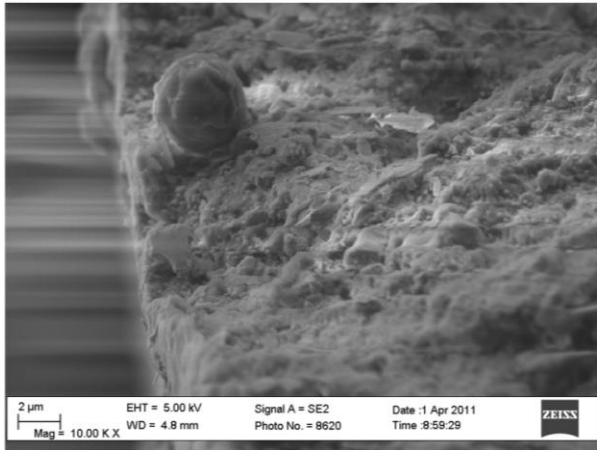


Figure VII.5: A further magnification of one of the balls in figure VII.4.

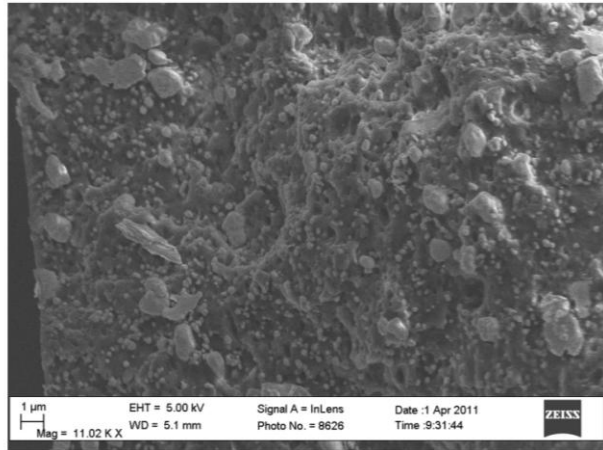


Figure VII.6: A view of the horizontal cut directly from above. The TiO_2 particles of different sizes can be seen as well as holes in the matrix where there previously have been TiO_2 particles.

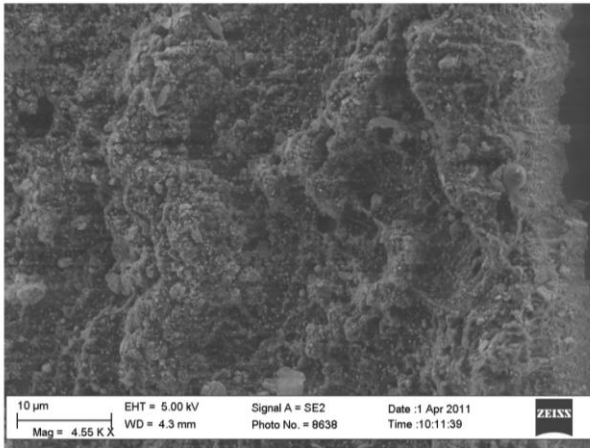


Figure VII.7: During the examination of this sample only one of the spherical particles were found close to the galvanized layer instead of the outermost layer. The ball is displayed to the right in the middle of this picture.

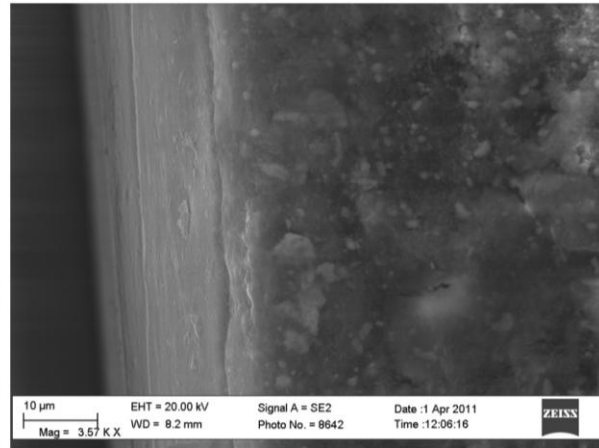


Figure VII.8: The absolute outermost layer of the varnish can be seen as the bright field to the left, the inner part of the coating has a totally different appearance consisting of more detectable particles.

Appendix VIII; Design of experiment (DOE)

Taguchi Design

Taguchi Orthogonal Array Design

L9(3**3)

Factors: 3

Runs: 9

Test.no.	Furnace - Electric			Sheet thickness - thin		
	A - Temp.	B - Time	C - TVL	Temp.	Time	TVL
7	1	1	1	160	13	thin
1	1	2	2	160	18	normal
4	1	3	3	160	28	thick
2	2	1	2	180	13	normal
5	2	2	3	180	18	thick
8	2	3	1	180	28	thin
6	3	1	3	200	13	thick
9	3	2	1	200	18	thin
3	3	3	2	200	28	normal

Test.no.	Furnace - Electric			Sheet thickness - thick		
	A - Temp.	B - Time	C - TVL	Temp.	Time	TVL
17	1	1	1	160	13	thin
11	1	2	2	160	18	normal
14	1	3	3	160	28	thick
12	2	1	2	180	13	normal
15	2	2	3	180	18	thick
18	2	3	1	180	28	thin
16	3	1	3	200	13	thick
19	3	2	1	200	18	thin
13	3	3	2	200	28	normal

Appendix IX; Colour measurements resulting from the design of experiment (DOE)

• Measurement A

Type of furnace: Electric convection oven

Component: Lid to detergent pocket (sample 7-9; with hole)

Sheet thickness: ≈ 0,65 mm

(TVL = thickness of varnish layer)

Furnace temperature: 160 °C										Furnace temperature: 180 °C										Furnace temperature: 200 °C									
Time in oven: 18 min										Time in oven: 13 min										Time in oven: 28 min									
Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*						
15/3-2011	86	0,41	0,21	-0,41	0,61	15/3-2011	85	0,34	0,23	-0,15	0,43	15/3-2011	84	0,16	0,23	0,25	0,37	15/3-2011	84	0,16	0,23	0,25	0,37						
15/3-2011	78	0,37	0,19	-0,52	0,67	15/3-2011	93	0,26	0,20	-0,20	0,39	15/3-2011	100	0,13	0,21	0,16	0,30	15/3-2011	76	0,05	0,19	0,12	0,23						
15/3-2011	102	0,42	0,19	-0,46	0,65	15/3-2011	87	0,27	0,22	-0,20	0,40	15/3-2011	76	0,05	0,19	0,12	0,23	15/3-2011	76	0,05	0,19	0,12	0,23						
15/3-2011	82	0,43	0,19	-0,41	0,63	15/3-2011	95	0,22	0,22	-0,20	0,37	15/3-2011	84	0,18	0,25	0,30	0,43	15/3-2011	84	0,18	0,25	0,30	0,43						
15/3-2011	96					15/3-2011	83					15/3-2011	84					15/3-2011	84										
15/3-2011	88,8	0,4075	0,195	-0,450	0,640	15/3-2011	88,6	0,2725	0,2175	-0,1875	0,3975	15/3-2011	84	0,13	0,22	0,2075	0,3325	15/3-2011	84	0,13	0,22	0,2075	0,3325						
15/3-2011	100	0,43	0,19	-0,37	0,59	15/3-2011	89	0,29	0,21	-0,20	0,41	15/3-2011	86	0,19	0,24	0,39	0,49	15/3-2011	86	0,19	0,24	0,39	0,49						
15/3-2011	98	0,42	0,09	-0,35	0,55	15/3-2011	71	0,20	0,17	-0,28	0,38	15/3-2011	87	0,04	0,20	0,30	0,37	15/3-2011	87	0,04	0,20	0,30	0,37						
15/3-2011	122	0,43	0,20	-0,40	0,62	15/3-2011	73	0,20	0,15	-0,27	0,37	15/3-2011	84	0,13	0,27	0,35	0,46	15/3-2011	84	0,13	0,27	0,35	0,46						
15/3-2011	99	0,44	0,22	-0,41	0,64	15/3-2011	93	0,16	0,20	-0,24	0,35	15/3-2011	106	0,09	0,22	0,30	0,38	15/3-2011	106	0,09	0,22	0,30	0,38						
15/3-2011	115					15/3-2011	89					15/3-2011	100					15/3-2011	100										
15/3-2011	106,8	0,430	0,175	-0,383	0,60	15/3-2011	83	0,2125	0,1825	-0,2475	0,378	15/3-2011	92,6	0,1125	0,2325	0,335	0,425	15/3-2011	92,6	0,1125	0,2325	0,335	0,425						
15/3-2011	81	0,46	0,21	-0,38	0,63	15/3-2011	77	0,26	0,19	-0,10	0,33	15/3-2011	71	0,11	0,21	0,03	0,24	15/3-2011	71	0,11	0,21	0,03	0,24						
15/3-2011	103	0,43	0,19	-0,42	0,63	15/3-2011	85	0,26	0,22	-0,17	0,38	15/3-2011	87	0,18	0,21	0,18	0,33	15/3-2011	87	0,18	0,21	0,18	0,33						
15/3-2011	95	0,40	0,17	-0,46	0,63	15/3-2011	77	0,12	0,31	0,01	0,33	15/3-2011	91	0,14	0,27	0,27	0,41	15/3-2011	91	0,14	0,27	0,27	0,41						
15/3-2011	89	0,39	0,11	-0,40	0,57	15/3-2011	83	0,22	0,16	-0,17	0,32	15/3-2011	69	0,14	0,24	0,17	0,33	15/3-2011	69	0,14	0,24	0,17	0,33						
15/3-2011	94					15/3-2011	83					15/3-2011	76					15/3-2011	76										
15/3-2011	92,4	0,420	0,170	-0,415	0,615	15/3-2011	81	0,215	0,22	-0,1075	0,34	15/3-2011	78,8	0,1425	0,2325	0,1625	0,3275	15/3-2011	78,8	0,1425	0,2325	0,1625	0,3275						
15/3-2011	77	0,39	0,19	-0,50	0,66	15/3-2011	76	0,25	0,20	-0,21	0,38	15/3-2011	72	0,09	0,24	0,26	0,37	15/3-2011	72	0,09	0,24	0,26	0,37						
15/3-2011	68	0,22	0,19	-0,57	0,64	15/3-2011	63	0,14	0,16	-0,38	0,44	15/3-2011	79	0,05	0,21	0,19	0,29	15/3-2011	79	0,05	0,21	0,19	0,29						
15/3-2011	77	0,35	0,17	-0,52	0,65	15/3-2011	68	0,18	0,22	-0,23	0,37	15/3-2011	69	-0,07	0,22	0,13	0,26	15/3-2011	69	-0,07	0,22	0,13	0,26						
15/3-2011	94	0,35	0,19	0,50	0,64	15/3-2011	66	0,07	0,15	-0,52	0,54	15/3-2011	69	0,06	0,22	0,21	0,31	15/3-2011	69	0,06	0,22	0,21	0,31						
15/3-2011	71					15/3-2011	68					15/3-2011	74					15/3-2011	74										
15/3-2011	77,4	0,3275	0,185	-0,27	0,6475	15/3-2011	68,2	0,16	0,1825	-0,34	0,4325	15/3-2011	72,6	0,0325	0,2225	0,20	0,3075	15/3-2011	72,6	0,0325	0,2225	0,20	0,3075						
15/3-2011	64	0,25	0,20	-0,59	0,67	15/3-2011	72	0,09	0,20	-0,42	0,47	15/3-2011	81	0,16	0,28	0,30	0,44	15/3-2011	81	0,16	0,28	0,30	0,44						
15/3-2011	72	0,18	0,16	-0,59	0,64	15/3-2011	76	0,30	0,22	-0,22	0,43	15/3-2011	79	0,17	0,26	0,35	0,47	15/3-2011	79	0,17	0,26	0,35	0,47						
15/3-2011	61	0,07	0,12	-0,75	0,76	15/3-2011	74	0,20	0,17	-0,36	0,45	15/3-2011	108	0,15	0,26	0,29	0,41	15/3-2011	108	0,15	0,26	0,29	0,41						
15/3-2011	71	0,33	0,15	-0,55	0,66	15/3-2011	72	0,16	0,20	-0,37	0,45	15/3-2011	84	0,15	0,23	0,29	0,4	15/3-2011	84	0,15	0,23	0,29	0,4						
15/3-2011	67					15/3-2011	65					15/3-2011	87					15/3-2011	87										
15/3-2011	67	0,2075	0,1575	-0,62	0,6825	15/3-2011	71,8	0,1875	0,20	-0,3425	0,45	15/3-2011	87,8	0,1575	0,2575	0,3075	0,43	15/3-2011	87,8	0,1575	0,2575	0,3075	0,43						

Furnace temperature: 160 °C
Time in oven: 28 min

Sample:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*
4.a	134	0.37	0.21	-0.21	0.48
	139	0.36	0.24	-0.22	0.49
	131	0.35	0.25	-0.27	0.50
	125	0.35	0.22	-0.23	0.47
	147				
Mean:	135.2	0.3575	0.23	-0.2325	0.485
4.b	152	0.39	0.21	-0.23	0.50
	187	0.37	0.22	-0.23	0.49
	145	0.36	0.23	-0.23	0.48
	158	0.38	0.22	-0.28	0.52
	159				
Mean:	160.2	0.375	0.22	-0.2425	0.50
4.c	123	0.40	0.22	-0.26	0.52
	134	0.41	0.20	-0.29	0.54
	145	0.42	0.19	-0.31	0.56
	128	0.37	0.20	-0.33	0.54
	129				
Mean:	131.8	0.40	0.2025	-0.2975	0.54
4.d	138	0.34	0.21	-0.19	0.44
	137	0.34	0.23	-0.21	0.46
	140	0.31	0.23	-0.22	0.45
	133	0.35	0.22	-0.30	0.51
	139				
Mean:	137.4	0.335	0.2225	-0.23	0.465
4.e	158	0.29	0.24	-0.19	0.42
	156	0.26	0.24	-0.20	0.41
	161	0.23	0.26	-0.22	0.41
	157	0.31	0.25	-0.23	0.46
	169				
Mean:	160.2	0.2725	0.2475	-0.21	0.425

Furnace temperature: 180 °C
Time in oven: 18 min

Sample:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*
5.a	169	0.16	0.27	0.07	0.32
	162	0.15	0.27	0.09	0.32
	164	0.17	0.27	0.05	0.33
	206	0.13	0.30	0.06	0.33
	150				
Mean:	170.2	0.1525	0.2775	0.0675	0.325
5.b	166	0.21	0.26	0.07	0.34
	157	0.25	0.23	0.03	0.34
	183	0.19	0.24	0.07	0.31
	142	0.12	0.30	0.10	0.33
	156				
Mean:	160.8	0.1925	0.2575	0.0675	0.3
5.c	131	0.13	0.30	0.08	0.33
	150	0.23	0.25	0.03	0.34
	133	0.20	0.24	0.04	0.31
	152	0.18	0.27	0.06	0.33
	129				
Mean:	139	0.185	0.265	0.0525	0.3275
5.d	159	0.23	0.25	0.08	0.35
	190	0.27	0.20	0.07	0.34
	165	0.23	0.23	0.04	0.32
	171	0.22	0.22	0.07	0.32
	159				
Mean:	168.8	0.2375	0.225	0.07	0.3325
5.e	156	0.19	0.27	0.03	0.33
	161	0.21	0.24	0.03	0.32
	191	0.18	0.27	0.06	0.33
	157	0.16	0.27	0.08	0.32
	149				
Mean:	162.8	0.185	0.2625	0.05	0.325

Furnace temperature: 200 °C
Time in oven: 13 min

Sample:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*
6.a	130	0.07	0.30	0.23	0.39
	141	0.07	0.29	0.23	0.38
	140	0.08	0.30	0.23	0.39
	146	0.01	0.32	0.28	0.43
	133				
Mean:	138	0.0575	0.3025	0.2425	0.3975
6.b	160	0.08	0.29	0.27	0.40
	174	0.08	0.28	0.31	0.43
	151	0.02	0.32	0.33	0.46
	150	0.04	0.28	0.36	0.46
	144				
Mean:	155.8	0.055	0.2925	0.3175	0.4375
6.c	150	0.01	0.32	0.40	0.52
	159	0.02	0.28	0.38	0.47
	194	-0.01	0.28	0.37	0.46
	168	0.04	0.32	0.36	0.48
	157				
Mean:	165.6	0.015	0.300	0.3775	0.4825
6.d	169	-0.02	0.34	0.35	0.49
	156	0.07	0.27	0.31	0.42
	177	0.06	0.28	0.31	0.42
	165	0.07	0.29	0.28	0.42
	152				
Mean:	163.8	0.045	0.295	0.3125	0.4375
6.e	132	-0.05	0.34	0.30	0.45
	160	0.08	0.29	0.27	0.41
	145	0.04	0.28	0.30	0.41
	134	0.06	0.30	0.26	0.40
	142				
Mean:	142.6	0.0325	0.30	0.2825	0.4175

Furnace temperature: 160 °C									
Time in oven: 13 min									
Date: 16/3-2011 Batch/box no: 2019642-1									
Sample:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	Sample:	TVL (µm)	Δ L*	Δ E*
7.a	49	-0,48	0,09	-1,47	1,54				
	51	-0,49	0,08	-1,48	1,57				
	49	-0,49	0,11	-1,49	1,57				
	72	-0,79	0,10	-1,68	1,86				
	47								
Mean:	53,6	-0,5625	0,095	-1,53	1,635				
7.b	46	-0,49	0,02	-1,43	1,51				
	48	-0,50	0,11	-1,45	1,54				
	52	-0,57	0,07	-1,57	1,67				
	49	-0,66	0,05	-1,58	1,72				
	47								
Mean:	48,4	-0,555	0,0625	-1,5075	1,610				
7.c	43	-0,83	0,11	-1,76	1,95				
	42	-0,69	0,05	-1,65	1,79				
	45	-0,62	0,12	-1,59	1,71				
	48	-0,63	0,12	-1,61	1,73				
	36								
Mean:	42,8	-0,6925	0,10	-1,6525	1,795				
7.d	44	-0,70	0,03	-1,69	1,82				
	41	-0,82	0,04	-1,75	1,94				
	39	-0,81	-0,01	-1,72	1,90				
	43	-0,92	0	-1,75	1,97				
	47								
Mean:	42,8	-0,8125	0,015	-1,7275	1,9075				
7.e	47	-0,69	0,09	-1,62	1,77				
	49	-0,53	0,08	-1,52	1,61				
	47	-0,43	0,09	-1,42	1,48				
	46	-0,43	0,10	-1,47	1,54				
	47								
Mean:	47,2	-0,52	0,09	-1,5075	1,60				

Furnace temperature: 180 °C									
Time in oven: 28 min									
Date: 16/3-2011 Batch/box no: 2019642-1									
Sample:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	Sample:	TVL (µm)	Δ L*	Δ E*
8.a	43	-0,50	0,08	-1,05	1,17				
	42	-0,68	0,06	-1,24	1,42				
	42	-0,78	0,03	-1,28	1,50				
	48	-0,49	0,06	-1,04	1,15				
	52								
Mean:	45,4	-0,6125	0,0575	-1,1525	1,31				
8.b	40	-1,14	0,08	-1,58	1,95				
	44	-1,15	0,06	-1,57	1,94				
	43	-1,21	0,07	-1,61	2,02				
	43	-1,17	0,08	-1,54	1,94				
	42								
Mean:	42,4	-1,1675	0,0725	-1,575	1,9625				
8.c	53	-0,35	0,12	-0,95	1,02				
	54	-0,40	0,12	-0,98	1,07				
	54	-0,47	0,12	-1,03	1,14				
	51	-0,42	0,11	-1,01	1,10				
	51								
Mean:	52,6	-0,41	0,1175	-0,9925	1,0825				
8.d	51	-0,67	0,11	-1,15	1,33				
	53	-0,57	0,08	-1,08	1,22				
	48	-0,70	0,13	-1,08	1,30				
	49	-0,51	0,11	-1,01	1,14				
	54								
Mean:	51	-0,6125	0,1075	-1,08	1,2475				
8.e	46	-0,48	0,10	-0,97	1,08				
	45	-0,50	0,15	-0,94	1,07				
	67	-0,55	0,16	-0,95	1,11				
	58	-0,48	0,15	-0,90	1,03				
	57								
Mean:	54,6	-0,5025	0,14	-0,94	1,0725				

Furnace temperature: 200 °C									
Time in oven: 18 min									
Date: 16/3-2011 Batch/box no: 2019642-1									
Sample:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	Sample:	TVL (µm)	Δ L*	Δ E*
9.a	55	-0,34	0,16	-0,43	0,57				
	61	-0,26	0,15	-0,34	0,46				
	60	-0,19	0,13	-0,31	0,39				
	58	-0,35	0,13	-0,40	0,55				
	52								
Mean:	57,2	-0,285	0,1425	-0,37	0,4925				
9.b	44	-0,62	0,12	-0,75	0,98				
	47	-1,03	0,03	-1,04	1,46				
	41	-0,87	0,08	-0,88	1,24				
	49	-0,97	0,06	-1,01	1,40				
	47								
Mean:	45,6	-0,8725	0,0725	-0,92	1,27				
9.c	40	-0,94	0,09	-1,14	1,47				
	39	-1,20	0,05	-1,33	1,79				
	40	-1,26	0,06	-1,35	1,85				
	47	-1,31	0,03	-1,38	1,90				
	40								
Mean:	41,2	-1,1775	0,0575	-1,30	1,7525				
9.d	48	-0,97	0,07	-1,07	1,45				
	60	-0,85	0,14	-0,80	1,18				
	43	-0,70	0,09	-0,79	1,06				
	49	-0,95	0,08	-1,00	1,38				
	48								
Mean:	49,6	-0,8675	0,095	-0,915	1,2675				
9.e	47	-0,74	0,07	-0,92	1,18				
	49	-0,51	0,10	-0,70	0,87				
	59	-0,65	0,09	-0,85	1,07				
	49	-0,66	0,09	-0,83	1,06				
	59								
Mean:	52,6	-0,64	0,09	-0,825	1,045				

• **Measurement B**

Type of furnace: Electric convection oven

Component: Reinforcement plate to the bottom sheet of DW

Sheet thickness: ≈ 3 mm

(TVL = thickness of varnish layer)

Furnace temperature: 200 °C Time in oven: 45 min						
Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	
16/3- 2011	Batch/box no: 20196424					
10.a	169	0,06	0,27	0,53	0,60	
	153	0,10	0,24	0,54	0,60	
	176	-0,06	0,26	0,60	0,66	
	195	0,07	0,23	0,55	0,60	
	183					
Mean:	175,2	0,0425	0,25	0,555	0,615	
10.b	131	0,07	0,25	0,47	0,54	
	153	0,04	0,26	0,46	0,53	
	136	0,01	0,28	0,51	0,58	
	153	0,02	0,26	0,51		
	166					
Mean:	147,8	0,035	0,2625	0,4875	0,550	
10.c	153	-0,01	0,27	0,54	0,60	
	158	0,02	0,25	0,53	0,59	
	133	0,04	0,27	0,48	0,55	
	161	0,05	0,25	0,49	0,55	
	152					
Mean:	151,4	0,025	0,260	0,510	0,5725	

(This test is a special extra test not included in the original DOE.)

Furnace temperature: 160 °C Time in oven: 18 min						
Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	
18/3- 2011	Batch/box no: 2019642-1					
11.a	75	0,36	0,15	-0,75	0,84	
	79	0,40	0,17	-0,61	0,75	
	89	0,42	0,17	-0,64	0,78	
	106	0,49	0,19	-0,51	0,73	
	120					
Mean:	93,8	0,418	0,170	-0,628	0,775	
11.b	82	0,37	0,14	-0,66	0,77	
	78	0,41	0,16	-0,59	0,73	
	87	0,39	0,16	-0,69	0,80	
	86	0,38	0,13	-0,71	0,82	
	87					
Mean:	84	0,388	0,148	-0,663	0,780	
11.c	68	0,24	0,14	-0,89	0,94	
	78	0,41	0,14	-0,58	0,72	
	87	0,33	0,19	-0,72	0,82	
	82	0,17	0,16	-0,85	0,88	
	99					
Mean:	83	0,288	0,158	-0,760	0,840	

Furnace temperature: 200 °C Time in oven: 28 min						
Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	
15/3- 2011	Batch/box no: 2019642-1					
13.a	103	0,16	0,14	-0,50	0,54	
	89	0,34	0,14	-0,18	0,42	
	90	0,43	0,17	-0,13	0,48	
	83	0,17	0,14	-0,53	0,57	
	113					
Mean:	95,6	0,275	0,1475	-0,335	0,5025	
13.b	129	0,34	0,18	-0,15	0,42	
	109	0,39	0,19	-0,17	0,47	
	102	0,40	0,20	-0,11	0,46	
	106	0,38	0,21	-0,08	0,44	
	150					
Mean:	119,2	0,378	0,195	-0,128	0,448	
13.c	146	0,31	0,25	-0,16	0,43	
	109	0,40	0,19	-0,12	0,46	
	97	0,38	0,20	-0,11	0,45	
	107	0,38	0,22	-0,07	0,45	
	102					
Mean:	112,2	0,368	0,215	-0,115	0,448	

Furnace temperature: 180 °C Time in oven: 13 min						
Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	
18/3- 2011	Batch/box no: 2019642-1					
12.a	116	0,34	0,18	-0,50	0,63	
	119	0,37	0,17	-0,49	0,63	
	95	0,40	0,21	-0,37	0,58	
	88	0,49	0,20	-0,39	0,66	
	101					
Mean:	103,8	0,4	0,19	-0,438	0,625	
12.b	95	0,44	0,21	-0,36	0,61	
	140	0,47	0,19	-0,38	0,63	
	107	0,38	0,17	-0,46	0,62	
	124	0,45	0,17	-0,42	0,64	
	142					
Mean:	121,6	0,435	0,185	-0,405	0,625	
12.c	135	0,30	0,15	-0,61	0,69	
	102	0,30	0,17	-0,61	0,70	
	95	0,50	0,18	-0,39	0,66	
	85	0,50	0,16	-0,37	0,64	
	90					
Mean:	101,4	0,4	0,165	-0,495	0,673	

Furnace temperature: 160 °C Time in oven: 28 min						
Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*	
18/3- 2011	Batch/box no: 2019642-1					
14.a	114	0,52	0,15	-0,41	0,67	
	117	0,54	0,18	-0,44	0,72	
	115	0,50	0,18	-0,43	0,68	
	138	0,50	0,18	-0,44	0,69	
	125					
Mean:	121,8	0,515	0,173	-0,43	0,69	
14.b	109	0,53	0,17	-0,45	0,72	
	131	0,42	0,14	-0,45	0,63	
	121	0,56	0,19	-0,42	0,72	
	127	0,53	0,17	-0,45	0,72	
	140					
Mean:	125,6	0,51	0,168	-0,443	0,698	
14.c	116	0,54	0,14	-0,43	0,70	
	177	0,45	0,18	-0,41	0,63	
	173	0,48	0,20	-0,39	0,65	
	145	0,55	0,18	-0,41	0,71	
	170					
Mean:	156,2	0,505	0,175	-0,41	0,673	

Furnace temperature: 180 °C
Time in oven: 18 min

Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*
15.a	140	0.43	0.20	-0.25	0.53
	147	0.30	0.20	-0.19	0.41
	148	0.42	0.23	-0.25	0.54
	144	0.48	0.19	-0.25	0.58
	134				
Mean:	142.6	0.408	0.205	-0.235	0.515
15.b	91	0.32	0.12	-0.57	0.67
	95	0.34	0.21	-0.54	0.65
	124	0.42	0.18	-0.29	0.56
	144	0.47	0.15	-0.29	0.58
	149				
Mean:	120.6	0.388	0.165	-0.423	0.615
15.c	137	0.34	0.17	-0.50	0.63
	93	0.30	0.19	-0.41	0.54
	167	0.47	0.19	-0.32	0.60
	92	0.44	0.18	-0.29	0.56
	90				
Mean:	115.8	0.388	0.183	-0.380	0.583

Furnace temperature: 160 °C
Time in oven: 13 min

Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*
17.a	75	0.23	0.13	-0.87	0.91
	78	-0.08	0.25	-0.86	0.89
	73	0.15	0.17	-0.84	0.87
	78				
	76				
Mean:	76	0.1	0.183	-0.857	0.89
17.b	85	0.42	0.19	-0.61	0.76
	80	0.44	0.17	-0.56	0.74
	83	0.36	0.15	-0.69	0.80
	94				
	83				
Mean:	85	0.407	0.170	-0.620	0.767
17.c	84	0.30	0.20	-0.63	0.72
	83	0.43	0.14	-0.69	0.82
	85	0.31	0.15	-0.65	0.73
	88				
	87				
Mean:	85.4	0.347	0.163	-0.657	0.757

Furnace temperature: 200 °C
Time in oven: 18 min

Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*
19.a	96	0.23	0.16	-0.25	0.38
	92	0.21	0.15	-0.22	0.34
	43	-0.03	0.16	-0.39	0.42
	56				
	81				
Mean:	73.6	0.1367	0.1567	-0.2867	0.3800
19.b	78	0.34	0.15	-0.20	0.42
	75	0.32	0.13	-0.19	0.39
	94	0.32	0.16	-0.18	0.40
	46				
	116				
Mean:	81.8	0.3267	0.1467	-0.1900	0.4033
19.c	94	-0.14	0.11	-0.88	0.90
	85	-0.48	0.12	-1.12	1.23
	95	-0.19	0.15	-0.84	0.87
	82				
	49				
Mean:	81	-0.270	0.127	-0.947	1.000

Furnace temperature: 200 °C
Time in oven: 13 min

Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*
16.a	160	0.40	0.17	-0.18	0.47
	153	0.39	0.16	-0.21	0.47
	156	0.39	0.21	-0.17	0.47
	139	0.38	0.21	-0.19	0.47
	130				
Mean:	147.6	0.39	0.188	-0.188	0.47
16.b	146	0.38	0.20	-0.20	0.47
	132	0.40	0.18	-0.20	0.48
	162	0.43	0.19	-0.22	0.52
	181	0.42	0.22	-0.24	0.53
	121				
Mean:	148.4	0.408	0.198	-0.215	0.500
16.c	134	0.31	0.20	-0.18	0.41
	156	0.36	0.20	-0.15	0.44
	172	0.30	0.23	-0.16	0.41
	181	0.29	0.22	-0.17	0.40
	193				
Mean:	167.2	0.315	0.213	-0.165	0.415

Furnace temperature: 180 °C
Time in oven: 28 min

Date:	TVL (µm)	Δ L*	Δ a*	Δ b*	Δ E*
18.a	66	0.22	0.09	-0.68	0.72
	70	0.25	0.11	-0.63	0.68
	73	0.27	0.11	-0.61	0.68
	76	0.23	0.11	-0.64	0.69
	73				
Mean:	71.6	0.243	0.105	-0.640	0.693
18.b	57	-0.98	0.08	-1.69	1.96
	68	-1.07	0.04	-1.52	1.86
	46	-0.18	0.10	-0.92	0.94
	96				
	64				
Mean:	66.2	-0.743	0.073	-1.377	1.587
18.c	89	-0.15	0.08	-1.03	1.05
	92	0.21	0.11	-0.54	0.59
	87	-0.16	0.11	-0.99	1.01
	58				
	60				
Mean:	77.2	-0.033	0.100	-0.853	0.883

Appendix X; Analysis of data from measurements A-B

- Thin sheet thickness

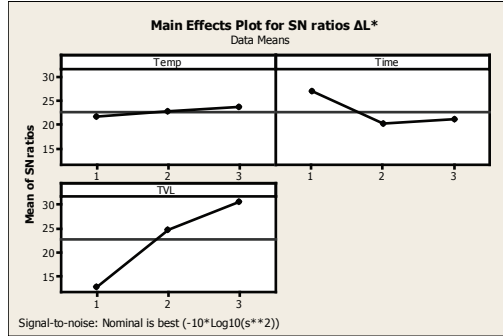
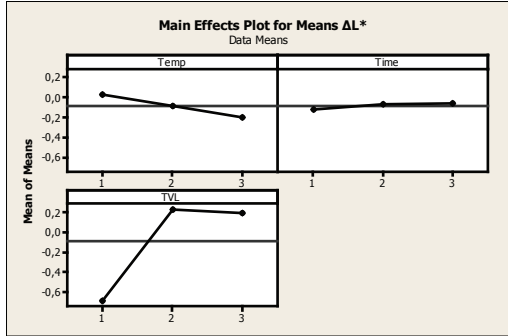
Taguchi Analysis: dL1; dL2; dL3; dL4; dL5
versus Temp; Time; TVL

Response Table for Signal to Noise Ratios
Nominal is best ($-10 \cdot \log_{10}(s^{**2})$)

Level	Temp	Time	TVL
1	21,71	27,00	12,82
2	22,84	20,16	24,79
3	23,64	21,03	30,57
Delta	1,92	6,83	17,75
Rank	3	2	1

Response Table for Means

Level	Temp	Time	TVL
1	0,02600	-0,12600	-0,68600
2	-0,08700	-0,07317	0,22767
3	-0,20417	-0,06600	0,19317
Delta	0,23017	0,06000	0,91367
Rank	2	3	1



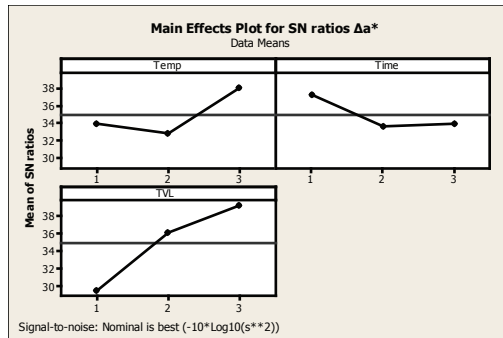
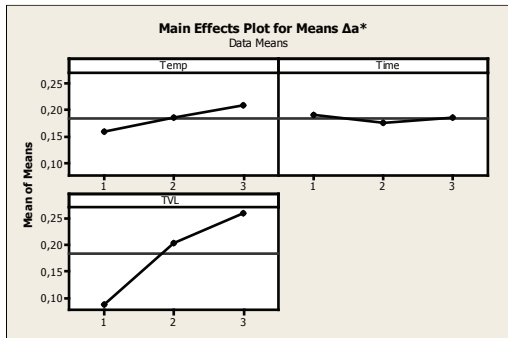
Taguchi Analysis: da1; da2; da3; da4; da5
versus Temp; Time; TVL

Response Table for Signal to Noise Ratios
Nominal is best ($-10 \cdot \log_{10}(s^{**2})$)

Level	Temp	Time	TVL
1	33,89	37,20	29,46
2	32,81	33,63	36,09
3	38,05	33,93	39,21
Delta	5,24	3,57	9,75
Rank	2	3	1

Response Table for Means

Level	Temp	Time	TVL
1	0,15783	0,19033	0,08767
2	0,18567	0,17517	0,20333
3	0,20750	0,18550	0,26000
Delta	0,04967	0,01517	0,17233
Rank	2	3	1



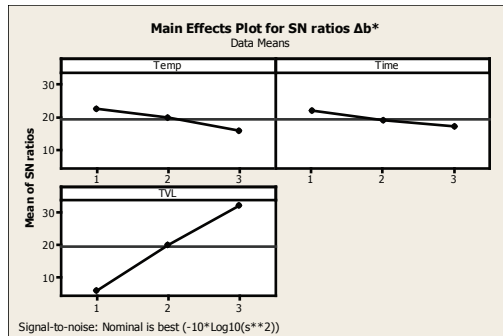
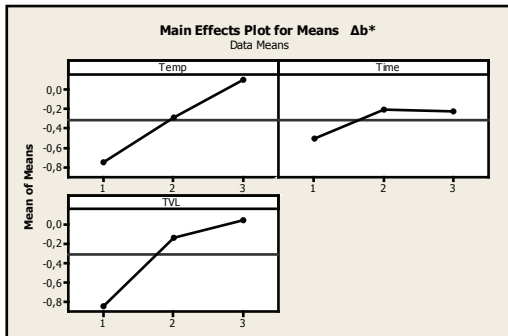
Taguchi Analysis: db1; db2; db3; db4; db5
versus Temp; Time; TVL

Response Table for Signal to Noise Ratios
Nominal is best ($-10 \cdot \log_{10}(s^{**2})$)

Level	Temp	Time	TVL
1	22,527	22,003	5,983
2	19,841	19,077	20,132
3	15,818	17,106	32,071
Delta	6,709	4,897	26,089
Rank	2	3	1

Response Table for Means

Level	Temp	Time	TVL
1	-0,75167	-0,50783	-0,84100
2	-0,28867	-0,20717	-0,14333
3	0,09783	-0,22750	0,04183
Delta	0,84950	0,30067	0,88283
Rank	2	3	1



- Thick sheet thickness

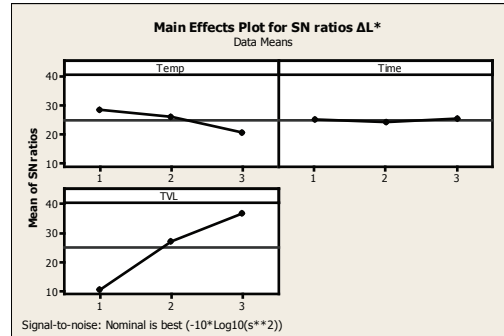
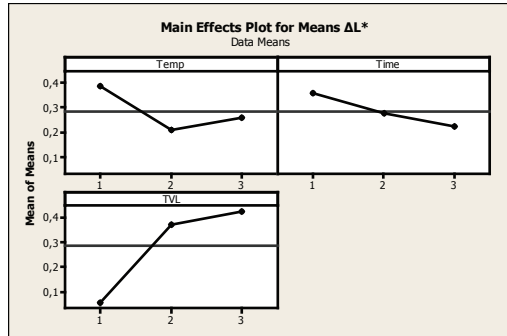
Taguchi Analysis: dL1; dL2; dL3 versus
Temp; Time; TVL

Response Table for Signal to Noise Ratios
Nominal is best ($-10 \cdot \log_{10}(s^{**2})$)

Level	Temp	Time	TVL
1	28,38	25,28	10,66
2	26,17	24,14	27,40
3	20,48	25,62	36,98
Delta	7,90	1,48	26,32
Rank	2	3	1

Response Table for Means

Level	Temp	Time	TVL
1	0,38621	0,35566	0,05697
2	0,20927	0,27427	0,37194
3	0,25843	0,22399	0,42500
Delta	0,17694	0,13167	0,36803
Rank	2	3	1



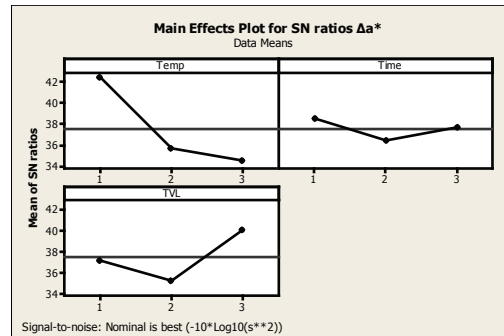
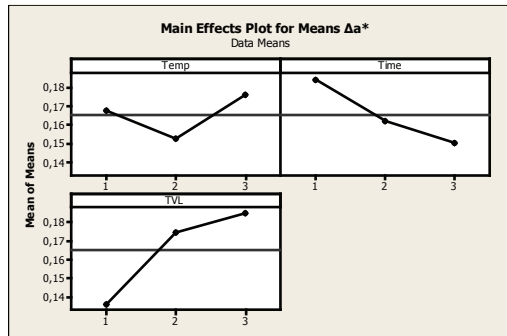
Taguchi Analysis: da1; da2; da3 versus
Temp; Time; TVL

Response Table for Signal to Noise Ratios
Nominal is best ($-10 \cdot \log_{10}(s^{**2})$)

Level	Temp	Time	TVL
1	42,39	38,47	37,18
2	35,63	36,41	35,24
3	34,51	37,64	40,11
Delta	7,88	2,06	4,86
Rank	1	3	2

Response Table for Means

Level	Temp	Time	TVL
1	0,1674	0,1838	0,1361
2	0,1523	0,1620	0,1747
3	0,1761	0,1501	0,1850
Delta	0,0238	0,0337	0,0489
Rank	3	2	1



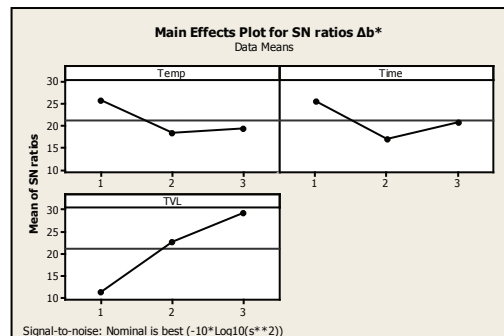
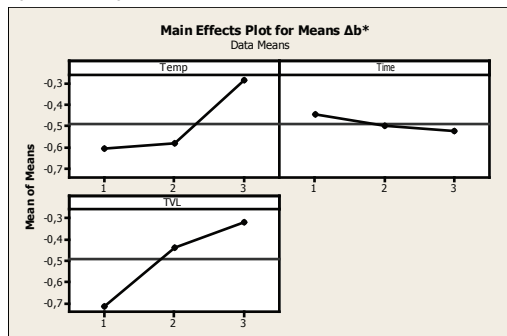
Taguchi Analysis: db1; db2; db3 versus
Temp; Time; TVL

Response Table for Signal to Noise Ratios
Nominal is best ($-10 \cdot \log_{10}(s^{**2})$)

Level	Temp	Time	TVL
1	25,62	25,58	11,34
2	18,47	17,04	22,75
3	19,30	20,76	29,29
Delta	7,16	8,54	17,95
Rank	3	2	1

Response Table for Means

Level	Temp	Time	TVL
1	-0,6073	-0,4487	-0,7141
2	-0,5828	-0,5012	-0,4406
3	-0,2854	-0,5256	-0,3208
Delta	0,3219	0,0768	0,3933
Rank	2	3	1



Appendix XI; Colour measurements of samples from electric convection oven vs. LPG furnace

• Measurement C

Test during normal operation;	
* curing in the LPG furnace or electric convection oven	* material temperature $\approx 180^{\circ}\text{C}$
* "normal" thickness of varnish layer (TVL)	* time in furnace ≈ 18 min
* Component: lid to detergent pocket (with or without hole).	
* Position on hanger: side 2	
* Colour and TVL have been measured on approximately the same spot of the samples.	
* From each hanger in the test, 2 components (a-b) have been cured in the electric convection oven and 5 components (a-e) in the LPG furnace.	

Type of furnace: Electric convection oven					Date,time, batch/box.no...	Type of furnace: LPG furnace				
sample	ΔL^*	Δa^*	Δb^*	TVL (μm)		sample	ΔL^*	Δa^*	Δb^*	TVL (μm)
E21.a	-0,06	0,20	0,03	80	Date: 22/3 - 2011	G21.a	-0,07	0,00	0,35	62
E21.b	0,28	0,20	-0,02	106	Time: approx. 13.30	G21.b	0,22	0,06	0,27	67
					Batch/box no. :	G21.c	-0,15	0,09	0,20	74
					201 96 42 - 3	G21.d	0,09	0,02	0,27	61
						G21.e	0,21	0,06	0,22	78
E22.a	0,18	0,16	-0,23	76	From five hangers	G22.a	0,12	0,04	0,23	62
E22.b	0,09	0,20	-0,07	84	placed directly after	G22.b	0,05	0,01	0,32	65
					each other.	G22.c	0,08	0,00	0,26	60
					with hole	G22.d	0,22	0,03	0,24	71
						G22.e	0,13	0,03	0,22	66
E23.a	0,19	0,17	-0,25	75		G23.a	-0,12	0,04	0,39	57
E23.b	-0,01	0,15	-0,50	60		G23.b	0,01	0,02	0,35	62
						G23.c	-0,10	0,01	0,53	58
						G23.d	-0,13	0,02	0,54	59
						G23.e	0,02	0,04	0,33	61
E24.a	0,19	0,18	-0,28	75		G24.a	0,03	0,02	0,33	62
E24.b	0,15	0,19	-0,34	74		G24.b	-0,06	-0,02	0,50	60
						G24.c	-0,04	0,00	0,38	56
						G24.d	0,02	-0,01	0,32	64
						G24.e	0,02	0,02	0,35	62
E25.a	0,21	0,21	-0,21	79		G25.a	0,27	0,09	0,29	82
E25.b	0,26	0,19	-0,12	92		G25.b	0,16	0,05	0,20	71
						G25.c	0,17	0,05	0,21	69
						G25.d	0,24	0,04	0,25	72
						G25.e	0,34	0,07	0,34	85
E26.a	0,25	0,20	-0,05	101	Date: 22/3 - 2011	G26.a	0,01	-0,01	-0,13	65
E26.b	0,14	0,16	-0,26	71	Time: approx. 15.50	G26.b	-0,01	-0,04	-0,21	59
					Batch/box no. :	G26.c	-0,03	-0,04	-0,16	60
					201 96 42 - 3	G26.d	0,20	-0,01	0,10	73
						G26.e	-0,01	-0,03	-0,16	61
E27.a	0,22	0,17	-0,19	82	From five hangers	G27.a	-0,17	-0,04	-0,33	59
E27.b	0,11	0,15	-0,19	69	placed directly after	G27.b	0,08	-0,03	-0,02	65
					each other, samples	G27.c	-0,12	-0,05	-0,30	56
					were collected from	G27.d	0,07	-0,02	-0,04	64
					no. 1,3 and 5.	G27.e	-0,04	-0,02	-0,18	58
E28.a	0,29	0,17	-0,10	93		G28.a	0,07	-0,03	-0,05	63
E28.b	0,22	0,17	-0,17	79	with hole	G28.b	0,16	0,01	0,04	67
						G28.c	0,31	0,01	0,20	85
						G28.d	0,17	-0,01	0,06	66
						G28.e	0,24	0,00	0,12	73

E29.a	0,06	0,15	-0,42	75	Date: 23/3 - 2011	G29.a	0,31	0,02	0,25	83
E29.b	0,28	0,20	-0,20	107	Time: approx. 08.50	G29.b	0,23	0,01	0,25	74
					Batch/box no. :	G29.c	0,20	0,00	0,12	75
					201 96 42 - 3	G29.d	0,32	0,03	0,28	91
					with hole	G29.e	0,23	0,03	0,24	83
E30.a	0,27	0,21	-0,19	79	Date: 23/3 - 2011	G30.a	0,14	0,00	0,01	65
E30.b	0,32	0,24	-0,02	105	Time: approx. 10.15	G30.b	0,10	0,01	-0,02	64
					Batch/box no. :	G30.c	0,20	0,01	0,17	74
					201 96 42 - 3	G30.d	0,19	-0,01	0,12	71
						G30.e	0,21	0,00	0,18	72
E31.a	0,28	0,23	-0,15	83	From five hangers	G31.a	0,13	-0,02	0,14	68
E31.b	0,11	0,21	-0,18	69	placed directly after	G31.b	-0,08	-0,05	0,22	61
					each other, samples	G31.c	0,07	-0,02	-0,03	65
					were collected from	G31.d	0,13	0,00	0,00	63
					no. 1,3 and 5.	G31.e	0,01	-0,04	-0,14	57
E32.a	0,23	0,22	-0,23	76		G32.a	-0,20	0,03	0,08	72
E32.b	0,00	0,18	-0,42	59	without hole	G32.b	0,36	0,10	0,29	97
						G32.c	0,25	0,05	0,18	75
						G32.d	0,05	-0,03	-0,02	58
						G32.e	0,28	0,04	0,25	80
E33.a	0,08	0,25	-0,35	89	Date: 23/3 - 2011	G33.a	0,32	0,05	0,08	80
E33.b	-0,14	0,23	-0,52	68	Time: approx. 11.35	G33.b	0,21	0,06	0,00	68
					Batch/box no. :	G33.c	0,36	0,09	0,15	94
					201 96 42 - 3	G33.d	0,31	0,09	0,08	84
					with hole	G33.e	0,33	0,08	0,13	86
E34.a	0,27	0,20	-0,25	75	Date: 23/3 - 2011	G34.a	-0,12	0,03	-0,45	57
E34.b	0,25	0,21	-0,22	79	Time: approx. 14.15	G34.b	-0,05	0,04	-0,42	53
					Batch/box no. :	G34.c	0,06	0,04	-0,26	61
					201 96 42 - 3	G34.d	0,14	0,04	-0,13	68
					From five hangers	G34.e	0,03	0,04	-0,23	63
E35.a	0,30	0,21	-0,21	88	placed directly after	G35.a	0,06	0,03	-0,29	57
E35.b	0,25	0,19	-0,20	82	each other, samples	G35.b	0,24	0,02	-0,03	65
					were collected from	G35.c	0,03	0,03	-0,31	59
					no. 2 and 4.	G35.d	0,14	0,03	-0,16	62
					without hole	G35.e	0,16	0,02	-0,13	66
E36.a	0,37	0,21	-0,33	87	Date: 24/3 - 2011	G36.a	0,24	0,07	0,16	74
E36.b	0,20	0,17	-0,65	66	Time: approx. 09.00	G36.b	0,26	0,07	0,09	69
					Batch/box no. :	G36.c	0,21	0,03	0,03	67
					201 96 42 - 3	G36.d	0,13	0,02	-0,04	64
					with hole	G36.e	0,20	0,07	0,11	69

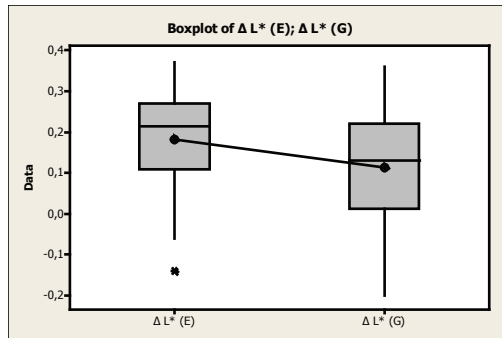
Appendix XII; Analysis of data from measurement C

Two-Sample T-Test and CI: ΔL^* (E); ΔL^* (G)

Two-sample T for ΔL^* (E) vs ΔL^* (G)

	N	Mean	StDev	SE Mean
ΔL^* (E)	32	0,183	0,118	0,021
ΔL^* (G)	80	0,113	0,141	0,016

Difference = $\mu(\Delta L^* (E)) - \mu(\Delta L^* (G))$
 Estimate for difference: 0,0694
 95% CI for difference: (0,0173; 0,1214)
 T-Test of difference = 0 (vs not =):
 T-Value = 2,66 P-Value = 0,010 DF = 67

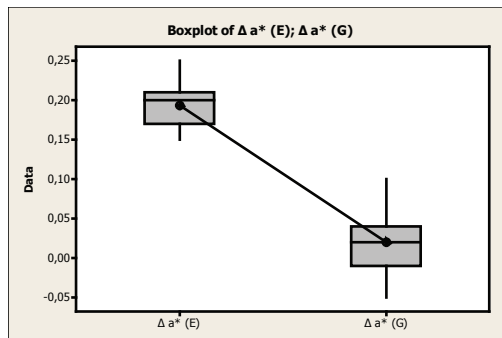


Two-Sample T-Test and CI: Δa^* (E); Δa^* (G)

Two-sample T for Δa^* (E) vs Δa^* (G)

	N	Mean	StDev	SE Mean
Δa^* (E)	32	0,1931	0,0264	0,0047
Δa^* (G)	79	0,0196	0,0364	0,0041

Difference = $\mu(\Delta a^* (E)) - \mu(\Delta a^* (G))$
 Estimate for difference: 0,17350
 95% CI for difference: (0,16114; 0,18587)
 T-Test of difference = 0 (vs not =):
 T-Value = 27,93 P-Value = 0,000 DF = 78

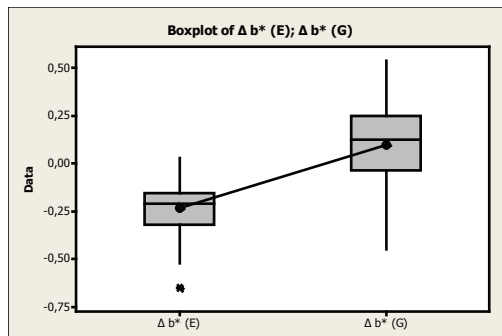


Two-Sample T-Test and CI: Δb^* (E); Δb^* (G)

Two-sample T for Δb^* (E) vs Δb^* (G)

	N	Mean	StDev	SE Mean
Δb^* (E)	32	-0,234	0,151	0,027
Δb^* (G)	80	0,097	0,221	0,025

Difference = $\mu(\Delta b^* (E)) - \mu(\Delta b^* (G))$
 Estimate for difference: -0,3313
 95% CI for difference: (-0,4037; -0,2590)
 T-Test of difference = 0 (vs not =):
 T-Value = -9,11 P-Value = 0,000 DF = 82

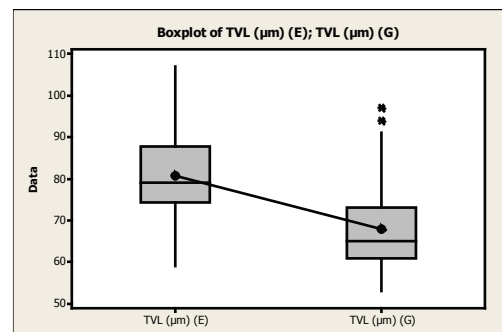


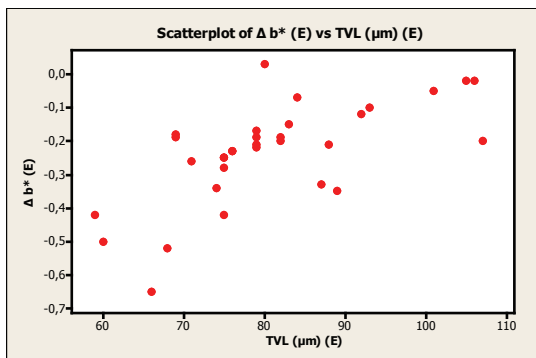
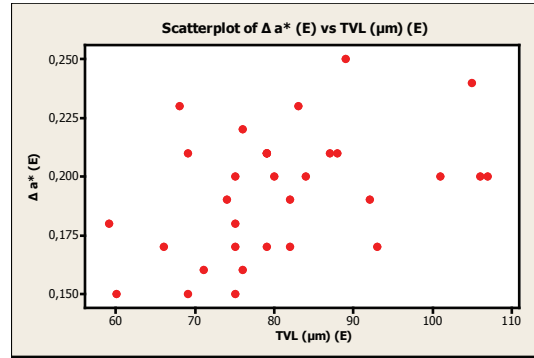
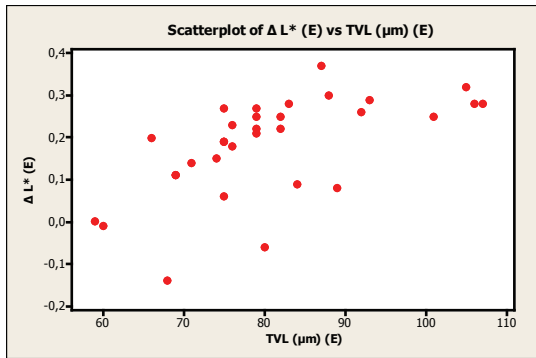
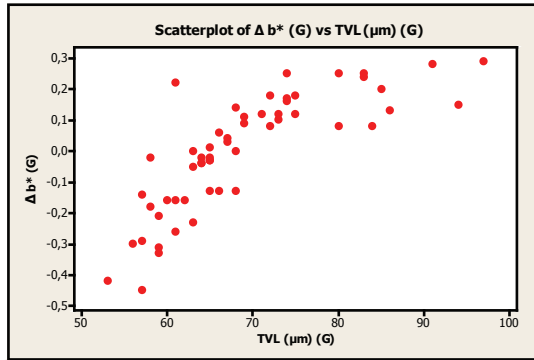
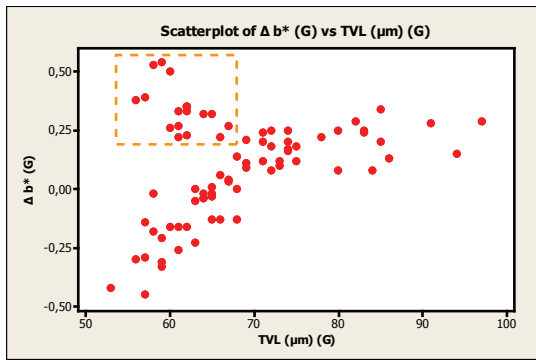
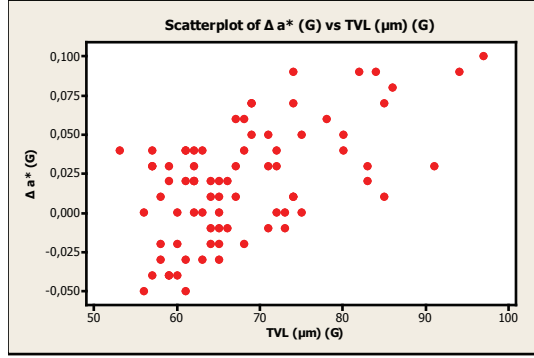
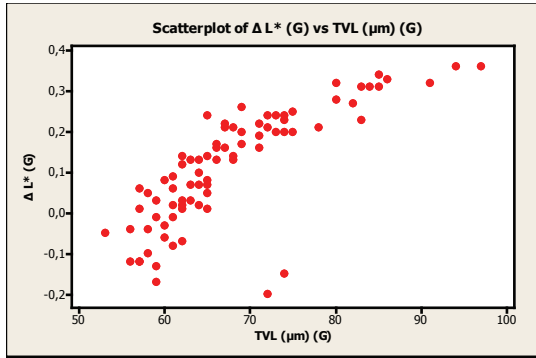
Two-Sample T-Test and CI: TVL (μm) (E); TVL (μm) (G)

Two-sample T for TVL (μm) (E) vs TVL (μm) (G)

	N	Mean	StDev	SE Mean
TVL (μm) (E)	32	80,7	12,3	2,2
TVL (μm) (G)	80	67,92	9,47	1,1

Difference = $\mu(\text{TVL } (\mu\text{m}) (E)) - \mu(\text{TVL } (\mu\text{m}) (G))$
 Estimate for difference: 12,79
 95% CI for difference: (7,93; 17,65)
 T-Test of difference = 0 (vs not =):
 T-Value = 5,30 P-Value = 0,000 DF = 46





Appendix XIII; Colour measurements of samples varnished and cured one respectively two times

• Measurement D

Second layer:	
Date:	24/3 - 2011
Time:	approx. 14.15
Batch/box.no:	201 96 42 - 3
Component:	Lid to detergent pocket (with hole)

Test during normal operation;	
* curing in the LPG furnace	* material temperature $\approx 180^{\circ}\text{C}$
* "normal" thickness of varnish layer (TVL)	* time in furnace ≈ 18 min
* (1) denotes measurements of the first layer and (2) of the second layer.	
* Colour and TVL have been measured on approximately the same spot of the samples.	

Date and batch/box no. first layer on G.20.9:	23/3 - 2011	201 96 42 - 3
Date and batch/box no. first layer on G.20.16:	24/3 - 2011	201 96 42 - 3

sample	$\Delta L^* (1)$	$\Delta a^* (1)$	$\Delta b^* (1)$	TVL (μm) (1)	pos. on hanger (1)	$\Delta L^* (2)$	$\Delta a^* (2)$	$\Delta b^* (2)$	TVL (μm) (2)	pos. on hanger (2)
G.20.9a	0,31	0,02	0,25	83	2	0,34	0,14	0,26	161	2
G.20.9b	0,23	0,01	0,25	74	2	0,37	0,12	0,25	148	2
G.20.9c	0,20	0	0,12	75	2	0,33	0,13	0,27	158	2
G.20.9d	0,32	0,03	0,28	91	2	0,35	0,13	0,26	174	2
G.20.9e	0,23	0,03	0,24	83	2	0,34	0,10	0,27	164	2
G.20.16a	0,24	0,07	0,16	74	2	0,42	0,09	0,25	145	4
G.20.16b	0,26	0,07	0,09	69	2	0,38	0,09	0,26	138	4
G.20.16c	0,21	0,03	0,03	67	2	0,42	0,09	0,28	155	4
G.20.16d	0,13	0,02	-0,04	64	2	0,36	0,13	0,35	177	4
G.20.16e	0,20	0,07	0,11	69	2	0,40	0,10	0,34	203	4

• Measurement E

Second layer:	
Date:	6/4-2011
Time:	approx. 8.30
Batch/box.no:	202 10 09 - 1
Component:	Lid to detergent pocket (without hole)

Test during normal operation;	
* curing in the LPG furnace	* material temperature $\approx 180^{\circ}\text{C}$
* "normal" thickness of varnish layer (TVL)	* time in furnace ≈ 18 min
* (1) denotes measurements of the first layer and (2) of the second layer.	
* Colour and TVL have been measured on approximately the same spot of the samples.	

Date and batch/box no. first layer:	6/4-2011	201 73 08 - 1
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sample	$\Delta L^* (1)$	$\Delta a^* (1)$	$\Delta b^* (1)$	TVL (μm) (1)	pos. on hanger (1)	$\Delta L^* (2)$	$\Delta a^* (2)$	$\Delta b^* (2)$	TVL (μm) (2)	pos. on hanger (2)
GG1	0,09	0,13	0,28	112	4	0,23	0,17	0,10	195	4
GG2	-0,02	0,07	0,12	73	4	0,23	0,17	0,08	152	4
GG3	-0,01	0,04	0,12	72	4	0,21	0,16	0,12	126	4
GG4	0,04	0,10	0,21	83	4	0,26	0,15	0,07	137	4
GG5	-0,02	0,13	0,23	85	4	0,23	0,18	0,01	140	4
GG6	0,06	0,12	0,21	96	4	0,23	0,16	0,05	143	2
GG7	-0,03	0,10	0,06	72	4	0,25	0,17	-0,01	115	2
GG8	-0,04	0,10	0,08	74	4	0,24	0,16	0,01	124	2
GG9	0,04	0,08	0,14	76	4	0,24	0,18	0,02	139	2
GG10	0,01	0,15	0,27	95	4	0,24	0,18	0,05	170	2

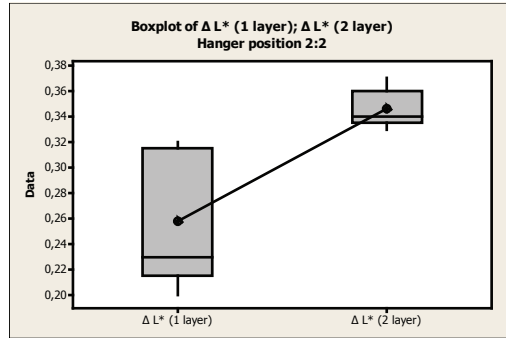
Appendix XIV; Analysis of data from measurements D-E

Two-Sample T-Test and CI: ΔL^* (1 layer); ΔL^* (2 layer)

Two-sample T for ΔL^* (1 layer) vs ΔL^* (2 layer)

	N	Mean	StDev	SE Mean
ΔL^* (1 layer)	5	0,2580	0,0536	0,024
ΔL^* (2 layer)	5	0,3460	0,0152	0,0068

Difference = μ (ΔL^* (1 layer)) - μ (ΔL^* (2 layer))
 Estimate for difference: -0,0880
 95% CI for difference: (-0,1571; -0,0189)
 T-Test of difference = 0 (vs not =): T-Value = -3,53
 P-Value = 0,024 DF = 4

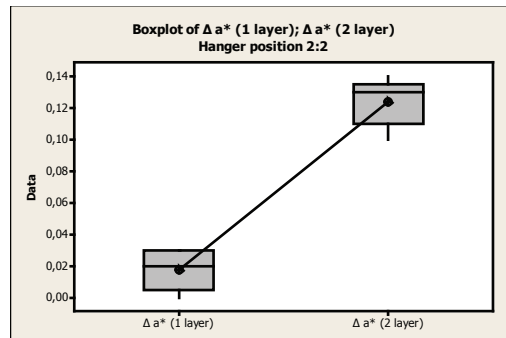


Two-Sample T-Test and CI: Δa^* (1 layer); Δa^* (2 layer)

Two-sample T for Δa^* (1 layer) vs Δa^* (2 layer)

	N	Mean	StDev	SE Mean
Δa^* (1 layer)	5	0,0180	0,0130	0,0058
Δa^* (2 layer)	5	0,1240	0,0152	0,0068

Difference = μ (Δa^* (1 layer)) - μ (Δa^* (2 layer))
 Estimate for difference: -0,10600
 95% CI for difference: (-0,12715; -0,08485)
 T-Test of difference = 0 (vs not =): T-Value = -11,85
 P-Value = 0,000 DF = 7

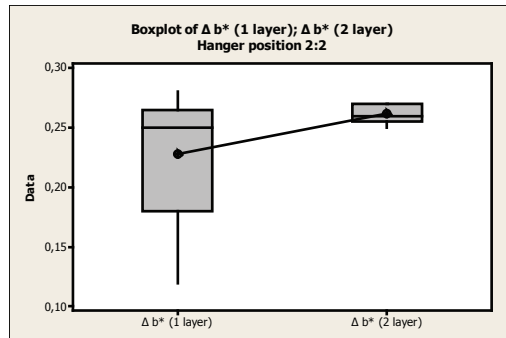


Two-Sample T-Test and CI: Δb^* (1 layer); Δb^* (2 layer)

Two-sample T for Δb^* (1 layer) vs Δb^* (2 layer)

	N	Mean	StDev	SE Mean
Δb^* (1 layer)	5	0,2280	0,0622	0,028
Δb^* (2 layer)	5	0,26200	0,00837	0,0037

Difference = μ (Δb^* (1 layer)) - μ (Δb^* (2 layer))
 Estimate for difference: -0,0340
 95% CI for difference: (-0,1119; 0,0439)
 T-Test of difference = 0 (vs not =): T-Value = -1,21
 P-Value = 0,292 DF = 4

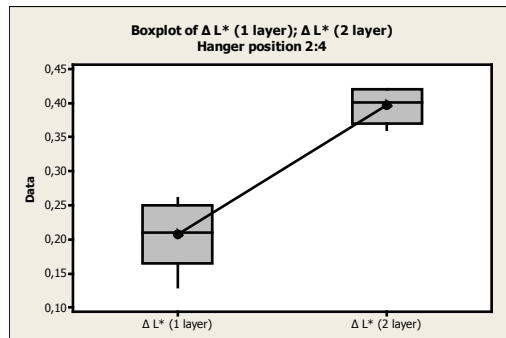


Two-Sample T-Test and CI: ΔL^* (1 layer); ΔL^* (2 layer)

Two-sample T for ΔL^* (1 layer) vs ΔL^* (2 layer)

	N	Mean	StDev	SE Mean
ΔL^* (1 layer)	5	0,2080	0,0497	0,022
ΔL^* (2 layer)	5	0,3960	0,0261	0,012

Difference = μ (ΔL^* (1 layer)) - μ (ΔL^* (2 layer))
 Estimate for difference: -0,1880
 95% CI for difference: (-0,2494; -0,1266)
 T-Test of difference = 0 (vs not =): T-Value = -7,49
 P-Value = 0,000 DF = 6

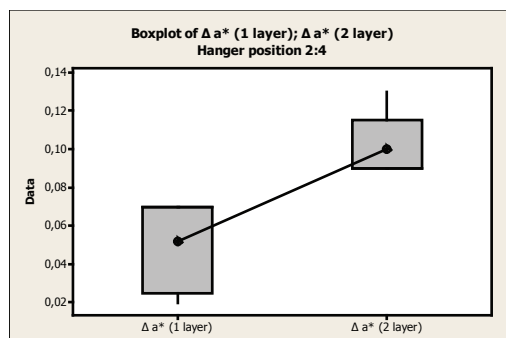


Two-Sample T-Test and CI: Δa^* (1 layer); Δa^* (2 layer)

Two-sample T for Δa^* (1 layer) vs Δa^* (2 layer)

	N	Mean	StDev	SE Mean
Δa^* (1 layer)	5	0,0520	0,0249	0,011
Δa^* (2 layer)	5	0,1000	0,0173	0,0077

Difference = μ (Δa^* (1 layer)) - μ (Δa^* (2 layer))
 Estimate for difference: -0,0480
 95% CI for difference: (-0,0801; -0,0159)
 T-Test of difference = 0 (vs not =): T-Value = -3,54
 P-Value = 0,009 DF = 7

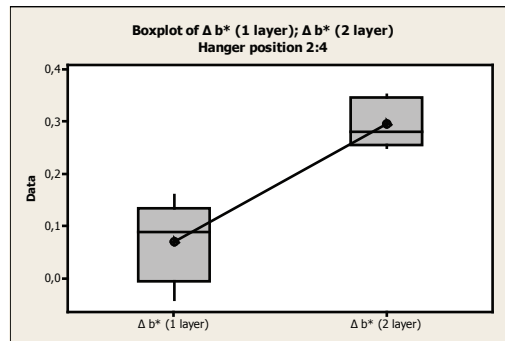


Two-Sample T-Test and CI: Δb^* (1 layer); Δb^* (2 layer)

Two-sample T for Δb^* (1 layer) vs Δb^* (2 layer)

	N	Mean	StDev	SE Mean
Δb^* (1 layer)	5	0,0700	0,0771	0,034
Δb^* (2 layer)	5	0,2960	0,0462	0,021

Difference = μ (Δb^* (1 layer)) - μ (Δb^* (2 layer))
 Estimate for difference: -0,2260
 95% CI for difference: (-0,3244; -0,1276)
 T-Test of difference = 0 (vs not =): T-Value = -5,62
 P-Value = 0,001 DF = 6

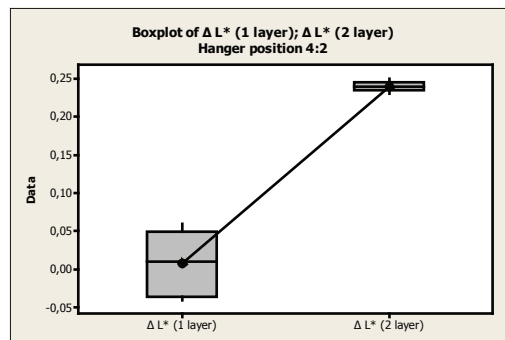


Two-Sample T-Test and CI: ΔL^* (1 layer); ΔL^* (2 layer)

Two-sample T for ΔL^* (1 layer) vs ΔL^* (2 layer)

	N	Mean	StDev	SE Mean
ΔL^* (1 layer)	5	0,0080	0,0432	0,019
ΔL^* (2 layer)	5	0,24000	0,00707	0,0032

Difference = μ (ΔL^* (1 layer)) - μ (ΔL^* (2 layer))
 Estimate for difference: -0,2320
 95% CI for difference: (-0,2864; -0,1776)
 T-Test of difference = 0 (vs not =): T-Value = -11,84
 P-Value = 0,000 DF = 4

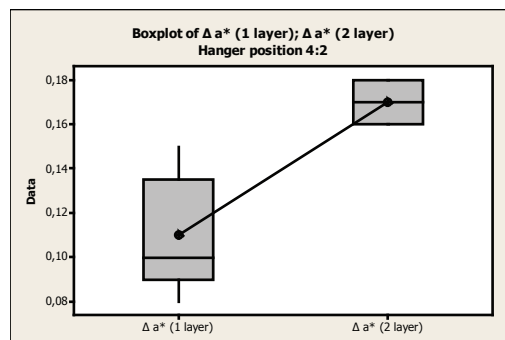


Two-Sample T-Test and CI: Δa^* (1 layer); Δa^* (2 layer)

Two-sample T for Δa^* (1 layer) vs Δa^* (2 layer)

	N	Mean	StDev	SE Mean
Δa^* (1 layer)	5	0,1100	0,0265	0,012
Δa^* (2 layer)	5	0,1700	0,0100	0,0045

Difference = μ (Δa^* (1 layer)) - μ (Δa^* (2 layer))
 Estimate for difference: -0,0600
 95% CI for difference: (-0,0925; -0,0275)
 T-Test of difference = 0 (vs not =): T-Value = -4,74
 P-Value = 0,005 DF = 5

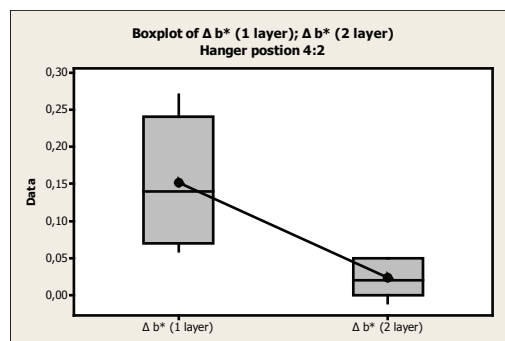


Two-Sample T-Test and CI: Δb^* (1 layer); Δb^* (2 layer)

Two-sample T for Δb^* (1 layer) vs Δb^* (2 layer)

	N	Mean	StDev	SE Mean
Δb^* (1 layer)	5	0,1520	0,0881	0,039
Δb^* (2 layer)	5	0,0240	0,0261	0,012

Difference = μ (Δb^* (1 layer)) - μ (Δb^* (2 layer))
 Estimate for difference: 0,1280
 95% CI for difference: (0,0139; 0,2421)
 T-Test of difference = 0 (vs not =): T-Value = 3,11
 P-Value = 0,036 DF = 4

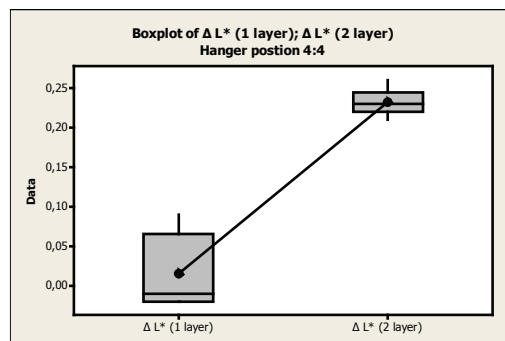


Two-Sample T-Test and CI: ΔL^* (1 layer); ΔL^* (2 layer)

Two-sample T for ΔL^* (1 layer) vs ΔL^* (2 layer)

	N	Mean	StDev	SE Mean
ΔL^* (1 layer)	5	0,0160	0,0483	0,022
ΔL^* (2 layer)	5	0,2320	0,0179	0,0080

Difference = μ (ΔL^* (1 layer)) - μ (ΔL^* (2 layer))
 Estimate for difference: -0,2160
 95% CI for difference: (-0,2752; -0,1568)
 T-Test of difference = 0 (vs not =): T-Value = -9,38
 P-Value = 0,000 DF = 5

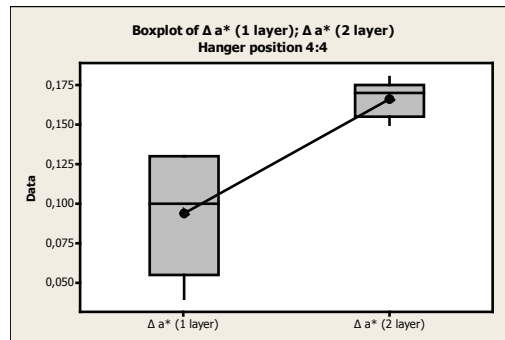


Two-Sample T-Test and CI: Δa^* (1 layer); Δa^* (2 layer)

Two-sample T for Δa^* (1 layer) vs Δa^* (2 layer)

	N	Mean	StDev	SE Mean
Δa^* (1 layer)	5	0,0940	0,0391	0,017
Δa^* (2 layer)	5	0,1660	0,0114	0,0051

Difference = μ (Δa^* (1 layer)) - μ (Δa^* (2 layer))
 Estimate for difference: -0,0720
 95% CI for difference: (-0,1226; -0,0214)
 T-Test of difference = 0 (vs not =): T-Value = -3,95
 P-Value = 0,017 DF = 4

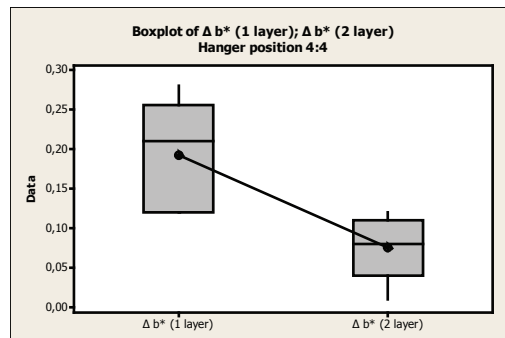


Two-Sample T-Test and CI: Δb^* (1 layer); Δb^* (2 layer)

Two-sample T for Δb^* (1 layer) vs Δb^* (2 layer)

	N	Mean	StDev	SE Mean
Δb^* (1 layer)	5	0,1920	0,0705	0,032
Δb^* (2 layer)	5	0,0760	0,0416	0,019

Difference = μ (Δb^* (1 layer)) - μ (Δb^* (2 layer))
 Estimate for difference: 0,1160
 95% CI for difference: (0,0264; 0,2056)
 T-Test of difference = 0 (vs not =): T-Value = 3,17
 P-Value = 0,019 DF = 6



Appendix XV; Colour measurements during normal operation

• Measurement F

Date: 24/3 - 2011
Time: approx. 13.15
Batch/box.no.: 201 96 42 - 3
Component: top sheet

Test during normal operation;

* curing in the LPG furnace * material temperature ≈ 180°C
 * "normal" thickness of varnish layer * time in furnace ≈ 18 min
 * Measurements were made on 20 hangers placed directly after each other,
 on every second two respectively four sheets were placed.
 * On the hangers with only two sheets, these were placed on position 2 and 4.
 * Only the first sheets were detached from the hangers and sorted with preserved order.

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger
0.34	0.04	0.34	1	4	0.29	0.01	0.12	?	1
0.19	0.07	-0.09	1	3	0.04	0.03	-0.22	?	2
0.19	0.05	0.03	1	2	0.25	0.05	0.00	?	3
0.21	0.00	0.11	1	1	0.35	0.06	0.27	?	4
0.33	0.05	0.28	2	4	0.05	0.03	-0.23	?	2
0.17	0.07	0.20	2	2	0.34	0.04	0.31	?	4
0.23	0.05	-0.04	3	3	0.07	0.02	-0.28	?	3
0.29	0.10	0.31	3	4	0.15	0.03	-0.05	?	2
0.18	0.13	0.19	3	1	0.32	0.06	0.23	?	4
0.25	0.02	0.01	3	2	0.21	0.07	-0.10	?	3
0.30	0.06	0.24	4	4	0.26	0.07	0.01	?	1
0.09	0.11	-0.01	4	2	0.11	0.03	-0.15	?	2
0.32	0.10	0.11	5	1	0.28	0.04	0.19	?	4
0.15	-0.01	-0.11	5	3	0.29	0.06	0.24	?	4
0.33	0.02	0.19	5	4	0.29	0.08	0.03	?	3
0.21	0.01	-0.01	5	2	0.26	0.06	0.00	?	3
0.31	0.03	0.22	?	4	0.06	0.06	-0.25	?	2
0.30	0.05	0.02	?	3	0.17	0.03	-0.06	?	2
0.32	0.07	0.12	?	1	0.30	0.05	0.18	?	4
0.10	-0.01	-0.12	?	2	0.27	0.07	0.17	?	4
0.21	0.05	0.02	?	2	0.29	0.09	0.09	?	1
0.25	0.07	0.21	?	4	0.29	0.08	0.21	?	4
0.31	0.06	0.08	?	1	0.22	0.06	0.03	?	2
0.29	0.09	0.25	?	4	0.13	0.07	-0.19	?	3
0.18	0.04	-0.04	?	2	-0.03	0.04	-0.30	?	2
0.14	0.10	0.00	?	2	0.26	0.08	0.04	?	1
0.30	0.03	0.25	?	4	0.23	0.05	-0.03	?	1
0.15	0.04	-0.08	?	1	0.25	0.07	0.00	?	1
0.31	0.04	0.21	?	4	0.24	0.06	-0.05	?	3
					0.11	0.04	-0.13	?	2
					0.31	0.05	0.21	?	4

• Measurement G

Date: 25/3 - 2011
Time: approx. 11.20
Batch/box.no.: 201 96 42 - 3

Test during normal operation;

* curing in the LPG furnace * material temperature ≈ 180°C
 * "normal" thickness of varnish layer * time in furnace ≈ 18 min
 * Measurements were made on 14 hangers placed directly after each other,
 on every second two respectively four sheets were placed.
 * On the hangers with only two sheets, these were placed on position 2 and 4.

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0.16	0	0.05	1	4	top sheet
0.24	0.04	0.12	1	2	top sheet
0.20	0.03	-0.08	2	3	top sheet
0.31	0.09	0.37	2	4	top sheet
0.23	0.04	0.11	2	1	top sheet
0.16	0.07	-0.01	2	2	top sheet
0.23	0.03	0.03	3	2	top sheet
0.27	0.04	0.17	3	4	top sheet
0.31	0.06	0.33	4	4	top sheet
0.13	0.03	-0.20	4	3	top sheet
0.15	0.03	-0.13	4	2	top sheet
0.31	0.06	0.12	4	1	top sheet
0.29	0.07	0.10	5	2	top sheet
0.29	0.05	0.18	5	4	top sheet
0.14	0.04	0.02	6	4	top sheet
0.18	0.06	-0.12	6	3	top sheet
0.16	0.06	-0.10	6	2	top sheet
0.33	0.08	0.12	6	1	top sheet
0.25	0.07	0.05	7	2	top sheet
0.29	0.06	0.21	7	4	top sheet
0.16	0.02	0.04	8	4	top sheet
0.29	0.08	0	8	3	top sheet
0.30	0.05	0.06	8	2	top sheet
0.22	0.07	0.05	8	1	top sheet
0.22	0.04	0.07	9	4	top sheet
0.25	0.04	0.05	9	2	top sheet
0.20	0.07	-0.13	10	3	top sheet
0.25	0.05	0.12	10	4	top sheet
0.05	0.02	-0.21	10	2	top sheet
0.13	0.09	-0.03	10	1	top sheet

● **Measurement H**

Date:	5/4-2011
Time:	approx. 12.00
Batch/box.no.:	201 73 08 - 1
Component:	top sheet

0.40	0.07	0.28	11	4	frontdoor WM/TD
0.40	0.07	0.16	11	2	frontdoor WM/TD
0.40	0.10	0.10	12	2	frontdoor WM/TD
0.41	0.10	0.11	12	1	frontdoor WM/TD
0.37	0.07	0.25	12	4	frontdoor WM/TD
0.33	0.10	0.09	12	3	frontdoor WM/TD
0.38	0.06	0.26	13	4	frontdoor WM/TD
0.41	0.08	0.10	13	2	frontdoor WM/TD
0.40	0.07	0.18	14	2	frontdoor WM/TD
0.42	0.09	0.12	14	1	frontdoor WM/TD
0.37	0.06	0.27	14	4	frontdoor WM/TD
0.41	0.06	0.12	14	3	frontdoor WM/TD

Test during normal operation;	
* curing in the LPG furnace	* material temperature \approx 180 °C
* "normal" thickness of varnish layer	* time in furnace \approx 18 min
* On every second hanger, two top sheets respectively two top sheets and two frames to laminate top sheets were placed.	
* On the hangers with only two top sheets, these were placed on position 2 and 4.	

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger
-0,01	0,11	0,12	1	2
-0,01	0,09	0,21	1	4
0,02	0,11	0,17	2	1
0,02	0,11	0,13	2	3
0,01	0,11	0,14	3	2
0,02	0,10	0,24	3	4
0,03	0,12	0,18	4	1
0,00	0,13	0,04	4	3
0,03	0,12	0,12	5	2
-0,01	0,08	0,15	5	4
-0,04	0,12	0,08	6	1
0,03	0,13	0,05	6	3
-0,04	0,10	0,06	7	2
0,00	0,08	0,15	7	4
0,03	0,10	0,09	8	1
0,03	0,13	0,06	8	3
0,04	0,08	0,09	9	2
-0,03	0,09	0,09	9	4
0,03	0,09	0,07	10	1
0,00	0,10	0,02	10	3

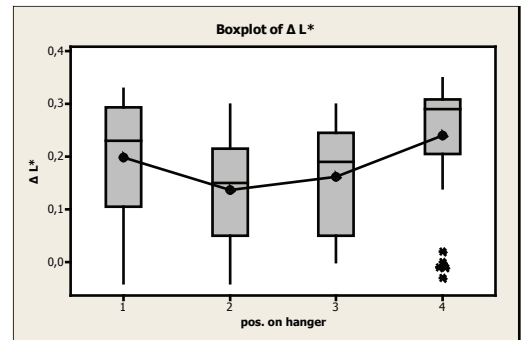
Appendix XVI; Analysis of data from measurements F-H

One-way ANOVA: ΔL^* versus Position on hanger
 Source DF SS MS F P
 Position på galgen 3 0,1940 0,0647 5,67 0,001
 Error 106 1,2092 0,0114
 Total 109 1,4032

S = 0,1068 R-Sq = 13,83% R-Sq(adj) = 11,39%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	StDev
1	22	0,1982	0,1160
2	33	0,1373	0,0946
3	21	0,1619	0,1011
4	34	0,2403	0,1149

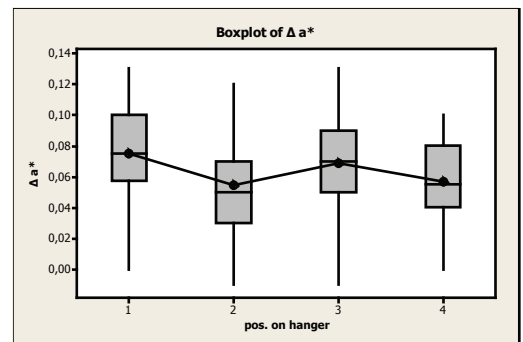


One-way ANOVA: Δa^* versus Position on hanger
 Source DF SS MS F P
 Position på galgen 3 0,007542 0,002514 2,57 0,058
 Error 106 0,103757 0,000979
 Total 109 0,111299

S = 0,03129 R-Sq = 6,78% R-Sq(adj) = 4,14%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	StDev
1	22	0,07500	0,03363
2	33	0,05424	0,03221
3	21	0,06857	0,03678
4	34	0,05676	0,02446

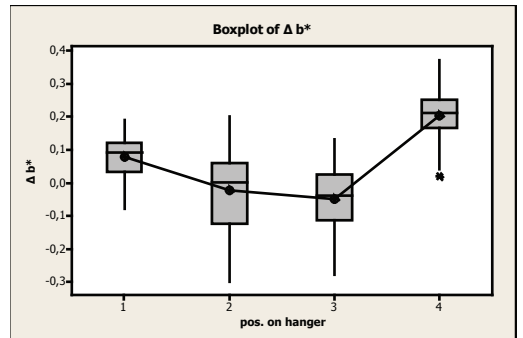


One-way ANOVA: Δb^* versus Position on hanger
 Source DF SS MS F P
 Position på galgen 3 1,18888 0,39629 40,22 0,000
 Error 106 1,04435 0,00985
 Total 109 2,23324

S = 0,09926 R-Sq = 53,24% R-Sq(adj) = 51,91%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	StDev
1	22	0,07818	0,07008
2	33	-0,02394	0,12550
3	21	-0,04952	0,10032
4	34	0,20324	0,08456



Appendix XVII; Colour measurements after 10 min break

• Measurement I

Date:	5/4-2011
Time:	approx. 14.50
Batch/box.no:	201 73 08 - 1
Component:	side sheet WM/TD

Test after 10 min break;	
* curing in the LPG furnace	* material temperature $\approx 180^{\circ}\text{C}$
* "normal" thickness of varnish layer	* time in furnace ≈ 28 min
* The sheets on these four hangers were cured during the break as test, in other words the sheets on the adjacent hangers were not varnished.	
* During the break these hangers were situated several meters from the openings of the furnace.	

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger
-0,08	-0,03	0,42	1	1
-0,14	-0,05	0,24	1	2
-0,10	-0,02	-0,22	1	3
-0,05	-0,09	0,75	1	4
-0,11	-0,05	0,40	2	1
0,01	-0,02	0,41	2	2
-0,09	-0,01	0,20	2	3
-0,09	-0,11	0,61	2	4
-0,03	-0,04	0,43	3	1
-0,05	-0,01	0,31	3	2
-0,04	0,00	0,31	3	3
0,01	-0,06	0,63	3	4
-0,03	-0,01	0,42	4	1
-0,08	-0,01	0,27	4	2
-0,01	0,00	0,39	4	3
0,02	-0,04	0,52	4	4

• **Measurement J**

Date:	6/4-2011
Time:	approx. 14.45
Batch/box.no:	202 10 09 - 1

Test after 10 min break;
 * curing in the LPG furnace * material temperature $\approx 180^{\circ}\text{C}$
 * "normal" thickness of varnish layer * time in furnace ≈ 28 min

* All sheets in this test have been placed on side 1 of a hanger.
 * After hanger 1-20 there were several meters of vacant space before hanger 21-30. After hanger 30 there was several meters of vacant space again, 6 hangers with sheets varnished in black, several meters of vacant space and finally hanger 31.
 * During the break hanger no. 31 was placed approximately 0,5 m from one of the openings of the furnace.
 Hanger no. 32-34 were placed outside the furnace during the break and was only measured as references.

ΔL^*	Δa^*	Δb^*	hanger no.	component
0,04	0,02	0,49	1	protective sheet DW
0,09	0,04	0,62	2	protective sheet DW
0,00	0,03	0,47	3	protective sheet DW
0,10	0,05	0,56	4	protective sheet DW
0,09	0,05	0,57	5	protective sheet DW
0,08	0,02	0,60	6	protective sheet DW
0,08	0,02	0,58	7	protective sheet DW
-0,10	0,00	0,25	8	protective sheet DW
0,02	0,03	0,56	9	protective sheet DW
-0,13	-0,01	0,31	10	protective sheet DW
0,05	0,01	0,52	11	protective sheet DW
0,12	0,04	0,59	12	protective sheet DW
0,09	0,01	0,63	13	protective sheet DW
0,06	-0,01	0,66	14	protective sheet DW
0,06	0,02	0,66	15	protective sheet DW
0,09	0,02	0,66	16	protective sheet DW
0,06	0,03	0,46	17	protective sheet DW
0,00	0,01	0,51	18	protective sheet DW
0,04	0,02	0,49	19	protective sheet DW
0,07	0,11	0,32	20	protective sheet DW
0,11	0,04	0,48	21	front sheet WM
0,18	0,04	0,56	22	front sheet WM
0,12	0,05	0,45	23	front sheet WM
0,18	0,02	0,52	24	front sheet WM
0,15	0,05	0,55	25	front sheet WM
0,23	0,02	0,58	26	front sheet WM
0,15	0,04	0,48	27	front sheet WM
0,14	0,07	0,59	28	front sheet WM
0,14	0,03	0,51	29	front sheet WM
0,15	0,04	0,64	30	front sheet WM
0,09	0,08	-0,13	31	side sheet WM/TD
0,22	0,12	0,03	32	side sheet WM/TD
0,30	0,14	0,08	33	side sheet WM/TD
0,16	0,14	-0,08	34	side sheet WM/TD

Appendix XVIII; Colour measurements after 45 min conveyor stop

• Measurement K

Date: 25/3 - 2011

Time: approx. 11.20

Batch/box.no.: 201 96 42 - 3

Test after approx. 45 min conveyor stop;

* curing in the LPG furnace

* "normal" thickness of varnish layer

* During the stop hanger no.1 was placed close to one of the openings of the furnace.

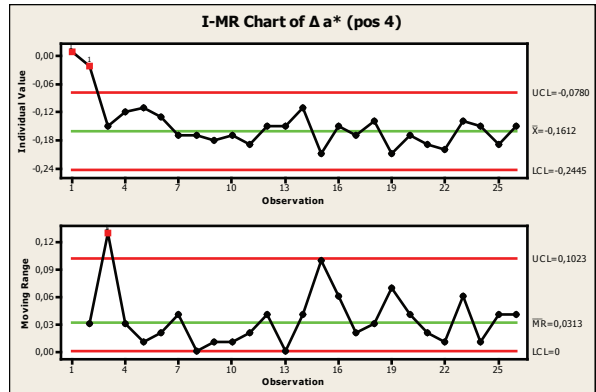
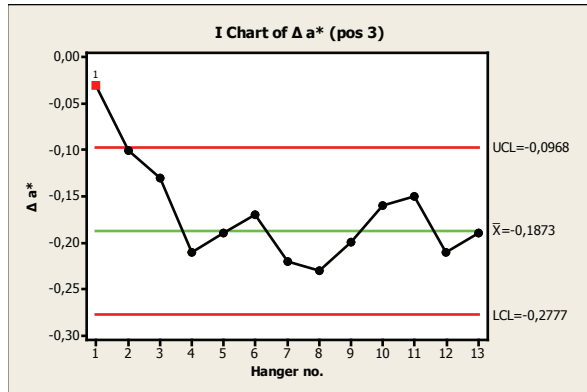
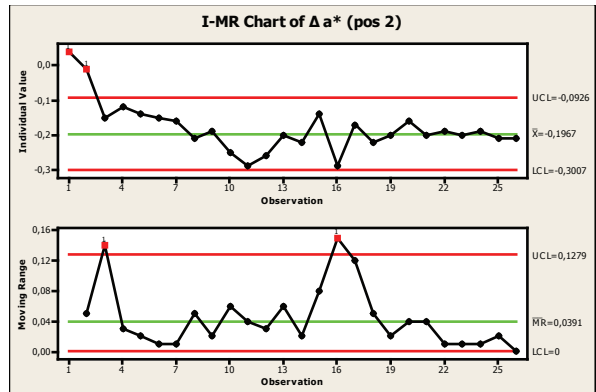
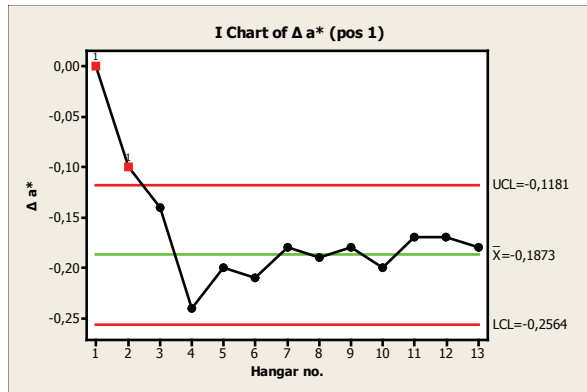
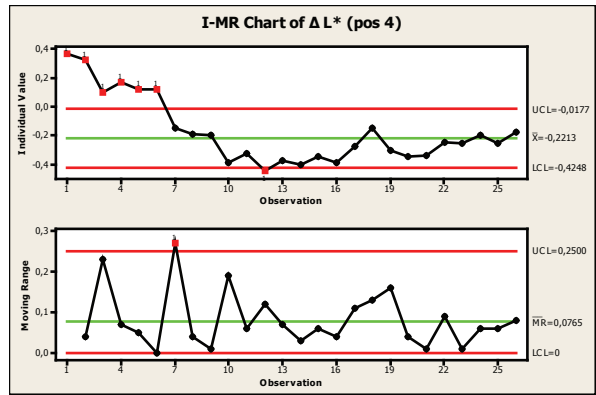
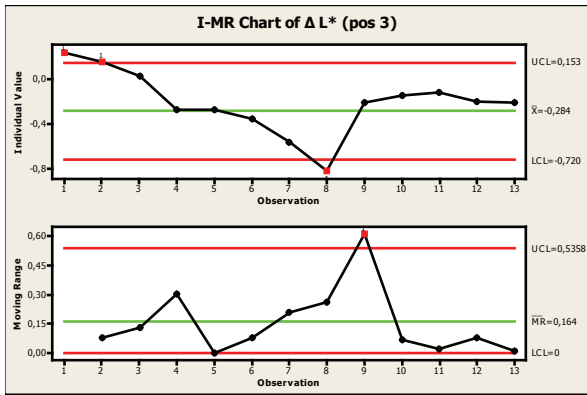
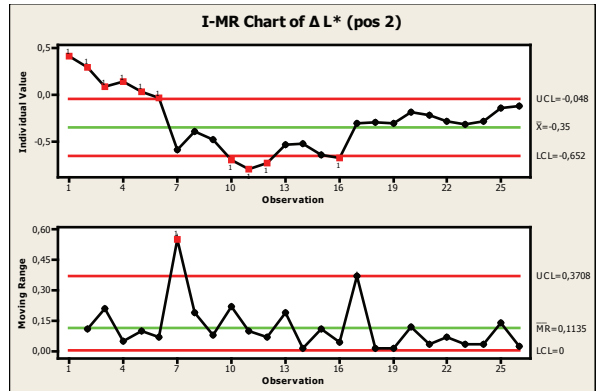
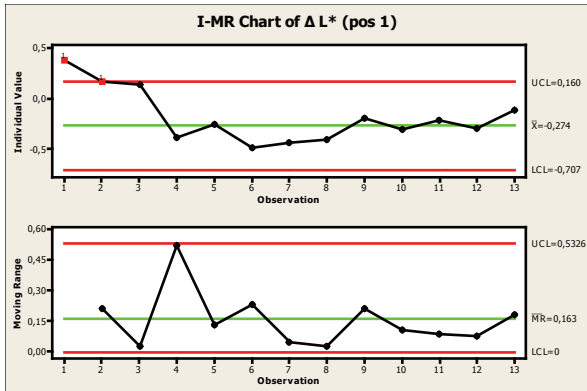
* material temperature $\approx 180\text{ }^{\circ}\text{C}$

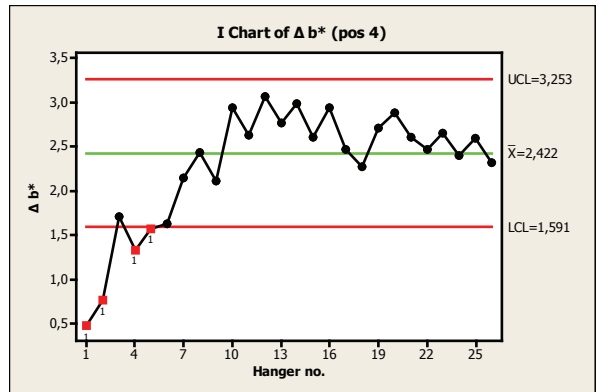
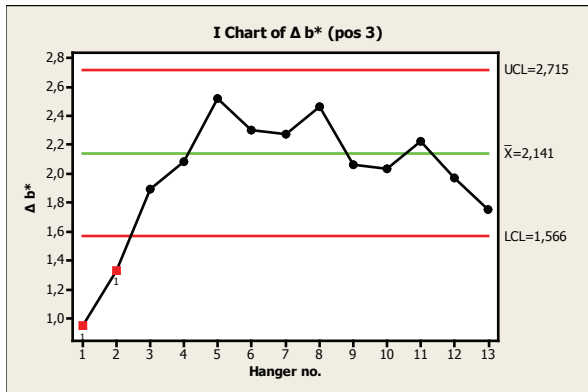
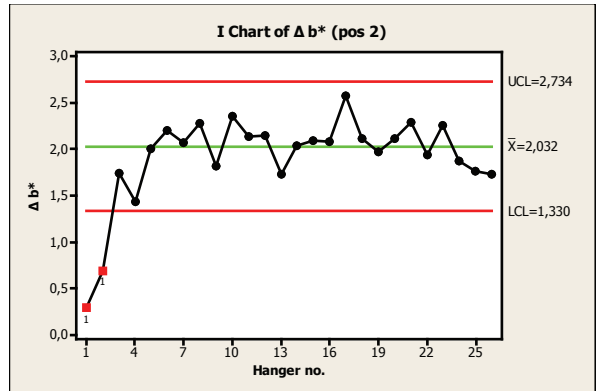
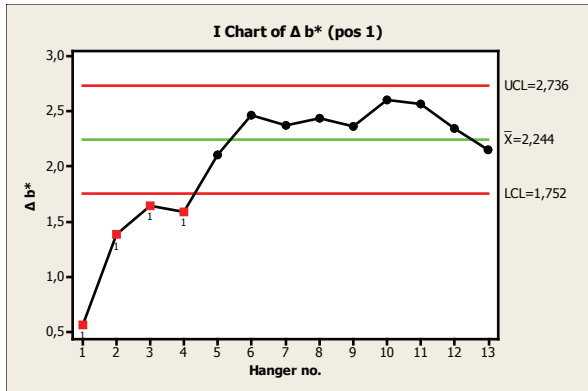
* time in furnace $\approx 63\text{ min}$

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0.37	0.01	0.47	1	4	front door WM/TD
0.40	0.04	0.29	1	2	front door WM/TD
0.29	-0.01	0.69	2	2	front door WM/TD
0.33	-0.02	0.76	2	4	front door WM/TD
0.24	-0.03	0.95	2	3	front door WM/TD
0.37	0.00	0.56	2	1	front door WM/TD
0.10	-0.15	1.70	3	4	front door WM/TD
0.08	-0.15	1.74	3	2	front door WM/TD
0.17	-0.12	1.33	4	4	front door WM/TD
0.16	-0.10	1.33	4	3	front door WM/TD
0.13	-0.12	1.43	4	2	front door WM/TD
0.16	-0.10	1.38	4	1	front door WM/TD
0.12	-0.11	1.57	5	4	front door WM/TD
0.03	-0.14	2.01	5	2	front door WM/TD
0.12	-0.13	1.62	6	4	front door WM/TD
0.03	-0.13	1.89	6	3	front door WM/TD
-0.04	-0.15	2.20	6	2	front door WM/TD
0.13	-0.14	1.64	6	1	front door WM/TD
-0.15	-0.17	2.14	7	4	domed outer door DW
-0.59	-0.16	2.07	7	2	domed outer door DW
-0.27	-0.21	2.08	8	3	domed outer door DW
-0.19	-0.17	2.43	8	4	domed outer door DW
-0.39	-0.24	1.59	8	1	domed outer door DW
-0.40	-0.21	2.28	8	2	domed outer door DW
-0.20	-0.18	2.11	9	4	domed outer door DW
-0.48	-0.19	1.82	9	2	domed outer door DW
-0.27	-0.19	2.52	10	3	domed outer door DW
-0.39	-0.17	2.94	10	4	domed outer door DW
-0.70	-0.25	2.36	10	2	domed outer door DW
-0.26	-0.20	2.11	10	1	domed outer door DW
-0.33	-0.19	2.63	11	4	domed outer door DW
-0.80	-0.29	2.14	11	2	domed outer door DW

-0.35	-0.17	2.30	12	3	domed outer door DW
-0.45	-0.15	3.06	12	4	domed outer door DW
-0.49	-0.21	2.47	12	1	domed outer door DW
-0.73	-0.26	2.15	12	2	domed outer door DW
-0.38	-0.15	2.76	13	4	domed outer door DW
-0.54	-0.20	1.73	13	2	domed outer door DW
-0.56	-0.22	2.27	14	3	domed outer door DW
-0.41	-0.11	2.98	14	4	domed outer door DW
-0.44	-0.18	2.38	14	1	domed outer door DW
-0.53	-0.22	2.04	14	2	domed outer door DW
-0.64	-0.14	2.09	15	2	domed outer door DW
-0.35	-0.21	2.60	15	4	domed outer door DW
-0.82	-0.23	2.46	16	3	domed outer door DW
-0.68	-0.29	2.08	16	2	domed outer door DW
-0.41	-0.19	2.44	16	1	domed outer door DW
-0.39	-0.15	2.93	16	4	domed outer door DW
-0.28	-0.17	2.46	17	4	top sheet
-0.31	-0.17	2.58	17	2	top sheet
-0.15	-0.14	2.27	18	4	top sheet
-0.21	-0.20	2.06	18	3	top sheet
-0.20	-0.18	2.37	18	1	top sheet
-0.30	-0.22	2.11	18	2	top sheet
-0.31	-0.21	2.71	19	4	top sheet
-0.31	-0.20	1.97	19	2	top sheet
-0.14	-0.16	2.03	20	3	top sheet
-0.35	-0.17	2.88	20	4	top sheet
-0.31	-0.20	2.61	20	1	top sheet
-0.19	-0.16	2.11	20	2	top sheet
-0.34	-0.19	2.60	21	4	top sheet
-0.22	-0.20	2.29	21	2	top sheet
-0.22	-0.17	2.57	22	1	top sheet
-0.25	-0.20	2.46	22	4	top sheet
-0.29	-0.19	1.94	22	2	top sheet
-0.12	-0.15	2.22	22	3	top sheet
-0.26	-0.14	2.65	23	4	top sheet
-0.32	-0.20	2.26	23	2	top sheet
-0.29	-0.19	1.87	24	2	top sheet
-0.30	-0.17	2.35	24	1	top sheet
-0.20	-0.15	2.40	24	4	top sheet
-0.20	-0.21	1.97	24	3	top sheet
-0.26	-0.19	2.59	25	4	top sheet
-0.15	-0.21	1.76	25	2	top sheet
-0.18	-0.15	2.31	26	4	top sheet
-0.21	-0.19	1.75	26	3	top sheet
-0.13	-0.21	1.73	26	2	top sheet
-0.12	-0.18	2.15	26	1	top sheet

Appendix XIX; Analysis of data from measurement K





Appendix XX; Colour measurements on samples from hangers with two vs. four sheets

● Measurement L

Date:	24/3 - 2011
Time:	approx. 13.15
Batch/box.no.:	201 96 42 - 3
Component:	top sheet

Test during normal operation;

- * curing in the LPG furnace * material temperature \approx 180 °C
- * "normal" thickness of varnish layer * time in furnace \approx 18 min
- * Measurements were made on 20 hangers placed directly after each other, on every second two respectively four sheets were placed.
- * On the hangers with only two sheets, these were placed on position 2 and 4.
- * Only the first sheets were detached from the hangers and sorted with preserved order.

Hanger with two sheets

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger
0,17	0,07	0,20	2	2
0,09	0,11	-0,01	4	2

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger
0,33	0,05	0,28	2	4
0,30	0,06	0,24	4	4

Hanger with four sheets

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger
0,21	0	0,11	1	1
0,18	0,13	0,19	3	1
0,32	0,10	0,11	5	1

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger
0,19	0,05	0,03	1	2
0,25	0,02	0,01	3	2
0,21	0,01	-0,01	5	2

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger
0,19	0,07	-0,09	1	3
0,23	0,05	-0,04	3	3
0,15	-0,01	-0,11	5	3

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger
0,34	0,04	0,34	1	4
0,29	0,10	0,31	3	4
0,33	0,02	0,19	5	4

● Measurement M

Date:	25/3 - 2011
Time:	approx. 11.20
Batch/box.no.:	201 96 42 - 3

Test during normal operation;

- * curing in the LPG furnace * material temperature \approx 180 °C
- * "normal" thickness of varnish layer * time in furnace \approx 18 min
- * Measurements were made on 14 hangers placed directly after each other, on every second two respectively four sheets were placed.
- * On the hangers with only two sheets, these were placed on position 2 and 4.

Hanger with two sheets

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0,24	0,04	0,12	1	2	top sheet
0,23	0,03	0,03	3	2	top sheet
0,29	0,07	0,10	5	2	top sheet
0,25	0,07	0,05	7	2	top sheet
0,25	0,04	0,05	9	2	top sheet
0,40	0,07	0,16	11	2	front door WM/TD
0,41	0,08	0,10	13	2	front door WM/TD

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0,16	0	0,05	1	4	top sheet
0,27	0,04	0,17	3	4	top sheet
0,29	0,05	0,18	5	4	top sheet
0,29	0,06	0,21	7	4	top sheet
0,22	0,04	0,07	9	4	top sheet
0,40	0,07	0,28	11	4	front door WM/TD
0,38	0,06	0,26	13	4	front door WM/TD

Hanger with four sheets

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0,23	0,04	0,11	2	1	top sheet
0,31	0,06	0,12	4	1	top sheet
0,33	0,08	0,12	6	1	top sheet
0,22	0,07	0,05	8	1	top sheet
0,13	0,09	-0,03	10	1	top sheet
0,41	0,10	0,11	12	1	front door WM/TD
0,42	0,09	0,12	14	1	front door WM/TD

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0,16	0,07	-0,01	2	2	top sheet
0,15	0,03	-0,13	4	2	top sheet
0,16	0,06	-0,10	6	2	top sheet
0,30	0,05	0,06	8	2	top sheet
0,05	0,02	-0,21	10	2	top sheet
0,40	0,10	0,10	12	2	front door WM/TD
0,40	0,07	0,18	14	2	front door WM/TD

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0.20	0.03	-0,08	2	3	top sheet
0.13	0.03	-0,20	4	3	top sheet
0.18	0.06	-0,12	6	3	top sheet
0.29	0.08	0	8	3	top sheet
0.20	0.07	-0,13	10	3	top sheet
0.33	0.10	0,09	12	3	front door WM/TD
0.41	0.06	0,12	14	3	front door WM/TD

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0.31	0.09	0,37	2	4	top sheet
0.31	0.06	0,33	4	4	top sheet
0.14	0.04	0,02	6	4	top sheet
0.16	0.02	0,04	8	4	top sheet
0.25	0.05	0,12	10	4	top sheet
0.37	0.07	0,25	12	4	front door WM/TD
0.37	0.06	0,27	14	4	front door WM/TD

● **Measurement N**

Date:	25/3 - 2011
Time:	approx. 11.20
Batch/box.no.:	201.96.42 - 3

Test after approx. 45 min conveyor stop;

- * curing in the LPG furnace
- * "normal" thickness of varnish layer
- * material temperature $\approx 180^\circ\text{C}$
- * time in furnace ≈ 63 min

* During the stop hanger no.1 was placed close to one of the openings of the furnace.

Hanger with two sheets

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0.40	0.04	0,29	1	2	front door WM/TD
0.08	-0,15	1,74	3	2	front door WM/TD
0.03	-0,14	2,01	5	2	front door WM/TD
-0,59	-0,16	2,07	7	2	domed outer door DW
-0,48	-0,19	1,82	9	2	domed outer door DW
-0,80	-0,29	2,14	11	2	domed outer door DW
-0,54	-0,20	1,73	13	2	domed outer door DW
-0,64	-0,14	2,09	15	2	domed outer door DW
-0,31	-0,17	2,58	17	2	top sheet
-0,31	-0,20	1,97	19	2	top sheet
-0,22	-0,20	2,29	21	2	top sheet
-0,32	-0,20	2,26	23	2	top sheet
-0,15	-0,21	1,76	25	2	top sheet

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0,37	0,01	0,47	1	4	front door WM/TD
0,10	-0,15	1,70	3	4	front door WM/TD
0,12	-0,11	1,57	5	4	front door WM/TD
-0,15	-0,17	2,14	7	4	domed outer door DW
-0,20	-0,18	2,11	9	4	domed outer door DW
-0,33	-0,19	2,63	11	4	domed outer door DW
-0,38	-0,15	2,76	13	4	domed outer door DW
-0,35	-0,21	2,60	15	4	domed outer door DW
-0,28	-0,17	2,46	17	4	top sheet
-0,31	-0,21	2,71	19	4	top sheet
-0,34	-0,19	2,60	21	4	top sheet
-0,26	-0,14	2,65	23	4	top sheet
-0,26	-0,19	2,59	25	4	top sheet

Hanger with four sheets

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0.37	0.00	0.56	2	1	front door WM/TD
0.16	-0.10	1.38	4	1	front door WM/TD
0.13	-0.14	1.64	6	1	front door WM/TD
-0.39	-0.24	1.59	8	1	domed outer door DW
-0.26	-0.20	2.11	10	1	domed outer door DW
-0.49	-0.21	2.47	12	1	domed outer door DW
-0.44	-0.18	2.38	14	1	domed outer door DW
-0.41	-0.19	2.44	16	1	domed outer door DW
-0.20	-0.18	2.37	18	1	top sheet
-0.31	-0.20	2.61	20	1	top sheet
-0.22	-0.17	2.57	22	1	top sheet
-0.30	-0.17	2.35	24	1	top sheet
-0.12	-0.18	2.15	26	1	top sheet

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0.29	-0.01	0.69	2	2	front door WM/TD
0.13	-0.12	1.43	4	2	front door WM/TD
-0.04	-0.15	2.20	6	2	front door WM/TD
-0.40	-0.21	2.28	8	2	domed outer door DW
-0.70	-0.25	2.36	10	2	domed outer door DW
-0.73	-0.26	2.15	12	2	domed outer door DW
-0.53	-0.22	2.04	14	2	domed outer door DW
-0.68	-0.29	2.08	16	2	domed outer door DW
-0.30	-0.22	2.11	18	2	top sheet
-0.19	-0.16	2.11	20	2	top sheet
-0.29	-0.19	1.94	22	2	top sheet
-0.29	-0.19	1.87	24	2	top sheet
-0.13	-0.21	1.73	26	2	top sheet

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0.24	-0.03	0.95	2	3	front door WM/TD
0.16	-0.10	1.33	4	3	front door WM/TD
0.03	-0.13	1.89	6	3	front door WM/TD
-0.27	-0.21	2.08	8	3	domed outer door DW
-0.27	-0.19	2.52	10	3	domed outer door DW
-0.35	-0.17	2.30	12	3	domed outer door DW
-0.56	-0.22	2.27	14	3	domed outer door DW
-0.82	-0.23	2.46	16	3	domed outer door DW
-0.21	-0.20	2.06	18	3	top sheet
-0.14	-0.16	2.03	20	3	top sheet
-0.12	-0.15	2.22	22	3	top sheet
-0.20	-0.21	1.97	24	3	top sheet
-0.21	-0.19	1.75	26	3	top sheet

ΔL^*	Δa^*	Δb^*	hanger no.	pos. on hanger	component
0.33	-0.02	0.76	2	4	front door WM/TD
0.17	-0.12	1.33	4	4	front door WM/TD
0.12	-0.13	1.62	6	4	front door WM/TD
-0.19	-0.17	2.43	8	4	domed outer door DW
-0.39	-0.17	2.94	10	4	domed outer door DW
-0.45	-0.15	3.06	12	4	domed outer door DW
-0.41	-0.11	2.98	14	4	domed outer door DW
-0.39	-0.15	2.93	16	4	domed outer door DW
-0.15	-0.14	2.27	18	4	top sheet
-0.35	-0.17	2.88	20	4	top sheet
-0.25	-0.20	2.46	22	4	top sheet
-0.20	-0.15	2.40	24	4	top sheet
-0.18	-0.15	2.31	26	4	top sheet

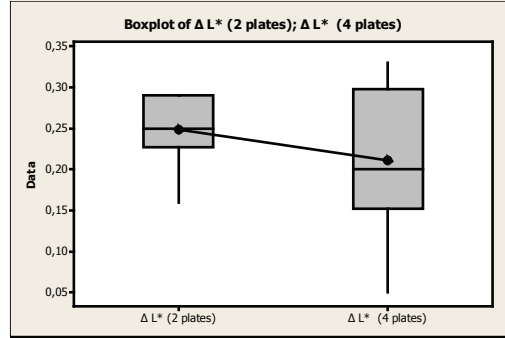
Appendix XXI; Analysis of data from measurements L-N

Two-Sample T-Test and CI: ΔL^* (2 plates); ΔL^* (4 plates)

Two-sample T for ΔL^* (2 plates) vs ΔL^* (4 plates)

	N	Mean	StDev	SE Mean
ΔL^* (2 plates)	10	0,2490	0,0404	0,013
ΔL^* (4 plates)	20	0,2105	0,0783	0,018

Difference = μ (ΔL^* (2 plates)) - μ (ΔL^* (4 plates))
 Estimate for difference: 0,0385
 95% CI for difference: (-0,0060; 0,0830)
 T-Test of difference = 0 (vs not =): T-Value = 1,78
 P-Value = 0,087 DF = 27

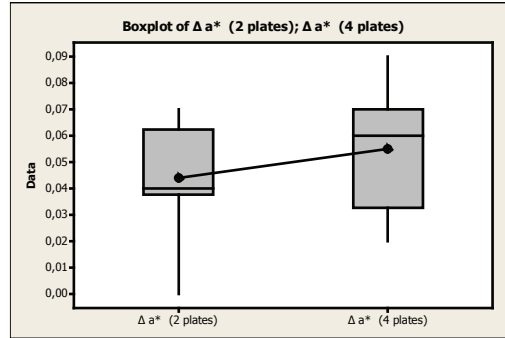


Two-Sample T-Test and CI: Δa^* (2 plates); Δa^* (4 plates)

Two-sample T for Δa^* (2 plates) vs Δa^* (4 plates)

	N	Mean	StDev	SE Mean
Δa^* (2 plates)	10	0,0440	0,0207	0,0065
Δa^* (4 plates)	20	0,0550	0,0221	0,0049

Difference = μ (Δa^* (2 plates)) - μ (Δa^* (4 plates))
 Estimate for difference: -0,01100
 95% CI for difference: (-0,02815; 0,00615)
 T-Test of difference = 0 (vs not =): T-Value = -1,34
 P-Value = 0,195 DF = 19

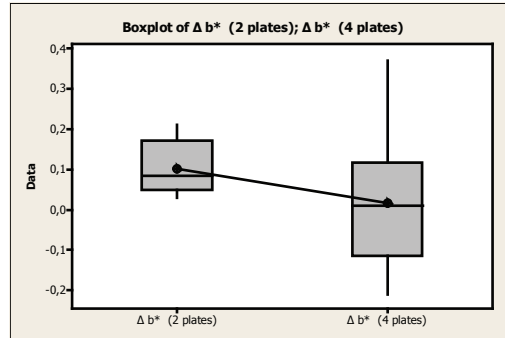


Two-Sample T-Test and CI: Δb^* (2 plates); Δb^* (4 plates)

Two-sample T for Δb^* (2 plates) vs Δb^* (4 plates)

	N	Mean	StDev	SE Mean
Δb^* (2 plates)	10	0,1030	0,0641	0,020
Δb^* (4 plates)	20	0,016	0,154	0,035

Difference = μ (Δb^* (2 plates)) - μ (Δb^* (4 plates))
 Estimate for difference: 0,0865
 95% CI for difference: (0,0043; 0,1687)
 T-Test of difference = 0 (vs not =): T-Value = 2,16
 P-Value = 0,040 DF = 27

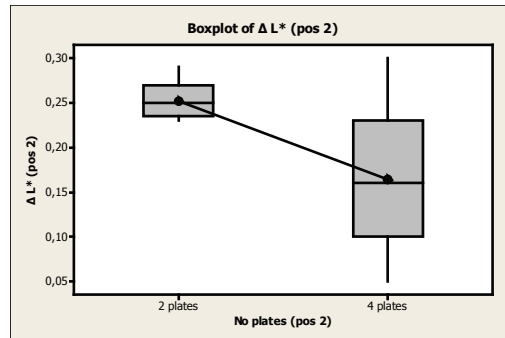


Two-Sample T-Test and CI: ΔL^* (pos 2); No plates (pos 2)

Two-sample T for ΔL^* (pos 2)

	N	Mean	StDev	SE Mean
No plates (pos 2)	5	0,2520	0,0228	0,010
2 plates	5	0,1640	0,0891	0,040

Difference = μ (2 plates) - μ (4 plates)
 Estimate for difference: 0,0880
 95% CI for difference: (-0,0261; 0,2021)
 T-Test of difference = 0 (vs not =): T-Value = 2,14
 P-Value = 0,099 DF = 4

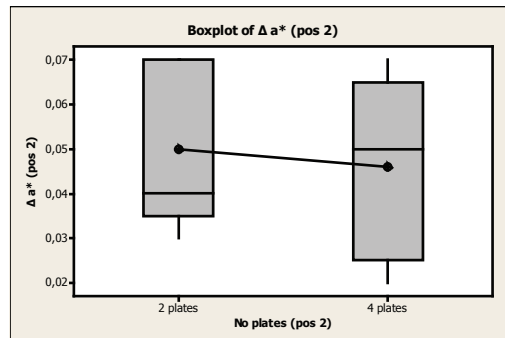


Two-Sample T-Test and CI: Δa^* (pos 2); No plates (pos 2)

Two-sample T for Δa^* (pos 2)

	N	Mean	StDev	SE Mean
No plates (pos 2)	5	0,0500	0,0187	0,0084
2 plates	5	0,0460	0,0207	0,0093

Difference = μ (2 plates) - μ (4 plates)
 Estimate for difference: 0,0040
 95% CI for difference: (-0,0255; 0,0335)
 T-Test of difference = 0 (vs not =): T-Value = 0,32
 P-Value = 0,758 DF = 7

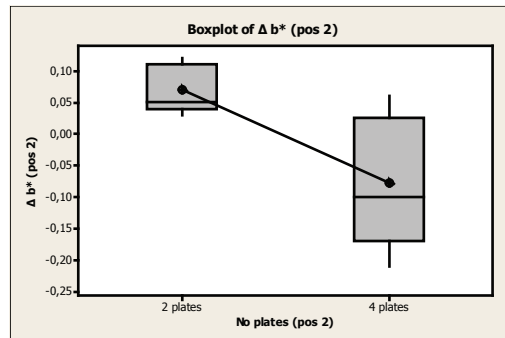


Two-Sample T-Test and CI: Δb^* (pos 2); No plates (pos 2)

Two-sample T for Δb^* (pos 2)

No plates (pos 2)				
	N	Mean	StDev	SE Mean
2 plates	5	0,0700	0,0381	0,017
4 plates	5	-0,078	0,105	0,047

Difference = μ (2 plates) - μ (4 plates)
 Estimate for difference: 0,1480
 95% CI for difference: (0,0194; 0,2766)
 T-Test of difference = 0 (vs not =): T-Value = 2,96
 P-Value = 0,032 DF = 5

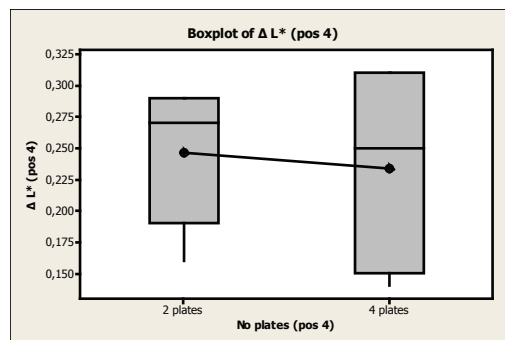


Two-Sample T-Test and CI: ΔL^* (pos 4); No plates (pos 4)

Two-sample T for ΔL^* (pos 4)

No plates (pos 4)				
	N	Mean	StDev	SE Mean
2 plates	5	0,2460	0,0559	0,025
4 plates	5	0,2340	0,0808	0,036

Difference = μ (2 plates) - μ (4 plates)
 Estimate for difference: 0,0120
 95% CI for difference: (-0,0919; 0,1159)
 T-Test of difference = 0 (vs not =): T-Value = 0,27
 P-Value = 0,793 DF = 7

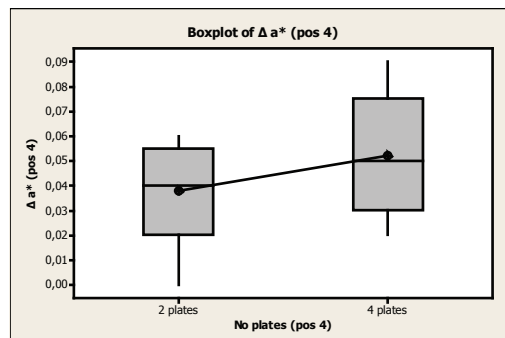


Two-Sample T-Test and CI: Δa^* (pos 4); No plates (pos 4)

Two-sample T for Δa^* (pos 4)

No plates (pos 4)				
	N	Mean	StDev	SE Mean
2 plates	5	0,0380	0,0228	0,010
4 plates	5	0,0520	0,0259	0,012

Difference = μ (2 plates) - μ (4 plates)
 Estimate for difference: -0,0140
 95% CI for difference: (-0,0505; 0,0225)
 T-Test of difference = 0 (vs not =): T-Value = -0,91
 P-Value = 0,394 DF = 7

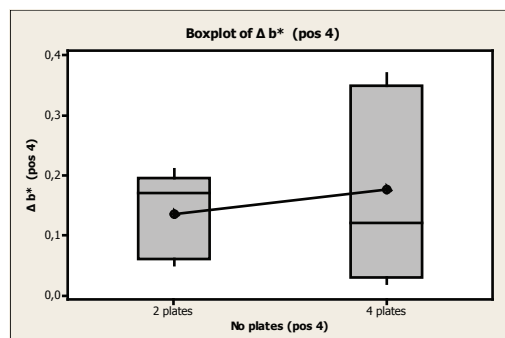


Two-Sample T-Test and CI: Δb^* (pos 4); No plates (pos 4)

Two-sample T for Δb^* (pos 4)

No plates (pos 4)				
	N	Mean	StDev	SE Mean
2 plates	5	0,1360	0,0713	0,032
4 plates	5	0,176	0,164	0,073

Difference = μ (2 plates) - μ (4 plates)
 Estimate for difference: -0,0400
 95% CI for difference: (-0,2454; 0,1654)
 T-Test of difference = 0 (vs not =): T-Value = -0,50
 P-Value = 0,638 DF = 5



Appendix XXII; Colour measurements of sheets along line A,B,C and D

Line B

pos. on hanger: 1			pos. on hanger: 2			pos. on hanger: 3			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0,25	0,07	0,13	0,11	0,06	-0,09	0,27	0,07	0,02	0,34	0,08	0,31
0,23	0,06	0,04	0,05	0,04	-0,21	0,23	0,04	-0,02	0,28	0,05	0,20
0,21	0,07	-0,03	0,18	0,03	-0,07	0,21	0,04	-0,09	0,28	0,04	0,17
0,15	0,03	-0,14	0,12	0,03	-0,13	0,18	0,03	-0,11	0,28	0,04	0,20
0,21	0,08	-0,06	0,18	0,03	-0,04	0,29	0,06	0,08	0,28	0,03	0,21
			0,22	0,05	0,01				0,28	0,04	0,22
			0,25	0,07	0,10				0,29	0,02	0,25
									0,31	0,05	0,30
									0,34	0,06	0,31

Line C

pos. on hanger: 1			pos. on hanger: 2			pos. on hanger: 3			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0,29	0,09	0,26	0,24	0,11	0,20	0,32	0,10	0,23	0,31	0,13	0,32
0,22	0,03	0,08	0,24	0,07	0,11	0,32	0,09	0,18	0,36	0,08	0,33
0,29	0,04	0,18	0,21	0,02	0,13	0,33	0,06	0,19	0,35	0,07	0,35
0,24	0,03	0,15	0,26	0,02	0,18	0,32	0,06	0,21	0,30	0,05	0,33
0,27	0,03	0,16	0,30	0,03	0,23	0,33	0,08	0,25	0,30	0,04	0,36

Line D

pos. on hanger: 1			pos. on hanger: 2			pos. on hanger: 3			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0,25	0,07	0,10	0,27	0,08	0,14	-0,04	0,01	-0,24	0,09	0,01	-0,01
0,18	0,08	-0,09	0,21	0,04	-0,02	0,08	0,04	-0,24	0,19	0,03	0,10
0,17	0,04	-0,08	0,26	0,06	0,03	0,20	0,05	-0,10	0,25	0,03	0,16
0,18	0,02	-0,02	-0,04	0,02	-0,33	0,22	0,06	0,08	0,24	0,03	0,16
0,28	0,05	0,21	0,13	0,02	-0,11	0,34	0,09	0,19	0,30	0,04	0,23
			0,27	0,05	0,10				0,33	0,05	0,30
			0,24	0,04	0,07				0,34	0,08	0,37
			0,30	0,04	0,13				0,34	0,08	0,37

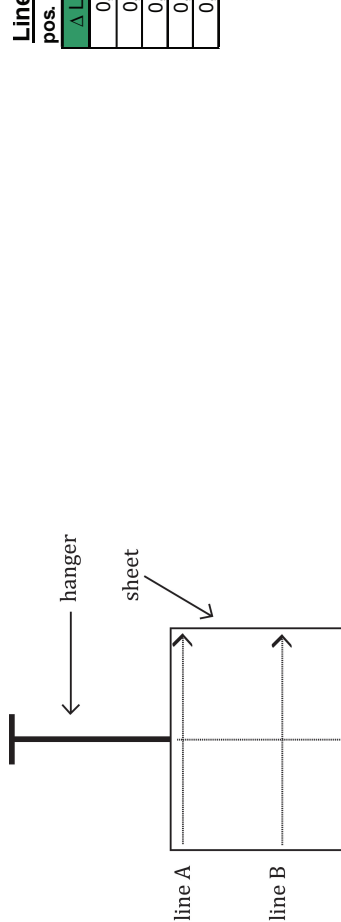


Figure XXII.1: The four different lines along which the colour has been measured.

• Measurement O

Date: 24/3 - 2011
 Time: approx. 13.15
 Batch/box.no: 201 96 42 - 3
 Component: top sheet

Test during normal operation;

* curing in the LPG furnace
 * "normal" thickness of varnish layer
 * material temperature $\approx 180^\circ\text{C}$
 * time in furnace ≈ 18 min

Line A

pos. on hanger: 1			pos. on hanger: 2			pos. on hanger: 3			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0,32	0,10	0,23	0,29	0,09	0,13	0,26	0,03	0,02	0,17	0,01	0,07
0,29	0,08	0,14	0,27	0,10	0,11	0,18	0,05	-0,08	0,07	0,01	-0,03
0,17	0,08	0,13	0,18	0,06	0,15	0,03	0,02	-0,20	0,09	0,00	0,08
0,26	0,07	0,03	0,30	0,10	0,15	0,22	0,07	0,04	0,15	0,02	0,08
0,31	0,07	0,08	0,31	0,10	0,17	0,29	0,06	0,11	0,29	0,07	0,26

● Measurement P

Date: 25/3 - 2011
 Time: approx. 08.50
 Batch/box.no: 201 96 42 - 3
 Component: top sheet

Test during normal operation;

* curing in the LPG furnace
 * "normal" thickness of varnish layer (TVL)

Line A

pos. on hanger: 2		pos. on hanger: 4	
ΔL^*	Δa^*	Δb^*	TVL (μm)
0.41	0.11	-0.03	90
0.33	0.12	-0.12	91
0.37	0.11	-0.04	104
0.40	0.12	-0.02	99
0.40	0.07	0.03	128

Line B

pos. on hanger: 2		pos. on hanger: 4	
ΔL^*	Δa^*	Δb^*	TVL (μm)
0.42	0.13	-0.02	99
0.27	0.07	-0.22	69
0.25	0.07	-0.23	76
0.35	0.06	-0.05	79
0.37	0.10	0.05	123

Line C

pos. on hanger: 2		pos. on hanger: 4	
ΔL^*	Δa^*	Δb^*	TVL (μm)
0.39	0.16	0.08	125
0.38	0.11	0.07	112
0.44	0.09	0.11	127
0.41	0.08	0.13	137
0.39	0.10	0.14	126

Line D

pos. on hanger: 2		pos. on hanger: 4	
ΔL^*	Δa^*	Δb^*	TVL (μm)
0.36	0.08	-0.02	94
0.36	0.08	-0.10	85
0.28	0.06	-0.18	75
0.30	0.05	0.34	76
0.42	0.09	0.07	113

● Measurement Q

Date: 25/3 - 2011
 Time: approx. 11.20
 Batch/box.no: 201 96 42 - 3
 Component: top sheet

Test after approx. 45 min conveyor stop;

* curing in the LPG furnace
 * "normal" thickness of varnish layer
 * material temperature $\approx 180^\circ\text{C}$
 * time in furnace ≈ 63 min

* These four sheets were placed on the same hanger during curing

Line A

pos. on hanger: 1		pos. on hanger: 2		pos. on hanger: 3		pos. on hanger: 4	
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*
-0.13	-0.13	2.30	-0.26	-0.17	2.56	-0.23	-0.19
-0.20	-0.15	2.24	-0.20	-0.17	2.46	-0.43	-0.26
-0.19	-0.17	2.23	-0.21	-0.17	2.37	-0.46	-0.25
-0.20	-0.15	2.30	-0.15	-0.14	2.41	-0.37	-0.23
-0.27	-0.12	2.58	-0.17	-0.11	2.48	-0.24	-0.17
					2.45	-0.15	-0.16
					2.30		

Line B

pos. on hanger: 1		pos. on hanger: 2		pos. on hanger: 3		pos. on hanger: 4	
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*
-0.19	-0.14	2.43	-0.21	-0.16	2.55	-0.23	-0.14
-0.30	-0.19	2.26	-0.20	-0.17	2.36	-0.22	-0.23
-0.23	-0.19	2.38	-0.32	-0.23	2.09	-0.21	-0.18
-0.24	-0.19	2.34	-0.33	-0.22	2.04	-0.20	-0.21
-0.28	-0.16	2.53	-0.23	-0.19	2.26	-0.24	-0.12
					2.51	-0.20	-0.15
					2.38		

Line C

pos. on hanger: 1		pos. on hanger: 2		pos. on hanger: 3		pos. on hanger: 4	
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*
-0.28	-0.14	2.78	-0.25	-0.15	2.50	-0.16	-0.09
-0.25	-0.16	2.71	-0.19	-0.15	2.42	-0.09	-0.13
-0.24	-0.17	2.73	-0.29	-0.17	2.37	-0.11	-0.12
-0.22	-0.19	2.66	-0.16	-0.18	2.37	-0.15	-0.16
-0.21	-0.17	2.62	-0.16	-0.14	2.42	-0.09	-0.11
					2.50	-0.22	-0.23
					2.59		

Line D

pos. on hanger: 1		pos. on hanger: 2		pos. on hanger: 3		pos. on hanger: 4	
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*
-0.19	-0.14	2.32	-0.24	-0.19	2.30	-0.37	-0.24
-0.20	-0.15	2.34	-0.24	-0.20	2.26	-0.41	-0.25
-0.22	-0.18	2.35	-0.29	-0.23	2.16	-0.20	-0.17
-0.30	-0.20	2.37	-0.29	-0.23	2.15	-0.11	-0.16
-0.23	-0.19	2.68	-0.27	-0.20	2.29	-0.10	-0.14
					2.26	-0.10	-0.14
					2.45		

• Measurement R

Date:	5/4 - 2011
Time:	approx. 8.55
Batch/box.no:	201 73 08 - 1
Component:	top sheet

Test during normal operation;

- * curing in the LPG furnace
- * "normal" thickness of varnish layer
- * material temperature $\approx 180^{\circ}\text{C}$
- * time in furnace ≈ 18 min

* The four hangers were placed directly after each other on the conveyor.

Hanger 3;

Line A

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.04	0.09	0.46	-0.12	0.06	0.33
-0.02	0.06	0.35	-0.31	-0.02	0.05
0.00	0.04	0.40	-0.30	0.00	0.10
-0.05	0.02	0.38	-0.16	0.01	0.21
-0.05	0.04	0.50	-0.03	0.07	0.57

Hanger 4;

Line A

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.00	0.11	0.49	-0.12	-0.02	0.35
-0.05	0.11	0.40	-0.27	0.00	0.14
-0.08	0.09	0.39	-0.43	-0.02	-0.09
0.00	0.09	0.39	-0.07	0.01	0.35
0.02	0.09	0.46	-0.07	0.09	0.62

Line B

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.06	0.08	0.43	-0.01	0.03	0.36
0.03	0.07	0.39	-0.18	0.01	0.14
0.01	0.05	0.41	-0.06	0.01	0.30
-0.02	0.03	0.34	-0.02	0.02	0.38
-0.15	0.07	0.49	-0.01	0.05	0.60

Line B

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.03	0.11	0.50	-0.05	0.03	0.40
-0.01	0.08	0.42	-0.06	-0.01	0.38
-0.01	0.05	0.45	-0.05	-0.01	0.41
-0.01	0.06	0.43	-0.01	0.00	0.50
-0.09	0.10	0.50	-0.11	0.01	0.68

Line C

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.01	0.10	0.54	-0.03	0.07	0.50
0.03	0.07	0.50	-0.05	0.02	0.39
0.02	0.08	0.50	-0.01	0.03	0.52
0.02	0.04	0.52	0.00	0.03	0.52
0.00	0.05	0.55	0.00	0.05	0.61

Line C

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
-0.02	0.14	0.57	0.04	0.05	0.54
0.02	0.08	0.56	0.04	0.02	0.56
0.04	0.06	0.58	0.02	0.00	0.65
0.03	0.09	0.60	0.01	-0.04	0.64
-0.06	0.14	0.63	-0.22	0.12	0.79

Line D

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
-0.04	0.06	0.36	-0.26	0.01	0.16
-0.01	0.04	0.34	-0.18	0.03	0.16
-0.01	0.05	0.40	-0.09	0.03	0.28
-0.06	0.01	0.32	-0.10	0.02	0.31
0.05	0.06	0.51	0.01	0.02	0.54

Line D

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
-0.08	0.08	0.37	-0.32	-0.02	0.04
-0.05	0.06	0.36	-0.17	0.00	0.19
-0.01	0.06	0.43	-0.03	-0.01	0.40
-0.06	0.06	0.37	-0.03	0.00	0.53
0.00	0.09	0.58	0.01	0.01	0.67

Hanger 1;

Line A

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.04	0.12	0.40	-0.06	0.05	0.48
0.00	0.06	0.24	-0.41	-0.06	0.11
0.01	0.05	0.28	-0.19	-0.01	0.33
0.06	0.05	0.33	-0.18	-0.02	0.30
-0.01	0.07	0.30	-0.03	0.05	0.54

Hanger 2;

Line A

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.04	0.07	0.44	-0.11	0.04	0.39
0.02	0.03	0.39	-0.33	-0.03	0.13
-0.02	0.02	0.39	-0.29	-0.05	0.29
0.04	0.04	0.38	-0.19	-0.04	0.36
0.03	0.04	0.43	-0.04	0.03	0.57

Line B

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.09	0.10	0.38	-0.01	0.03	0.47
0.03	0.06	0.36	-0.09	-0.01	0.45
0.02	0.05	0.34	-0.06	0.00	0.41
0.01	0.06	0.33	-0.05	-0.02	0.56
0.03	0.08	0.41	0.04	0.04	0.56

Line B

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.06	0.06	0.48	0.00	0.03	0.50
0.02	0.04	0.40	-0.04	0.01	0.46
0.00	0.03	0.38	-0.04	-0.01	0.54
0.00	-0.01	0.32	-0.05	-0.01	0.57
-0.01	0.06	0.46	-0.06	0.02	0.65

Line C

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.05	0.10	0.48	0.01	0.08	0.49
0.02	0.07	0.47	0.05	0.05	0.49
0.03	0.04	0.49	0.07	0.03	0.50
0.07	0.03	0.47	0.04	0.01	0.56
0.08	0.04	0.53	-0.04	0.08	0.56

Line C

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.03	0.10	0.53	0.00	0.06	0.61
0.05	0.05	0.48	0.01	0.04	0.63
0.04	0.04	0.49	0.02	0.03	0.70
0.05	0.01	0.52	0.00	0.00	0.73
0.01	0.02	0.54	-0.05	0.03	0.72

Line D

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
0.01	0.07	0.28	-0.20	-0.05	0.22
0.03	0.06	0.30	-0.12	-0.04	0.32
0.04	0.03	0.35	-0.07	-0.01	0.39
0.03	0.03	0.34	-0.03	-0.02	0.44
0.05	0.02	0.47	0.07	0.03	0.51

Line D

pos. on hanger: 2			pos. on hanger: 4		
ΔL^*	Δa^*	Δb^*	ΔL^*	Δa^*	Δb^*
-0.02	0.05	0.37	-0.41	-0.04	0.15
-0.01	0.04	0.34	-0.18	-0.04	0.33
-0.01	0.03	0.37	-0.06	0.00	0.51
0.00	0.02	0.37	-0.08	-0.01	0.50
0.05	0.04	0.49	0.00	0.01	0.66

Appendix XXIII; Analysis of data from measurements O-R

- ΔL^*

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.29	0.41	0.04	0.04	0.04	0.04	0.00	0.14	0.04	0.17	0.41
	0.27	0.33	0.00	0.02	0.02	0.02	-0.05	0.10	0.02	0.16	0.33
	0.18	0.37	0.01	-0.02	0.00	-0.08	0.08	0.01	0.17	0.37	-0.08
	0.30	0.40	0.06	0.04	0.05	0.02	0.14	0.06	0.17	0.4	0.00
right:	0.31	0.40	-0.01	0.03	-0.05	0.02	0.12	0.03	0.19	0.4	-0.05
	0.02	-0.01	-0.05	-0.01	-0.09	0.02					
	0.16	0.33	-0.01	-0.02	-0.05	-0.06					
	0.31	0.41	0.06	0.04	0.05	0.02					
	0.13	0.08	0.07	0.06	0.10	0.10					
diff. right-left	0.09										
min	0.09										
max	0.03										
mean diff.max-min	0.06										
st.dev. diff.max-min	0.13										
min diff.max-min	0.13										
max diff.max-min	28.11										
RSD; diff.max-min (%)											

Pos.2, line A

diff. right-left
min
max
mean diff.max-min
st.dev. diff.max-min
min diff.max-min
max diff.max-min
RSD; diff.max-min (%)

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.11	0.42	0.09	0.06	0.06	0.03	0.13	0.08	0.15	0.42	0.03
	0.13	0.27	0.03	0.02	0.03	-0.01	0.08	0.03	0.11	0.27	-0.01
	0.12	0.25	0.02	0.00	0.01	-0.01	0.07	0.02	0.10	0.25	-0.01
	0.20	0.35	0.01	0.00	-0.02	-0.01	0.09	0.01	0.15	0.35	-0.02
right:	0.25	0.37	0.03	-0.01	-0.15	-0.09	0.07	0.01	0.20	0.37	-0.15
	0.14	-0.05	-0.06	-0.07	-0.21	-0.12					
	0.11	0.25	0.01	-0.01	-0.15	-0.09					
	0.25	0.42	0.09	0.06	0.06	0.03					
	0.14	0.17	0.08	0.07	0.21	0.12					
diff. right-left	0.13										
min	0.13										
max	0.06										
mean diff.max-min	0.07										
st.dev. diff.max-min	0.21										
min diff.max-min	40.59										
max diff.max-min											
RSD; diff.max-min (%)											

Pos.2, line B

diff. right-left
min
max
mean diff.max-min
st.dev. diff.max-min
min diff.max-min
max diff.max-min
RSD; diff.max-min (%)

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.24	0.39	0.05	0.03	0.01	-0.02	0.12	0.04	0.16	0.39	-0.02
	0.24	0.38	0.02	0.05	0.03	0.02	0.12	0.04	0.15	0.38	0.02
	0.21	0.44	0.03	0.04	0.02	0.04	0.13	0.04	0.17	0.44	0.02
	0.26	0.41	0.07	0.05	0.02	0.03	0.14	0.06	0.16	0.41	0.02
right:	0.30	0.39	0.08	0.01	0.00	-0.06	0.12	0.05	0.18	0.39	-0.06
	0.06	0.00	0.03	-0.02	-0.01	-0.04					
	0.21	0.38	0.02	0.01	0.00	-0.06					
	0.30	0.44	0.08	0.05	0.03	0.04					
	0.06	0.06	0.06	0.04	0.03	0.10					
diff. right-left	0.06										
min	0.06										
max	0.03										
mean diff.max-min	0.03										
st.dev. diff.max-min	0.10										
min diff.max-min	43.15										
max diff.max-min											
RSD; diff.max-min (%)											

Pos.2, line C

diff. right-left
min
max
mean diff.max-min
st.dev. diff.max-min
min diff.max-min
max diff.max-min
RSD; diff.max-min (%)

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
top:	0.27	0.36	0.01	-0.02	-0.04	-0.08	0.08	-0.01	0.18	0.36	-0.08
	0.26	0.36	0.03	-0.01	-0.01	-0.05	0.10	0.01	0.17	0.36	-0.05
	0.05	0.28	0.04	-0.01	-0.01	-0.01	0.06	0.02	0.11	0.28	-0.01
	0.27	0.30	0.03	0.00	-0.06	-0.06	0.08	0.02	0.16	0.3	-0.06
bottom:	0.30	0.42	0.05	0.05	0.05	0.00	0.15	0.05	0.17	0.42	0.00
	0.03	0.06	0.04	0.07	0.09	0.08					
	0.05	0.28	0.01	-0.02	-0.06	-0.08					
	0.30	0.42	0.05	0.05	0.05	0.00					
	0.25	0.14	0.04	0.07	0.11	0.08					
diff. right-left	0.12										
min	0.12										
max	0.07										
mean diff.max-min	0.04										
st.dev. diff.max-min	0.25										
min diff.max-min	64.78										
max diff.max-min											
RSD; diff.max-min (%)											

Pos.2, line D

diff. right-left
min
max
mean diff.max-min
st.dev. diff.max-min
min diff.max-min
max diff.max-min
RSD; diff.max-min (%)

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.17	0.37	-0.06	-0.11	-0.12	-0.12	0.02	-0.09	0.20	0.37	-0.12
	0.07	0.29	-0.41	-0.33	-0.31	-0.27	-0.16	-0.29	0.28	0.29	-0.41
	0.09	0.29	-0.19	-0.28	-0.30	-0.43	-0.14	-0.24	0.27	0.29	-0.43
	0.15	0.35	-0.18	-0.19	-0.16	-0.07	-0.02	-0.12	0.22	0.35	-0.19
right:	0.29	0.24	-0.03	-0.04	-0.03	-0.07	0.06	-0.03	0.16	0.29	-0.07
	0.12	-0.13	0.03	0.07	0.09	0.05					
	0.07	0.24	-0.41	-0.33	-0.31	-0.43					
	0.29	0.37	-0.03	-0.04	-0.03	-0.07					
	0.22	0.13	0.38	0.29	0.28	0.36					
diff. right-left	0.28										
min	0.28										
max	0.09										
mean diff.max-min	0.13										
st.dev. diff.max-min	0.38										
min diff.max-min	33.34										
max diff.max-min											
RSD; diff.max-min (%)											

Pos.4, line A

diff. right-left
min
max
mean diff.max-min
st.dev. diff.max-min
min diff.max-min
max diff.max-min
RSD; diff.max-min (%)

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.34	0.39	-0.01	0.00	-0.01	-0.05	0.11	-0.01	0.20	0.39	-0.05
	0.28	0.20	-0.09	-0.04	-0.18	-0.06	0.02	-0.05	0.18	0.28	-0.18
	0.28	0.18	-0.06	-0.04	-0.06	-0.05	0.04	-0.05	0.15	0.28	-0.06
	0.29	-0.03	-0.05	-0.05	-0.02	-0.01	0.02	-0.03	0.13	0.29	-0.05
right:	0.34	0.01	0.04	-0.06	-0.01	-0.11	0.04	0.00	0.16	0.34	-0.11
	0.00	0.38	0.05	-0.06	0.00	-0.06					
	0.26	-0.03	-0.09	-0.06	-0.18	-0.11					
	0.34	0.39	0.04	0.00	-0.01	-0.01					
	0.06	0.42	0.13	0.06	0.17	0.10					
diff. right-left	0.16										
min	0.16										
max	0.14										
mean diff.max-min	0.06										
st.dev. diff.max-min	0.42										
min diff.max-min	86.85										
max diff.max-min											
RSD; diff.max-min (%)											

Pos.4, line B

diff. right-left
min
max
mean diff.max-min
st.dev. diff.max-min
min diff.max-min
max diff.max-min
RSD; diff.max-min (%)

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.31	0.43	0.01	0.00	-0.03	0.04	0.13	0.03	0.19	0.43	-0.03
	0.36	0.43	0.05	0.01	-0.05	0.04	0.14	0.05	0.20	0.43	-0.05
	0.35	0.40	0.07	0.02	0.01	0.02	0.15	0.05	0.18	0.4	0.01
	0.30	0.18	0.04	0.00	0.00	0.01	0.09	0.03	0.12	0.3	0.00
right:	0.30	0.28	-0.04	-0.05	0.00	-0.22	0.05	-0.02	0.20	0.3	-0.22
	-0.01	-0.15	-0.05	-0.05	0.03	-0.26					
	0.30	0.18	-0.04	-0.05</							

- Δa*

Pos.2, line A

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.09	0.11	0.12	0.07	0.09	0.11	0.10	0.10	0.02	0.12	0.07
	0.10	0.12	0.06	0.03	0.06	0.11	0.08	0.08	0.04	0.12	0.03
	0.06	0.11	0.05	0.02	0.04	0.09	0.06	0.06	0.03	0.11	0.02
	0.10	0.12	0.05	0.04	0.02	0.09	0.07	0.07	0.04	0.12	0.02
right:	0.10	0.07	0.07	0.04	0.04	0.09	0.07	0.07	0.02	0.12	0.04
	0.01	-0.04	-0.05	-0.03	-0.05	-0.02					
	0.06	0.07	0.05	0.02	0.02	0.09					
	0.10	0.12	0.12	0.07	0.09	0.11					
	0.05	0.05	0.07	0.05	0.07	0.02					
diff. right-left	0.05	0.05	0.05	0.05	0.05	0.05					
min	0.06	0.07	0.05	0.02	0.02	0.09					
max	0.10	0.12	0.12	0.07	0.09	0.11					
diff. max-min	0.04	0.05	0.07	0.05	0.07	0.02					
mean diff.max-min	0.06	0.07	0.05	0.02	0.02	0.09					
median diff.max-min	0.05	0.05	0.07	0.05	0.07	0.02					
st.dev. diff.max-min	0.02	0.02	0.02	0.02	0.02	0.02					
min diff.max-min	0.02	0.02	0.02	0.02	0.02	0.02					
max diff.max-min	0.07	0.07	0.07	0.07	0.07	0.07					
RSD; diff.max-min (%)	37.95										

Pos.4, line A

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.01	0.12	0.05	0.04	0.06	0.02	0.05	0.05	0.04	0.12	0.01
	0.04	0.08	-0.06	-0.03	-0.02	0.00	0.00	-0.01	0.05	0.08	-0.06
	0.00	0.07	-0.01	-0.05	0.00	-0.02	0.00	-0.01	0.04	0.07	-0.05
	0.02	0.06	-0.02	-0.04	0.01	0.01	0.01	0.01	0.03	0.06	-0.04
right:	0.07	0.08	0.05	0.03	0.07	0.09	0.06	0.07	0.02	0.09	0.03
	0.06	-0.06	0.00	-0.01	0.01	0.07					
	0.00	0.06	-0.06	-0.05	-0.02	-0.09					
	0.07	0.12	0.05	0.04	0.07	0.09					
	0.07	0.06	0.11	0.09	0.09	0.11					
diff. right-left	0.09	0.09	0.09	0.09	0.09	0.09					
min	0.00	0.06	-0.06	-0.05	-0.02	-0.09					
max	0.07	0.12	0.05	0.04	0.07	0.09					
diff. max-min	0.07	0.06	0.11	0.09	0.09	0.11					
mean diff.max-min	0.06	0.07	0.05	0.03	0.07	0.09					
median diff.max-min	0.05	0.05	0.07	0.05	0.07	0.02					
st.dev. diff.max-min	0.02	0.02	0.02	0.02	0.02	0.02					
min diff.max-min	0.02	0.02	0.02	0.02	0.02	0.02					
max diff.max-min	0.11	0.11	0.11	0.11	0.11	0.11					
RSD; diff.max-min (%)	23.11										

Pos.2, line B

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.06	0.13	0.10	0.06	0.08	0.11	0.09	0.09	0.03	0.13	0.06
	0.04	0.07	0.06	0.04	0.07	0.08	0.06	0.07	0.02	0.08	0.04
	0.03	0.07	0.05	0.03	0.05	0.05	0.05	0.05	0.02	0.07	0.03
	0.05	0.06	0.06	-0.01	0.03	0.06	0.04	0.06	0.03	0.06	-0.01
right:	0.07	0.10	0.08	0.06	0.07	0.10	0.08	0.08	0.02	0.1	0.06
	0.01	-0.03	-0.02	0.00	-0.01	-0.01					
	0.03	0.06	0.05	-0.01	0.03	0.05					
	0.07	0.13	0.10	0.06	0.06	0.11					
	0.04	0.07	0.05	0.07	0.05	0.06					
diff. right-left	0.06	0.06	0.06	0.06	0.06	0.06					
min	0.03	0.06	0.05	-0.01	0.03	0.05					
max	0.07	0.13	0.10	0.06	0.06	0.11					
diff. max-min	0.04	0.07	0.05	0.07	0.05	0.06					
mean diff.max-min	0.06	0.06	0.06	0.06	0.06	0.06					
median diff.max-min	0.06	0.06	0.06	0.06	0.06	0.06					
st.dev. diff.max-min	0.01	0.01	0.01	0.01	0.01	0.01					
min diff.max-min	0.04	0.04	0.04	0.04	0.04	0.04					
max diff.max-min	0.12	0.12	0.12	0.12	0.12	0.12					
RSD; diff.max-min (%)	21.37										

Pos.2, line C

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.11	0.16	0.10	0.10	0.10	0.14	0.12	0.11	0.03	0.16	0.10
	0.07	0.11	0.07	0.05	0.07	0.08	0.06	0.06	0.07	0.11	0.05
	0.02	0.09	0.04	0.04	0.08	0.06	0.06	0.05	0.03	0.09	0.02
	0.02	0.08	0.03	0.01	0.04	0.09	0.05	0.04	0.03	0.09	0.01
right:	0.03	0.10	0.04	0.02	0.05	0.14	0.06	0.05	0.05	0.14	0.02
	-0.08	-0.06	-0.06	-0.08	-0.05	0.09					
	0.02	0.08	0.03	0.01	0.04	0.06					
	0.11	0.16	0.10	0.10	0.10	0.14					
	0.09	0.08	0.07	0.09	0.06	0.06					
diff. right-left	0.08	0.08	0.08	0.08	0.08	0.08					
min	0.02	0.08	0.03	0.01	0.04	0.06					
max	0.11	0.16	0.10	0.10	0.10	0.14					
diff. max-min	0.09	0.08	0.07	0.09	0.06	0.06					
mean diff.max-min	0.08	0.08	0.08	0.08	0.08	0.08					
median diff.max-min	0.08	0.08	0.08	0.08	0.08	0.08					
st.dev. diff.max-min	0.01	0.01	0.01	0.01	0.01	0.01					
min diff.max-min	0.06	0.06	0.06	0.06	0.06	0.06					
max diff.max-min	0.16	0.16	0.16	0.16	0.16	0.16					
RSD; diff.max-min (%)	14.92										

Pos.2, line D

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
top:	0.08	0.08	0.07	0.05	0.06	0.08	0.07	0.08	0.01	0.08	0.05
	0.06	0.08	0.06	0.04	0.04	0.06	0.06	0.06	0.02	0.08	0.04
	0.02	0.06	0.03	0.03	0.05	0.06	0.04	0.04	0.02	0.06	0.02
	0.05	0.05	0.03	0.02	0.01	0.06	0.04	0.04	0.02	0.06	0.01
bottom:	0.04	0.08	0.02	0.04	0.06	0.09	0.06	0.05	0.03	0.09	0.02
	-0.04	0.01	-0.05	-0.01	0.00	0.01					
	0.02	0.05	0.02	0.02	0.01	0.06					
	0.08	0.09	0.07	0.05	0.06	0.09					
	0.06	0.04	0.05	0.03	0.05	0.05					
diff. right-left	0.04	0.04	0.04	0.04	0.04	0.04					
min	0.02	0.05	0.02	0.02	0.01	0.06					
max	0.08	0.09	0.07	0.05	0.06	0.09					
diff. max-min	0.06	0.04	0.05	0.03	0.05	0.05					
mean diff.max-min	0.04	0.04	0.04	0.04	0.04	0.04					
median diff.max-min	0.04	0.04	0.04	0.04	0.04	0.04					
st.dev. diff.max-min	0.01	0.01	0.01	0.01	0.01	0.01					
min diff.max-min	0.02	0.02	0.02	0.02	0.02	0.02					
max diff.max-min	0.08	0.08	0.08	0.08	0.08	0.08					
RSD; diff.max-min (%)	27.95										

Pos.4, line C

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	median	st.dev.	max	min
left:	0.13	0.14	0.08	0.06	0.07	0.05	0.09	0.08	0.04	0.14	0.05
	0.08	0.10	0.05	0.04	0.02	0.02	0.05	0.05	0.03	0.1	0.02
	0.07	0.09	0.03	0.03	0.03	0.00	0.04	0.03	0.03	0.09	0.00
	0.05	0.04	0.01	0.00	0.03	-0.04	0.02	0.02	0.03	0.05	-0.04
right:	0.04	0.05	0.08	0.03	0.05	0.12	0.06	0.05	0.03	0.12	0.03
	-0.09	-0.09	0.00	-0.03	-0.02	0.07					
	0.04	0.04	0.01	0.00	0.02	-0.04					
	0.13	0.14	0.08	0.06	0.07	0.12					
	0.09	0.10	0.07	0.06	0.05	0.16					
diff. right-left	0.09	0.09	0.09	0.09	0.09	0.09					
min	0.04	0.04	0.01	0.00	0.02</						

Appendix XXIV; Illustrations of colour measurements along line A,B,C and D (normal operation)

- Δb^* from position 2

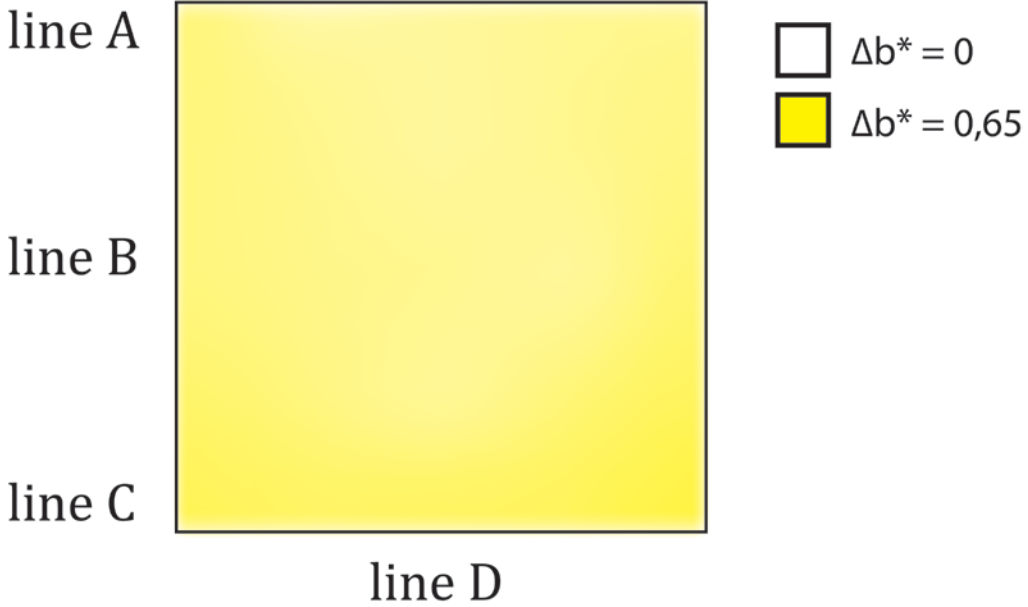


Figure XXIV.1: Schematic illustration of how Δb^* varies along the sheet on position 2 of a hanger.

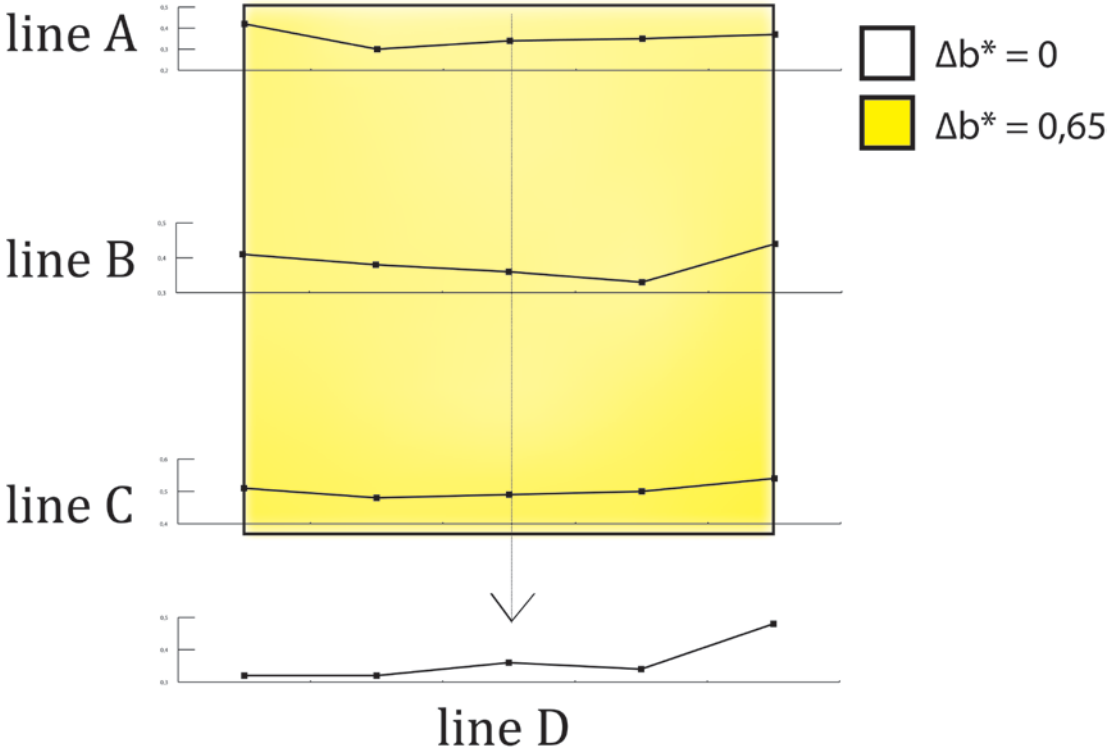


Figure XXIV.2: Schematic illustration of how Δb^* varies along the sheet on position 2 of a hanger. Graphs are included to elucidate the colour gradient along the lines of measurement.

- Δb^* from position 4

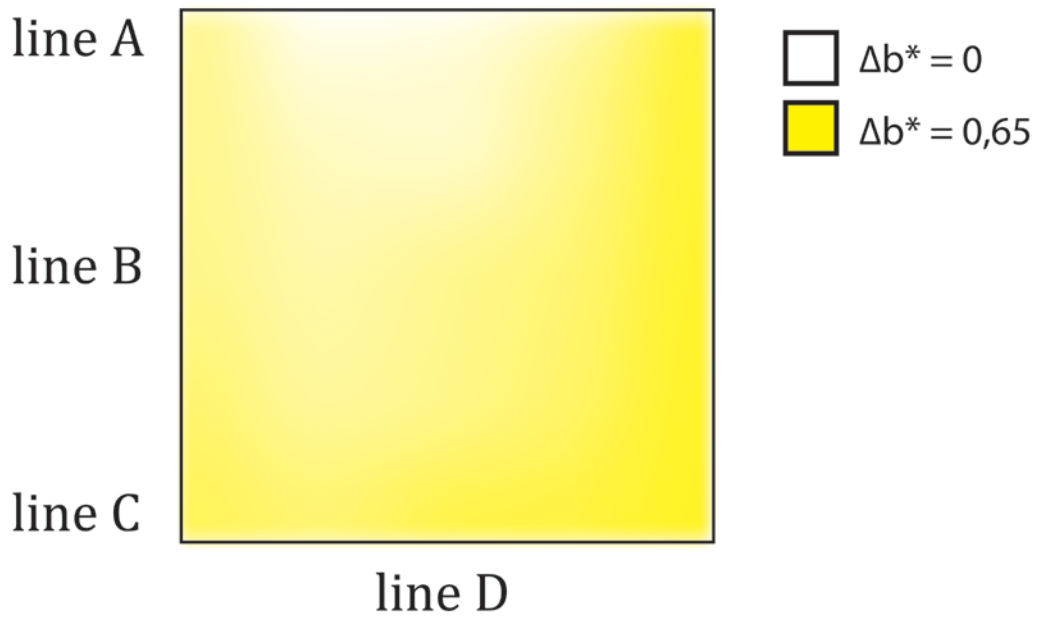


Figure XXIV.3: Schematic illustration of how Δb^* varies along the sheet on position 4 of a hanger.

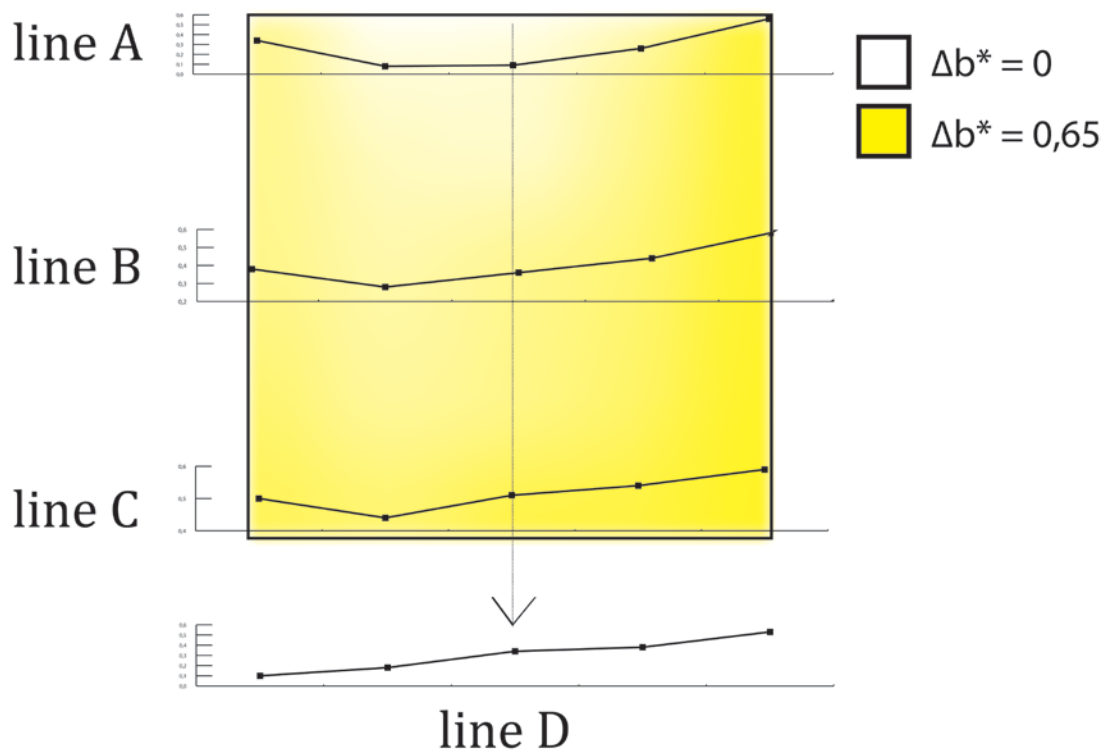


Figure XXIV.4: Schematic illustration of how Δb^* varies along the sheet on position 4 of a hanger. Graphs are included to elucidate the colour gradient along the lines of measurement.