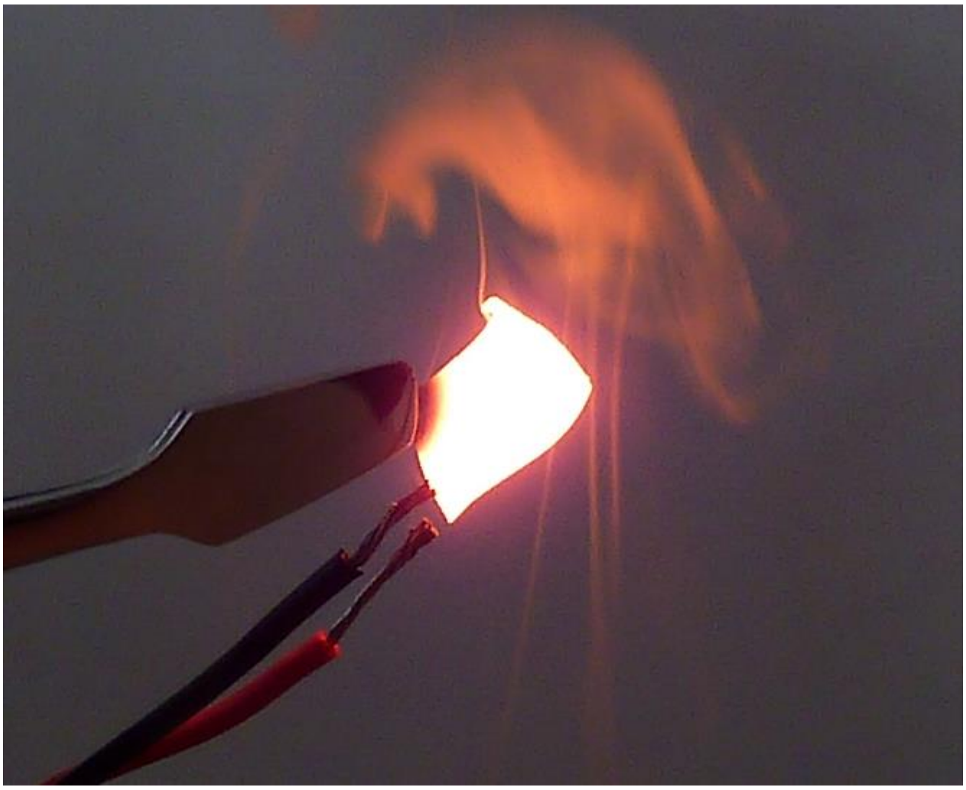


Nanomaterials in Design

Development of concepts based on nanomaterials in SAAB Electronic Defence Systems products

Master of Science Thesis

Eric Bjärkvik

Fredrik Franzén

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2012

MASTER'S THESIS

Nanomaterials in design

Master's Thesis in the Master's programme Materials Engineering and the Master's programme Product Development

Eric Bjärkvik

Fredrik Franzén

Department of Product and Production Development

CHALMERS UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden 2012

Nanomaterials in design

Master's Thesis in the Master's programme Materials Engineering and the Master's programme Product Development
ERIC BJÄRKVIK
FREDRIK FRANZÉN

Master's Thesis
Department of Product and Production Development
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
Exothermal reaction of activated nanofoil.

Göteborg, Sweden 2012

Abstract

This Master's Thesis project was to, within the timeframe of 20 weeks, develop concepts matching with SAAB EDS products, utilizing and implementing the properties of nanomaterials. To evaluate these concepts each should be defined in detail with respect to the theory, application, material and how the concept's main properties could be verified. Apart from the concept development process, another purpose of this project was to increase the awareness of nanomaterials within the company.

In the beginning, a vast literature study was carried out, along with a workshop, sharing the gained knowledge with employees at SAAB EDS and discussing possible applications to be matched with the material properties found. This resulted in many promising concepts, yet, after several elimination processes nine concepts were chosen to be fully developed. Among these nine, four proved to have high implementation potential, three required further research and two were not recommended for implementation.

The concepts with high implementation potential were recommended based on several factors all focusing on value creation for SAAB EDS.

Two concepts focus on the air quality inside lasers. In one case, a dense nanocoating is applied on outgassing polymers to contain gas compounds from reaching the atmosphere. The other concept is based on tailor made nano porous zeolites that adsorbs non desirable gas compounds inside lasers.

Furthermore, the material properties of an erosion resistant nanostructured polymer coating were suggested for usage on rain erosion exposed components.

A highly thermal conductive material to be implemented in a heat sink application, was labelled as a concept that requires further research because the material is not commercially available yet. However, a numerical thermal analysis was carried out, proving that a replacement of the materials in the heat sink would contribute to a weight reduction of 50%.

For further support in the decision making process, the properties of two concepts were chosen to be evaluated through testing. One of them also considered having a high implementation potential and regards an alternative joining method of aluminium. The concept is based on a nanofoil with nano-thin layers of aluminium and nickel and reacts exothermally when activated. It was physically verified in lab by analysing the strength, electrical and microstructural properties of a joint made with this joining nanofoil. As a result, it was concluded that the joint might not be a supplement for welding but could have beneficial properties compared to conducting glues, since the joint proved to be highly conductive and sufficient in strength.

Even though this project has addressed many applications, fact is, the nanomaterial research is an ongoing process where new materials emerge every day. Thus, it was concluded that SAAB EDS should continue to explore this area, not least because of the limitless application areas and properties of nanomaterials.

Sammanfattning

Detta examensarbete hade som målsättning att, inom 20 veckor, utveckla koncept som matchas med SAAB EDS produkter genom att utnyttja nanomaterialegenskaper. För att utvärdera dessa ska varje koncept vara väl definierat med avseende på teori, applikation, material och hur huvudegenskaperna skulle kunna verifieras. Förutom utvecklingen av nya koncept, syftar projektet även till att öka kunskapen bland företagets anställda kring nanomaterial och dess egenskaper och applikationsområden.

I början genomfördes en grundlig litteraturstudie, följt av en workshop där de samlade kunskaperna inom nanomaterialsområdet delades med till anställda på SAAB EDS samt för att diskutera möjliga applikationer för de funna materialegenskaperna. Detta resulterade i många lovande koncept som efter flertalet elimineringsprocesser reducerades till nio fullt utvecklade koncept. Utav dessa nio konstaterades att fyra har hög potential att bli implementerade, tre kräver ytterligare forskning och två rekommenderas inte att för implementering.

Koncepten med hög potential för implementering rekommenderades baserat på flertalet faktorer med fokus på värdet för SAAB EDS, däribland applikationen i en existerande produkt och materialegenskaper. Följaktligen handlar applikationen för två av koncepten om att förbättra luftkvalitén i en laser genom olika metoder. I ena fallet, används egenskaperna hos en tät nanobeläggning på polymerer som innesluter och förhindrar gas från att läka ut i luften medan det andra konceptet istället adsorberar de utgasade ämnena i luften med specialanpassade nanoporösa zeoliter. Vidare föreslås användandet av egenskaperna hos en nanostrukturerad polymerbeläggning som skydd mot regnerosion på utsatta komponenter.

Som ytterliggare hjälp i utvärderingsprocessen, valdes att verifiera huvudegenskaperna hos två koncept. En av dessa, också ansedd som ett koncept med hög potential till implementering, utgörs av en alternativ fogningsmetod för aluminiumdelar, genom en exoterm reaktion av en tunn nanofolie med lager av aluminium och nickel. I utvärderingen analyserades mekaniska, elektriska och mikrostrukturella egenskaper av en fog skapad med fogningsmetoden. Trots goda testresultat konstaterades att metoden inte tros kunna ersätta svetsning men skulle kunna ha fördelaktiga egenskaper jämfört med ledande limmer, eftersom fogen visade på goda elektriska egenskaper och tillräckliga mekaniska egenskaper.

Det andra konceptet, ansett som ett koncept som kräver ytterliggare forskning eftersom det inte finns tillgängligt på marknaden än, utvärderades som implementering i en kylsänka p.g.a. sin goda termiska ledningsförmåga. En numerisk termisk analys, gav en viktreduktion av köldsänkan på 50% om materialet ersattes med det nya.

Trots att detta projekt har uppmärksammat många applikationer, så är det ett faktum att nanomaterialsforskningen är i ständig utveckling. Därför konstaterades det att SAAB EDS bör fortsätta utforskningen av detta område, inte minst med tanke på nanomaterialens outtömliga applikationsmöjligheter och egenskaper.

Acknowledgements

As a result of this project, application areas of nanomaterials at SAAB Electronic Defence Systems have been identified and new concepts developed. The work was carried out at SAAB EDS office in Lackarebäck during the spring semester from January to June 2012.

The thesis project was registered at the Department of Product and Production Development, Chalmers University of Technology, Sweden.

For all support and help during the project we would like to thank the following persons:

Elin Dornerus, our supervisor at SAAB EDS who has provided us with product information, discussions on project direction, contacts to other employees with specific product experience, expertise during the test phase in the lab and feedback on the written report. Furthermore, Jan Ryden, Lena Kull, Torbjörn Nilsson, Stefan Brunzell, Jan Lindahl, Thomas Green and Anna Lindgren contributed with information, knowledge and a good discussion on the present products of SAAB EDS as participants at the workshop. We also received useful feedback on the work progress from our examiner Dr Göran Brännare at Chalmers, who always helped us through regular meetings.

Finally, we would like to thank all colleagues who have made the work very enjoyable.

Göteborg, June 2012

Eric Bjärkvik

Fredrik Franzén

Table of contents

Notations

The following notations are used in this paper and apply unless not stated otherwise. Some of the terminologies have different meanings depending on where they are addressed in the report.

Terminology

C_0	Acoustic velocity [m/s]
Å	Ångström [10^{-10} m]
ρ	Density [kg/m^3]
P	Emitted power [W] or Load [kg]
W	Energy [J]
F	Force [N]
f	Frequency [Hz] or Friction coefficient
C_p	Heat capacity [J/K]
$\vec{q}$	Heat flux [W/m2]
m	Mass [kg]
x_i	Mole fraction [%]
ε	Normal strain [%] or Emissivity
p_i	Partial pressure [N/m^2]
G	Shear modulus [Pa]
γ	Shear strain [%]
τ	Shear stress [Pa]
C	Shock velocity [m/s]
A	Surface area [m^2] or Cross-sectional area [m^2]
T	Temperature [°C]
∇T	Temperature gradient
σ	Tensile stress [Pa] or Stefan–Boltzmann constant [W/(m^2·K^4)]
p	Total pressure [N/m^2]
λ	Wave length [m]
v	Wave propagation speed [m/s] or Impact velocity [m/s]
E	Young's modulus of elasticity [Pa]

Units

cSt	CentiStokes
wt%	Weight Percent

Abbreviations

AEW&C	Airborne Early Warning & Control
AFM	Atomic Force Microscopy
AMB	Agile Multi-Beam
APL	Antenna Plate
ASTM	American Society for Testing and Materials
BVR	Beyond Visual Range
CFRP	Carbon Fibre Reinforced Polymer
CHT	Critical Heat Transfer
CNT	Carbon Nano Tube
CNTRP	Carbon Nano Tube Reinforced Polymer
DOU	Dorsal Unit
EMC	Electromagnetic Compatibility

FEM	Finite Element Method
FSS	Frequency Selective Surface
FTIR	Fourier Transform Infrared Spectroscopy
IFF	Identification Friend or Foe
ISO	International Organization for Standardization
MLG	Multilayered Graphene
MWCNT	Multi Walled Carbon Nano Tube
NBC	Nuclear, Biological, Chemical
PET	Polyethylene Terephthalate
PVC	Polyvinyl Chloride
RMNF	Reactive Multilayered Nano Foil
RPM	Revolutions Per Minute
SEM	Scanning Electron Microscopy
SAE	Society of Automotive Engineers
SPM	Scanning Probe Microscopy
STM	Scanning Tunnelling Microscopy
SWCNT	Single Walled Carbon Nano Tube
TAS	True Air Speed
TEM	Transmission Electron Microscopy
TWT	Travelling Wave Tube
VOC	Volatile Organic Compound
WLR	Weapon Locating Radar
WLS	Weapon Locating System
XRD	X-Ray Diffraction

1 Introduction

This Master thesis covers the process from initiation to final delivery of a few concepts, based on the implementation of nanomaterials in the design of SAAB Electronic Defense Systems products.

1.1 Background

The history of SAAB AB Corporation reaches all the way back to 1937, when the company was founded. Initially, the main focus was to establish a domestic military aircraft industry, which still is one of the company's essential areas, delivering military equipment to almost the whole global defence industry. With around 13,000 employees divided into the five business areas Aeronautics, Dynamics, Electronic Defence Systems, Security and Defence Solutions and Support and Services, the company reaches annual sales of about SEK 24 billion. (SAAB Group, 2012)

As new nanomaterials are rapidly developing and many applications exist, mainly within fields such as medicine, communication, consumer goods and engineering, SAAB EDS wants to identify what special properties this fairly new material group can offer. All engineering materials based on nanotechnology, involving the understanding of physical properties and how they change with material dimensions, are to be considered alternatives in existing products. Especially, with decreasing prices and refined manufacturing processes, nanomaterials represent a possible alternative for a broader range of applications, outperforming many of today's engineering materials.

1.2 Aim

This project is to, within the timeframe, deliver a few carefully engineered concepts that improve SAAB EDS products through the application of nanoscience. The final concepts should prove to have at least a few improved properties compared to existing products. To the extent possible, the results of the modifications will be verified through tests or analytical methods. Furthermore, the project should increase the awareness of nanomaterials within SAAB EDS and distribute the gained knowledge.

1.3 Purpose

As all companies need to continue the development of their products to stay competitive on the market, so does SAAB EDS. Especially, since their radar systems have been around a long time, they have to find new ways to improve the performance of their products. Thus, nanomaterials are interesting, considering the vast amount of available or developing applications and solutions emerging.

1.4 Boundaries

Since the topic of this project is nanomaterials, all concerned materials should relate to nanoscience. Still, the field of nanoscience is constantly developing, which is why only present nanotechnologies will be investigated and no research to develop new nanomaterials will be performed. The project is delimited to look on only SAAB EDS existing products. But due to the fact that their product portfolio is quite extensive, the main focus will concern mechanical and surface properties, although keeping other options in mind.

2 Method

Even though this project was not focused on one particular product, the work approach comes close to a general product development process. To provide a guideline for the project a so-called "development funnel" was used, see Figure 1. This model helped to narrow down the many ideas represented by the circles to only a few promising concepts in the end. The overall execution of the project will be described in the following sub-chapters.

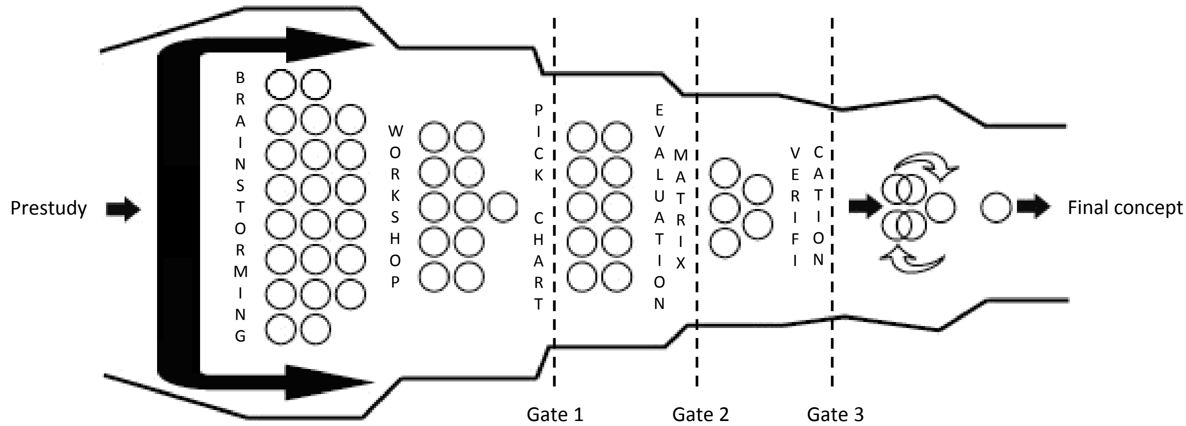


Figure 1 - The "Development funnel".

2.1 Planning phase

At project initiation, a project plan was created along with a Gantt chart, a weekly schedule with a list of tasks to be carried out during the course of the project, which enabled a better overview of the project outline and easier dividing of the work, see Appendix A. However, this plan was continuously updated throughout the progress of the project and made sure, at an early stage, not to miss out on important steps in the development process.

2.2 Literature study

To create a better understanding and knowledge about nanomaterials, the planning phase was followed by an extensive literature study, as part of the prestudy seen in Figure 1. This provided insight to the different applications available today, what kind of nanomaterials exists and what might be developed in the near future. Most of the information was derived from articles and books found at the Chalmers library literature database, choosing search criteria to cover the area of nanomaterials used in engineering applications. Additional information was gathered through meetings with employees at the Materials department at Chalmers University. All information was summarized to give a good overview of the present state of nanotechnology. Furthermore, the team also attended a doctoral dissertation on the subject of carbon nano tubes and a nanotechnology exhibition called Nano Update, providing the possibility to share ideas and get inspired by others working within nanoscience.

2.3 Product analysis

During this phase, also part of the prestudy, see Figure 1, carried out in parallel with the literature study, SAAB EDS products were studied and categorized. As for the literature study, the gathered product information from different sources was compiled to provide an overview of the concerned products and related components. The product database at the company, interviews with employees and guided tours of the manufacturing and assembly facilities, were all sources, used to find possible improvements in SAAB EDS products.

2.4 Brainstorming

With support from the literature study and the product analysis, ideas were generated, represented as circles in the development funnel, see Figure 1. These ideas were written down continuously without any restrictions to plausibility, cost or implementation timeframe, thinking wide and not dismissing any ideas. To further increase the idea generation, meetings were held to discuss ideas and come up with new ones.

2.4.1 Workshop

While the product analysis and brainstorming sessions resulted in some ideas for nanomaterial applications, it was realised that the project needed to get access to the explicit knowledge possessed by the employees, regarding the company's products. Due to their specific design responsibilities, in some cases spanning over many years of experience, they know where problems exist and improvements are needed, which can not be obtained in a few weeks of research. Therefore, eight employees from different departments were invited to participate in a well-planned two-hour workshop on the field of nanomaterials. To make sure not to miss out on important product fields, the participants were selected carefully in collaboration with the project supervisor at SAAB EDS. Employees from the mechanical department, working with design and strength analysis of the products including ARTHUR WLS, GIRAFFE AMB, ERIEYE and JAS, were chosen as well as people involved in material selection, thermal analysis and protective coatings.

The actual workshop was commenced by a presentation on the present state of relevant nanomaterials available on the market and their applications; information derived from the initial literature study. Some predefined, early thoughts on possible applications of nanomaterials for SAAB EDS products were also shared, in order to trigger the idea generation and develop the right mindset of the participants. Thereafter, the workshop was continued with some specific questions prepared in advance, regarding for instance material, thermal and component related problems for the products used today. Finally and most importantly, the questions were followed by a brainstorming session, where the members were asked to form ideas related to nanomaterial applications and improvements in their particular field. The participants were divided into groups, with respect to their different backgrounds, one addressing mechanical properties and the other concentrating on thermal properties and protective coatings. Once an idea had taken shape, it was written down on a post-it note, specifying the suggested material and product application. In order to simplify the selection of promising ideas to proceed with, the participants had to sort their post-it notes on a Pick chart, a sorting method that displays a trade-off between the ideas cost and value of implementation at SAAB EDS. This step represents Gate 1 in the evaluation process, see Figure 1. Though the main idea of the workshop was to extract information and generate ideas, it also served as a tool to spread the accumulated information about nanomaterials to the organization.

2.5 Form concepts of ideas

As the next step, the concept development phase was initiated, starting with an assessment of the generated ideas from the brainstorming and workshop sessions. The ideas with the highest value for SAAB EDS, according to the placement of the post-it notes on the Pick chart, were chosen and matched with a suitable application and nanomaterial and compiled in a table, labelled Evaluation matrix in Figure 1. The Evaluation matrix is a tool developed to compare early concepts with respect current maturity state, specific properties, manufacturing possibilities and implementation potential for each material.

At this stage it was not yet known where real value is gained, which is why a wide range of ideas were considered, still, the formed concepts were designed in a way that enables further development and no contradictions with the stated boundaries in chapter 1.4.

2.6 Evaluate concepts

To choose which concepts that should be analysed in detail, the Evaluation matrix was used. By introducing a grading system, verifying the fulfilment of the main properties, a total score value was obtained for each listed concept, indicating the value for SAAB EDS considering all areas, see chapter 5. Utilizing these values in the evaluation discussion, also incorporating how different the concepts were and opinions from SAAB EDS, resulted in a few concepts that passed the second elimination, illustrated as Gate 2 in Figure 1.

2.7 Refine concepts

In the refinement process, further development of the concepts that passed Gate 2 was carried out and a detailed analysis focusing on revealing weaknesses or unexpected drawbacks. Important information was gathered, in order to define the principal theory behind, exact application, material properties and how the performance of each concept could be verified.

To be able to improve properties of existing products at SAAB EDS, it was necessary to understand the interaction between the main components and how they would be affected by the intended concepts. Therefore, employees with expertise within the different areas of concern were interviewed. Additionally, information regarding material properties was acquired through a continues dialog with the nanomaterial suppliers, throughout the refinement process.

2.8 Verification of concepts

As one of the main criteria in the refinement process, a verification method was provided for each of the fully developed concepts, through which their performance could be verified. Because of the limited timeframe and the cost aspect, only a few of the verifications could be executed. Thus, to make a decision in this matter a meeting with personal at SAAB EDS was held, presenting the most interesting concepts to verify. During the meeting the verification methodology, timeframe and budget was presented followed by a discussion on which tests to perform. Hence, in the end only two of the fully developed concepts were evaluated with the described verification methods.

2.9 Final evaluation

Even though all concepts that passed Gate 2, see Figure 1, were considered possible concepts to be implemented within a specific timeframe at SAAB EDS, information emerged along the development process that reduced the potential of some concepts. Naturally, these concepts were not chosen to be high value concepts, but as concepts not recommended for further analysis. This separation was part of a three-way categorisation of the concepts, corresponding to Gate 3 in the development funnel of Figure 1, where the other two categories state the recommendations that the concept either has high implementation potential or requires further research.

3 Nanomaterials in mechanical design

The following chapter concerns the theory of nanomaterials derived from the literature study. Nano is referring to the length of 10^{-9} meters which is the same length as just a couple of atoms stacked on top of each other. A nanomaterial is a material that has nanostructured components in any of the three space dimensions, see Figure 2, generally in the range of 1-100nm. In a way, all materials are nanomaterials since all materials are made out of atoms, however in nanoscience; nanomaterials are tailor made on an atomic level, often with entirely new properties. There are many reasons for these new properties, one is the large surface area nanoparticles have but also quantum effects, that has a larger impact when size is reduced to the nanoscale. Also, new nanoparticles are discovered that have unique properties and shapes.

Figure 2 - From left to right (zero-, one-, two- and three-dimensions).

3.1 Characterisation of nanomaterials

In order to observe small nanoparticles, very specific instruments have to be used that enable a resolution on atomic-level. For this purpose a couple of different tools have been applied throughout the years of nanoresearch, using different techniques for characterization. A common factor for these techniques is the analysis of the structural composition as a characterization method, similar to techniques developed for bulk materials. Generally, the most widely used techniques include X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and scanning probe microscopy (SPM), divided into the two main groups scanning tunneling microscopy (STM) and atomic force microscopy (AFM). (Cao, 2004)

3.1.1 X-ray diffraction

X-ray diffraction is a basic method, commonly used to determine the crystal structure of nanoparticles by exposing the specimen with X-ray beams and measuring the diffraction from the crystalline phases (Hosokawa et al., 2007). If needed, a more detailed characterization of the crystal structure for each nanoparticle can be done with e.g. electron beam diffraction (SEM/TEM) (Hosokawa et al., 2007). For simpler applications XRD is applicable, due to the easy sample preparation, no requirement for a special atmosphere (Hosokawa et al., 2007) and its non-destructive effects (Cao, 2004).

3.1.2 Scanning electron microscopy

Although SEM provides a lower resolution then TEM and SPM (Hosokawa et al., 2007), it is still used extensively for the characterization of nanomaterials. Through this method the user receives topographical information about the specimen but also the chemical composition at the surface. The analysis is usually performed by focusing a source of electrons into a beam, moved over the sample surface in a grid format with the help of deflection coils. When the electrons penetrate the surface it causes an emission of electrons and photons. These electrons are then captured on a cathode ray tube, creating SEM images. (Cao, 2004).

3.1.3 Transmission electron microscopy

With TEM a high resolution rate of a thin nano specimen can be obtained, by subjecting it to accelerated electrons that are either undeflected or deflected when they strike and penetrate the surface. Although it provides a good resolution rate this microscope has a limited depth resolution resulting in a limitation for the thickness of the examined specimen (Cao, 2004). Furthermore, the observation has to be performed in vacuum environment and the preparation of the sample is rather complicated (Hosokawa et al., 2007). However, in addition to the high magnification provided by this technique an advantage concerns the ability to provide both image and diffraction information with the same characterization method (Cao, 2004).

3.1.4 Scanning probe microscopy SPM

The two major techniques of SPM are STM (scanning tunnelling microscopy) and ATM (atomic force microscopy), that both have the unique ability to create three-dimensional images of the examined sample surface. STM is limited to electrically conductive sample surfaces, but through further development AFM was created which is not restricted to conductive samples (Cao, 2004). The AFM technique uses a sharp tip (probe) mounted on a piezo-driven leaf spring. The tip, with a radius of only a few nanometers, sweeps over the sample and measures the forces of the surface atoms. This induces a vertical deflection on the leaf spring, detected by a photodiode that records the reflections from a laser. In addition to the advantage of 3-D image creation, these characterization methods are easy to prepare and can be carried out in air, vacuum, liquid and gas (Hosokawa et al., 2007).

3.1.5 Gas absorption

By using gas absorption, the surface area and characteristic size of particles can be determined. Under the right temperature and pressure conditions gas molecules will, once in contact with a solid surface, be adsorbed to saturate and the surface energy will be reduced (Cao, 2004).

3.2 Classification of nanomaterials

In the introduction it was stated that nanomaterials must have structured components where at least one of the dimensions is in nano range. This is also a common way to classify nanomaterials because it clearly defines if it concerns particles, fibers, flakes or a nanostructured bulk material. In this project the nanomaterials will not be classified in such a manner but instead use classes more similar to conventional materials.

All nanomaterials will not be included in this classification but only the ones relevant for SAAB EDS applications. Nanoparticles will be treated separately as an introduction to the following material groups:

- Nanocomposites
- Nanocrystalline materials
- Nanoporous materials
- Nano-structured surfaces
- Nanofluids

3.3 Nanoparticles

Nanoparticles are different from larger particles in many ways. First of all nanoparticles consists of less atoms and the fraction of the atoms located on the surface of a particle is higher. In Figure 3 it is visualised how one 1 mg of 1 nm^3 sized particles has equal amount of surface area as 1 kg of 1 mm^3 sized particles. A high surface area to volume ratio will affect nanoparticles reactivity but can also affect commonly physical stationary properties such as melting point and dielectric properties. It is known that particles with a diameter less than 50 nm behave differently and below 10 nm it starts to be very difficult to predict material's physical properties (Hosokawa et al., 2007). Physical properties that change with particle size is referred to as the "size effect" which involves quantum physics that allow new physical events to take place. This includes effects as tunnelling where electrons are conducted more effectively, because their physical position in space is not defined in the same way as larger particles.

Figure 3 - 1 kg of particles of 1 mm^3 has the same surface area as 1 mg of particles of 1 nm^3. (Wikipedia, 2012)

3.3.1 Organic nanoparticles

Organic nanoparticles are carbon based and can take on many different molecular configurations. In addition to diamond, graphite and amorphous carbon it has recently been discovered more allotropes of carbon. One important allotrope in nanoscience is the so called CNT (Carbon Nano Tube), which officially was discovered 1991 but papers on nanotubes have been published before that (Monthious & Kuznetsov, 2006).

Carbon Nano Tubes

CNTs are as the name inclines hollow tubes that usually have a diameter in nano range and a length in µm range, made out of carbon. The CNT is made from rolled graphene, a one atomic layer thick carbon sheet. The first method to produce CNTs was with an arc discharge process but today several methods to create CNTs exist with different physical properties as a result. CNTs can vary a lot in size depending on processing method and multi-walled carbon nanotubes (MWCNT) can be created which are tubes with different diameters stacked inside each other.

Graphene layers that constitute the CNTs can be rolled in different angels, so called chiral angels, which affect properties such as conductivity. It means that CNTs can be both conductive as well as semi conductive depending on what chiral angle it has, which generally is not easy to control during manufacturing. Approximately, one third of the tubes are conductive due to random distribution of chiral angles (Grimes, 2001). However, MWCNTs are said to be conductive because it is very likely that one of their many layers has a conducting chiral angle (Grimes, 2001).

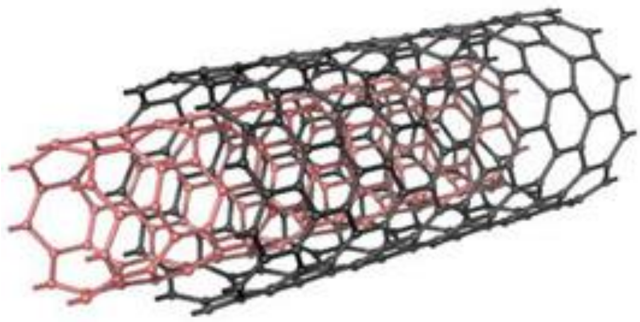


Figure 4 - Illustration of a double walled carbon nano tube. (Bundesanstalt für materialforchung und –prüfung, 2012)

CNTs do get a lot of attention in scientific journals, partly because of their remarkable mechanical properties, with the highest tensile strength of all materials yet discovered. Single-walled carbon nanotubes (SWCNTs) have up to 100GPa in tensile strength (Yu, et al, 2000), thus if it would be possible to enlarge or create a wire of CNTs with a cross sectional area of 1 cm^2, it would hold for 1000 cars in approximation. Unfortunately, it is not yet possible to create such a wire, though CNTs are instead used as mechanical reinforcement in many applications. A CNT can bend up to 90% in the radial axis and have a density of roughly 1.4 g/cm3 (Pugno, 2006) making them perfect as fillers. CNTs conductive properties have been desirable in for example polymer blends, usable both as reinforcement and to make a normally isolating material conductive.

Already today it is possible to buy CNTs, and they are used in applications such as for mechanical reinforcement in composites or as fillers in antistatic materials.

Amorphous carbon

Carbon that does not have an ordered crystal structure but random distributed carbon atoms, is called amorphous carbon or in everyday language soot or coal. In material science amorphous carbon is mainly used to tint rubbers and make it more wear resistant. In these applications Carbon Black has been used a long time, which is an amorphous carbon made from incomplete combustion of carbon rich products. This material has a very big surface area and due to its very small carbon particles it is suitable for tinting applications.

Fullerenes

Another newly discovered carbon allotrope is the fullerene that was discovered in 1985 (Kaiser, 2000). It is closely related to the CNT but is shaped as a sphere instead of a tube. This particle can also be called Buckyball because of its football shape like structure; an extremely stable molecule with the roundest geometry of its size.

3.3.2 Inorganic nanoparticles

Even though inorganic nanoparticles do not have the same extreme mechanical properties as the organic, it is still a very interesting field of science. Inorganic nanoparticles are nanocrystals of metals or oxides.

Nanocrystals

Nanocrystals can have different shapes and sizes which hugely affect their properties. However, particles larger than 50 nm are said to act similar to the bulk material, while particles smaller than that often have completely different properties. To create nano sized inorganic particles there are plenty of processing methods or so called synthesis that can be used. These methods can be divided in two main groups, namely chemical and physical. The physical methods to create nanoparticles normally involve high temperatures to which material is vaporised and condensed on a cold substrate, see Figure 5. The temperatures can be reached by resistance heating, an electron beam, a laser beam or by an arc discharge.

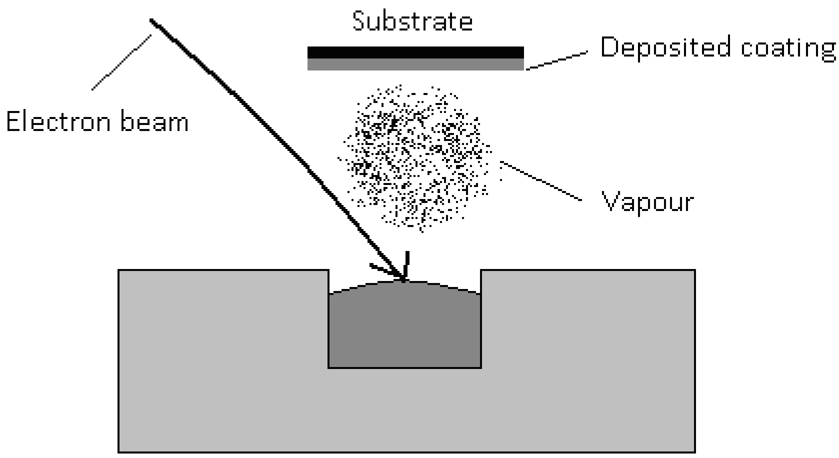


Figure 5 - Physical Vapour Deposition with electron beam.

Chemical methods do not need as much energy as the physical methods to create nanoparticles. Instead, they can be made on an electrochemical basis where the particles will be dispersed in a sol, which is a liquid medium with dispersed solid nano sized precipitates.

3.4 Nanocomposites

Many of the present nanocomposites are made out of dispersed nanoparticles in a matrix of polymers, metals or ceramics. The particles can have different composition and shapes, which means that the variety of possible nanomaterials that can be made with help of nanoparticles is vast.

Creating a uniform nanocomposite is not an easy task. Nanoparticles always agglomerate when exposed to one another, which is not desirable in most applications. Therefore, the dispersion of the filler material in a matrix is a critical step in the manufacturing process of nanocomposites. Ways of dispersing nanoparticles in a liquid can be done by using high energetic ultra sound or by treating the particles chemically so they repel each other. However, the intermolecular attraction force (van der Walls) is present at all surface interactions of small particles (Hosokawa et al. 2007).

3.4.1 Polymer matrix

A common high strength polymer composite is carbon fibre reinforced plastic (CFRP). The reason for its desirable material properties can be explained with the useful combination of flexibility and low weight of the polymer along with high strength fibres, which together constitutes a very light weight and strong material. The interaction between fibres and a polymer matrix is very important for the composites properties. Desirable in most cases is a fibre/matrix interface that can take up load without the fibres slipping out to easily nor take up too much load, as the fibres brake because there is no possibility for the fibres to elongate. The so called slipping out effect is when fibres after failure have been taking up load in the material by gradually being pulled out of their position. This is a desirable effect which is studied to estimate the efficiency of a fibre composite, since when the fibres are pulled out it normally means that the fibres have been taking up load over time.

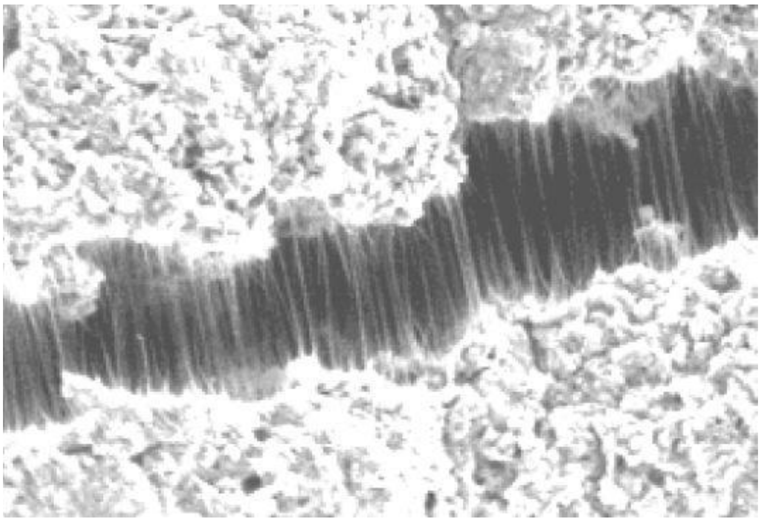


Figure 6 - Crack in polymer matrix reinforced with CNTs. (Ajayan PM et al., 2000)

Carbon nanotube reinforced plastics (CNTRPs), see Figure 6, are proven to have higher strength than conventional polymer composites, which allows the possibility to create more lightweight composites, which is of great importance in many fields of engineering.

Other possibilities with CNTRPs include the ability to use coating methods otherwise only suitable for conductive materials. One such method is powder coating, made possible due to the CNTs excellent electrical conductivity properties.

3.4.2 Elastomer matrix

Elastomers in car tires has been used with nano fillers a long time e.g. to increase strength, tint and improve friction properties. The old filler material used is often amorphous carbon or so called carbon black which is a nano material that exists naturally in for example coal and soot. The largest application area for elastomeric nanocomposites is by far the tire industry where also a lot of research is being made. Today, elastomers can get improved properties with other nano fillers such as CNTs or plate like nano particles (layered silicate and graphene) all with aim to decrease rolling resistance, increase braking friction and increase wear resistance in tires.

Layered nano silicate which is a clay mineral does not only increase the strength of elastomers but it has also been found that they can achieve good gas barrier properties due to their shape. Therefore these composites can be applicable in food packaging or in other applications were oxygen, carbon dioxide, vapor or other light weight molecules should be secluded (Heggli, 2001).

3.4.3 Ceramic matrix

As for conventional ceramic composites, nano ceramic composites are often used in high temperature application due to its excellent heat resistance properties. For mechanical purposes ceramics has a limited area of use because of brittleness. A lot of the research being made on the subject is to reduce the brittleness, which would turn ceramics into a material that could withstand both heat and tensile load. There are plenty of ways to increase fracture toughness in ceramics and some of these methods involve nano technology.

It has been shown that nano sized carbides drastically can limit crack growth of Al_2O_3 which is a common ceramic (Xiaolei, 2010). Ceramics reinforced with CNTs has also shown to raise the fracture toughness with up to 3 times and 1.6 times for Al_2O_3 (Lian, et al. 2006). Furthermore plasma sprayed ceramic composites surfaces can be made with nano-sized grains. These surfaces can show lower friction, higher hardness and better wear resistance (Dejang et al. 2010).

3.4.4 Metallic matrix

A well-known metallic matrix composite is the hard metals consisting of cobalt reinforced with tungsten carbides. Yet, there is a wide range of particles that can be dispersed in metallic matrixes and when the particle size is decreased down to nano range many properties can be improved. In recent years CNTs has been a common topic concerning metal matrixes, however it is considerable more difficult to disperse CNTs in metals compared to polymers. Successful research have been performed on aluminium and magnesium reinforced with CNTs and where strengths has been improved (Qianqian, et al. 2010). CNT reinforced metals can be used in various light weight applications with tensile strength being proved to be 8% better and the elongation at fracture is proven to be 27% higher than those of an Al-alloy without CNTs; This with just 0.05%wt of CNTs.

CNTs dispersed in Cu, is also a very interesting field concerning heat conductivity. The reason for that is that test results has turned out to be very successful showing low thermal expansion and high thermal conductivity (Molina-Aldareguia, 2010).

Nanoparticles in metal matrixes can also affect the grain growth behaviour, which then can be used to control grain shape and size in a metal. This makes it possible to influence many mechanical properties.

3.5 Nanocrystalline materials

Nanocrystalline materials are materials with a grain size between 1-250nm (Meyers, 2006). These materials show different properties compared to those of bulk material with the same chemical composition. Since the size of the grains is so small, the grain boundary surface is vastly increased and more atoms are located on a grain boundary, see Figure 7. It is recognised that these materials have better mechanical properties concerning hardness and tensile strength. As an example, conventional Ni has yield strength of 103 MPa but Ni with nanocrystalline structure (grain size 10nm) has a yield strength that is over 900MPa (Davis, Joseph R 1993). This improvement of yield strength can partly be described with the so called Hall-Petch effect that is a relationship between yield strength and the average grain size diameter. However nanocrystalline materials with very small grain sizes often show less tensile strength than the Hall-Petch equation predicts, this is most likely because the grain boundary surface is so big that new effects take place, as grain boundary sliding and diffusional creep (Koch & Knovel, 2007). Another effect of nano crystallinity is the decrease in elastic modulus which occurs for very small grains.

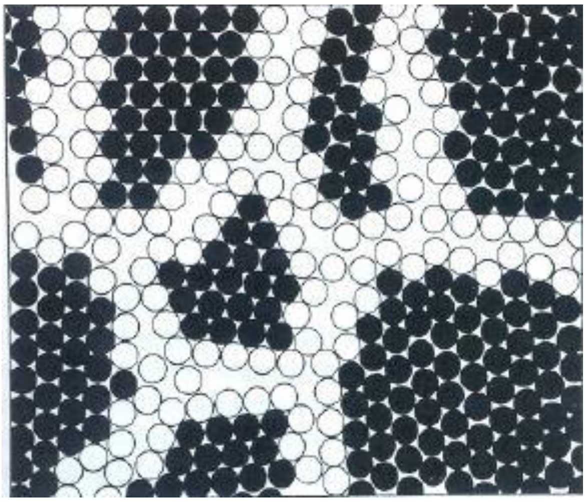


Figure 7 - Nanocrystal material, white areas grain boundaries, black areas grains.

There are multiple methods to create nano crystalline materials. One common way is to quench a liquid metal at a rate of at least around 10^6 K/s. At this rate crystallization is suppressed and an amorphous structure is attained. When annealed, crystals starts to precipitate and if no further heating is applied a nano crystalline material is reached.

3.6 Nanoporous materials

The difference between a normal porous material and a nano porous material is solely the size of the pores. A nano porous material has pores between 1-100nm and is normally built up by ceramics, metals or polymers (Gogotsi, 2006). Since the size of the pores is so small these materials can be used as filters for molecules or other very small particles. Also the porousness vastly increases the materials surface area which can enhance the efficiency for catalysts. Today many new ways or producing these materials are explored and new areas of applications are also found rapidly.

3.6.1 Zeolites

Zeolites are a naturally occurring material that has a distinctive porous crystal structure, see Figure 8. It is a crystalline hydrated aluminosilicate with pores from 1-20 Å in diameter. Because of these very small and uniformed pores, zeolites can be used as selective separation membranes of chemicals, adsorbents or catalysts.

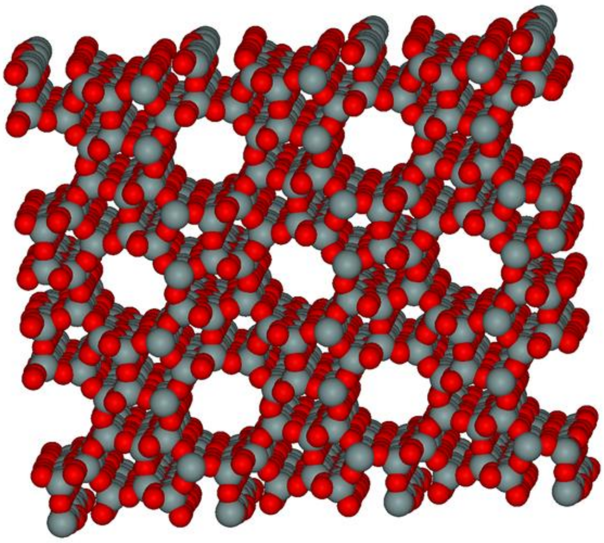


Figure 8 - An open crystal structure of a zeolite. (Wikipedia, 2012)

Because of zeolite's great potential to separate chemical compounds on a molecular level a lot of effort has been made to develop zeolites into membranes. This has pushed the development forward and zeolites are today used in separating processes in bio-ethanol production (Hosokawa, et al. 2007). One advantage of using zeolite membranes is that zeolites are more heat resistant, compared to polymers, which is another common selective membrane.

3.6.2 Porous polymers

Polymers are preferable made into nano porous material because of easier manufacturing methods compared to the zeolites. Also the range of different polymers that can be used makes it possible to get desired properties out of the material. As the zeolites, polymers can act as separation membranes to where molecule-size and chemical reactivity of the permeants determines if it can penetrate the membrane or not. This can be used to separate gases from each other or filter small particles. The efficiency of the membrane material is in many cases depending on the uniformity of pore sizes.

Porous nano polymers are also an important tool for the creation nano fibers/wires where the polymer acts as a mold. The mold can be filled with a metallic material and create a network of metal in the pores of the polymer. If later on, the polymer is heated up to such temperature that it melts, what's left is a nano metal fibre network or so called a nanowire network. Also polymer composites can be made in somewhat the same manner but instead polymer is induced in the pores and a polymer/polymer composite is created with possible unique properties.

3.7 Nano structured surfaces

The reason why it is important to modify a surface can be many and often with different purposes. With nanotechnology new surfaces can be made that can protect or change important properties on the surface of a material. In this chapter some different kinds of nanostructured surfaces will be discussed in terms of composition and application areas.

3.7.1 Nanocrystalline surfaces

The properties of nanocrystalline materials that are described in chapter 3.5 are very suitable for surfaces in mechanical applications. Nanocrystalline surfaces can be obtained by for instance different deposition methods. There are many variants of this technique and today these nano crystalline films can protect its underlying material from among other things corrosion and erosion. Coatings for cutting tools where hardness, wear and heat resistance are critical properties, have also been developed with this technique. Electrodeposited nanocrystalline cobalt-based coatings have been tested as a replacement for normal chrome coatings that are strictly regulated due to its toxic composition. The result showed that the Cobalt based coatings had higher hardness and better wear- and corrosion resistance (Prado, 2009).

3.7.2 Self cleaning surfaces

Self cleaning surfaces is today the accepted name for the lotus leaf imitation surface that has the property of staying clean by strongly repel water and dirt. A lotus leaf consists of a hydrophobic surface with nano/micro sized bumps that effectively decrease the contact area between a water droplet and the leaf. This property is called the Lotus Effect and has now been replicated by scientists. The Lotus leaf is super hydrophobic which means that a droplet has a contact angle higher than 150° degrees from a surface.

Figure 9 - Droplet on a superhydrophobic surface. (The future of things, 2012)

In order to produce hydrophobic surfaces the underlying material must have low surface energy and to get super hydrophobic properties the surface roughness must also be high. Both these requirements can be obtained with alkyl and fluorinated alkyl groups that possess a roughened surface. With this principal, many materials can become super hydrophobic, for instance copper can get super hydrophobic when copper nanowires are grown on a copper substrate and oxidized (Colin R. et al. 2010). In the same manner there are many more ways of creating super hydrophobic surfaces that can be used in application of self cleaning applications but also for de-icing or make materials more corrosion resistant.

3.7.3 Spray on nano capacitors

Unfortunately, this interesting material is not very well documented, mainly because the research team at Chamtech Operations claim to have exclusive rights to this product. In essence, it is a spray with nanocapacitors that can be sprayed on any surface to create a very efficient antenna. This works through an automatic alignment of the nanocapacitors on the applied surface, enabling a rapid charge and discharge in order to send and receive signals. Since no documents are published of this exact product, it is impossible to go any deeper in the functionality of the antenna coating. However, this fairly new product was recently presented at the Google project “Solve for X”, emphasizing the products credibility. (Anthony Sutera, 2012)

3.8 Nanofluids

It has recently been discovered that nanoparticles that are dispersed in a cooling liquid can vastly increase the heat transfer performance. When nanoparticles are mixed in a less conductive cooling liquid, they enhance the overall heat conductivity of the liquid. This is up to this date not fully understood but theories suggest that nanoparticles interfere with the boundary layer, enabling more efficient heat transfer.

As for all particles in suspensions, agglomeration must be overcome and that can be achieved with different techniques. One effective way is mixing with ultrasound, but to keep the dispersion stable, surfactants must be used. Surfactants are molecules with one hydrophilic end and one hydrophobic and do therefore accumulate on surfaces in a suspension such as surfaces on particles, see Figure 10.

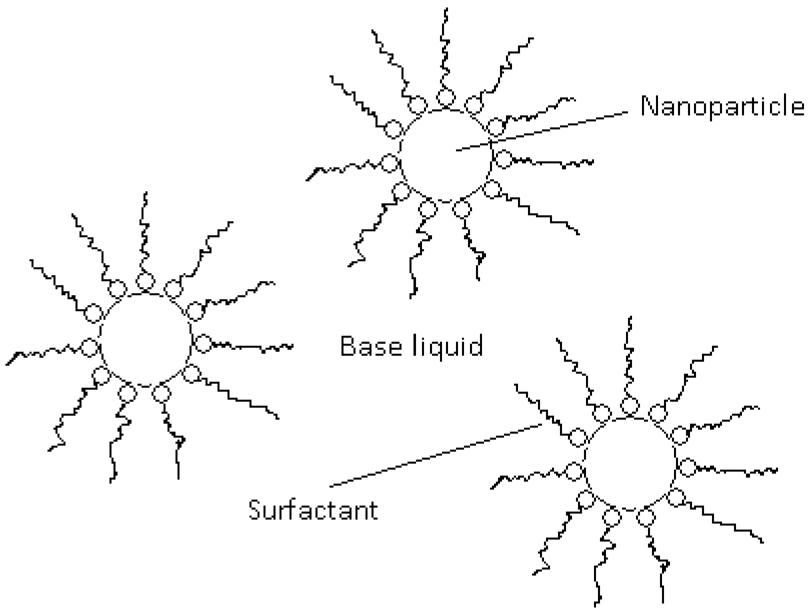


Figure 10 - Nanoparticles dispersed with help of surfactants.

Nanofluids have also been successfully used as lubricant additives to efficiently reduce friction. By performing a disk-on-disk tribotest, it was realised that the friction coefficient in the system decreased with 90% compared to conventional oil. This result was obtained with 0.1% volume fraction of fullerene nanoparticles dispersed in a mineral oil, usable in many lubricant systems (Kwangho Lee, et al. 2009).

Prior to full commercialisation of nanofluids, further research is necessary to keep suspensions of nanoparticles stable. Today they tend to clog and agglomerate over time. Furthermore, it has to be clarified how nanoparticles affect a liquids viscosity and how flow changes when nanoparticles are introduced. However, despite the current obstacles the nanofluids show great potential. For instance, a nanofluid with just 4% Al_20_3 wt% dispersed in water, achieved a 32% enhancement in heat conductivity. (Veeranna Sridhara & Lakshmi Narayan Satapathy, 2010). Hence, nanofluids are expected to be in wider use in the near future and many parallel projects work on improving the properties of nanofluids.

4 Product analysis

The SAAB EDS product portfolio is very extensive and covers land, air and sea applications. Since the systems have many similarities and the project has a limited timeframe, this work is focused on five main systems, being the LASER products, the land based radar systems Arthur and Giraffe as well as the air based Erieye and Gripen. In the following subchapters the systems are described generally, including some general and environmental requirements as well as figures showing the specific product.

4.1 General requirements and tests

Since the various products have to be able to operate in very different environments, the company has developed some general guiding environmental requirements and tests to be considered in the design process. Due to the low production volume and high customization level, the purchase of a product usually implies a high investment cost for SAAB EDS customers, which is why the lifetime is requested to be at least 20 years. Regarding temperature the products, including both land and air units, are required to withstand major variations from far beneath 0°C to high above. Furthermore, the large amount of electric equipment has resulted in mandatory tests of the Electro Magnetic Compatibility (EMC) of the systems.

Considering specific environmental requirements for the land based applications, the equipment should withstand normal solar radiation and high wind speeds, even up to hurricane level. Additionally, the equipment should be able to operate at normal atmospheric pressure and relative humidity. While most of these requirements also apply for the airborne applications, they become quite different at higher altitudes, which is why these conditions are presented under the related chapter.

4.2 ARTHUR Weapon Locating System

The ARTHUR WLS is a fully coherent radar system, designed to detect artillery weapons and projectiles in a range of maximum 60 km. It can also predict the impact points of projectiles, which enables it to work as a threat detection warning system for the soldiers on the ground.

It consists of several main sub-systems, all mounted on a vehicle for superior flexibility and mobility. This is usually a tracked vehicle with a front and rear cabin. (see Figure 11) The power system, navigation system and communication equipment, including the communication antennas on the roof, are all located in the front cabin. The rear cabin is specially designed for ARTHUR Weapon Locating Radar (WLR), containing the operator room, transceiver unit, signal processing unit, data processing unit and in particular the main radar antenna and turntable on the roof. For reasons of stabilization and levelling, the rear cabin is also equipped with support legs in each of the four corners. The cabin works as protective shelter against fragments as well as some protection against nuclear, biological and chemical (NBC) weapons and is provided with air conditioning and ventilation. In order to avoid damage to components through static electricity, the whole cabin, including most of the contained components, is conductively connected.

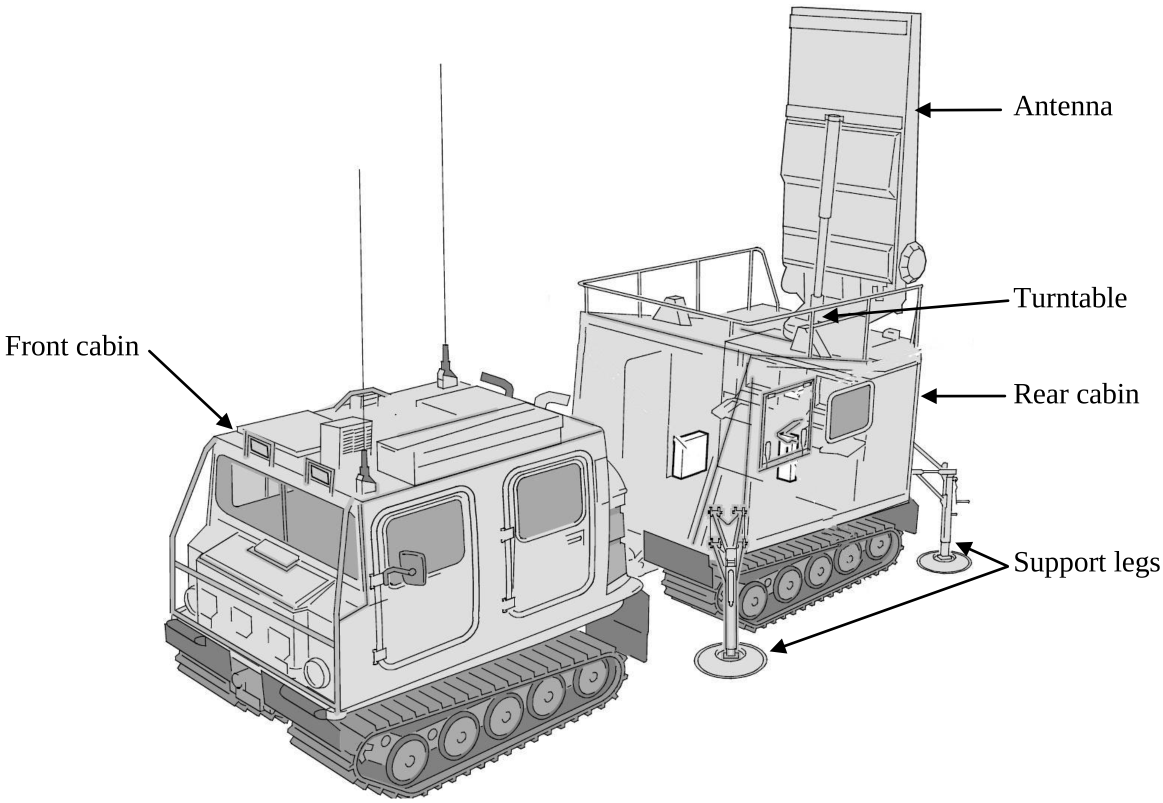


Figure 11 - The ARTHUR WLS tracked vehicle.

As part of the ARTHUR WLR, the Transceiver unit is responsible for the radio frequency creation and consists of the Radio Frequency Generator (Exciter and Receiver), Microwave unit and Transmitter unit. The Microwave unit is used to amplify the radio frequency and has to be cooled efficiently with either air or liquid due to high temperatures.

Mounted on top of the rear cabin roof, the mechanical turntable functions as the link between the antenna and the radar while enabling the antenna to be directed in a desired search direction. The turntable is equipped with an electric motor that performs the rotation of the antenna and through an elevation motor connected to a ballscrew, the antenna can also be raised or lowered. In case of a breakdown or power loss, the antenna can be lowered manually by disengaging the motors. The antenna unit, mainly composed of waveguides, phase shifters, a power unit and power divider, is responsible for the transmission of the radio waves.

In addition to the general requirements mentioned in the previous chapter, some specific requirements also apply. Related to environment conditions, the ARTHUR WLS equipment should remain unaffected by heavy rain, snowfall (including ice formation) and extensive sand and dust abrasion. Furthermore, considering more physical properties, the ballscrew responsible for the fold down and raise of the antenna must withstand the significant forces that the heavy antenna causes.

4.3 GIRAFFE Agile Multi-Beam Radar System

The Giraffe AMB is a radar system that enables a weapon tracking surveillance of the surrounding airspace, which can be modified for sea surveillance. It provides 360° supervision and can locate threats from missiles and artillery.

The whole system is built around an ISO standard container, which simplifies mobility, since it can be loaded on different vehicles equipped for ISO-standard measures, see

Figure 12. This container also serves as a cabin for protection and operation and contains most of the electronics and other components that the system requires. A sandwich panel design, made out of aluminium coating with cellular core, enables a lightweight structure with good insulation and strength properties to provide protection against splinter and NBC. Attached on the back of the cabin, a power plant with a diesel engine and generator serves as an electric power supply for the whole system. To deal with uneven surfaces, the cabin is equipped with support legs in all four corners.

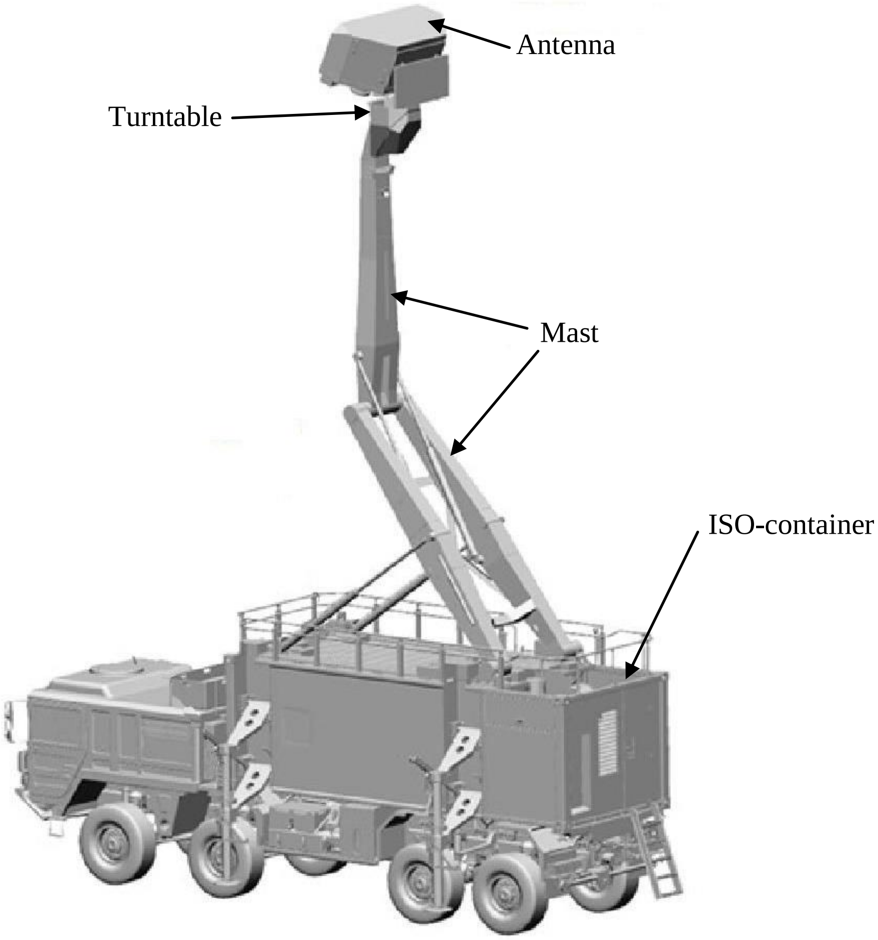


Figure 12 - The GIRAFFE AMB system mounted on a vehicle.

The steel mast, mounted on top of the cabin, consists of two main sections. The lower section, made from two long rectangular tubes welded together in an A-shape and reinforced by several crossbeams, and the upper part, which consists of a long rectangular tube hinged at the bottom with the lower section, while the upper part ends with an interface for the turntable. To elevate the mast, it is equipped with four hydraulic cylinders, two for the lower and two for the upper section.

In order for the antenna to provide a 360° monitoring, it is mounted on top of a turntable. Depending on the desired range, the turntable rotates the antenna at a revolution rate between 30 to max. 60 rpm. This rotational movement is provided by an electric motor connected to a rotary joint. Apart from these components the turntable is also equipped with a smaller engine for the parking procedure.

When the mast is fully extended it measures 9 m, elevating the antenna to 13 m above ground, due to the 4 m ISO container it is mounted on. The main function of the antenna is to transmit the radar signal from the transmitter to the air and return the received signal. This is achieved by a number of components enclosed in the antenna, including antenna boards, phase shifter, receiver and a fan for internal cooling. As the antenna rotates, outside air is sucked in by the fan and flows through the interior and out on the opposite side of the unit, cooling the internal components.

As for the ARTHUR WLS, the GIRAFFE AMB has to be able to withstand sand and dust abrasion as well as allowing it to operate even in case of heavy rain, snowfall and thick ice layers. Due to the exposed design of the mast, a buckling safety should be provided.

4.4 ERIEYE Airborne Early Warning & Control System

ERIEYE AEW&C is a radar system mounted on top of an aircraft, as illustrated in Figure 13, used to effectively surveil a large area of the surrounding air and ground. It can detect small air targets, missiles and hovering helicopters but also small sea targets, and identify friend from foe.

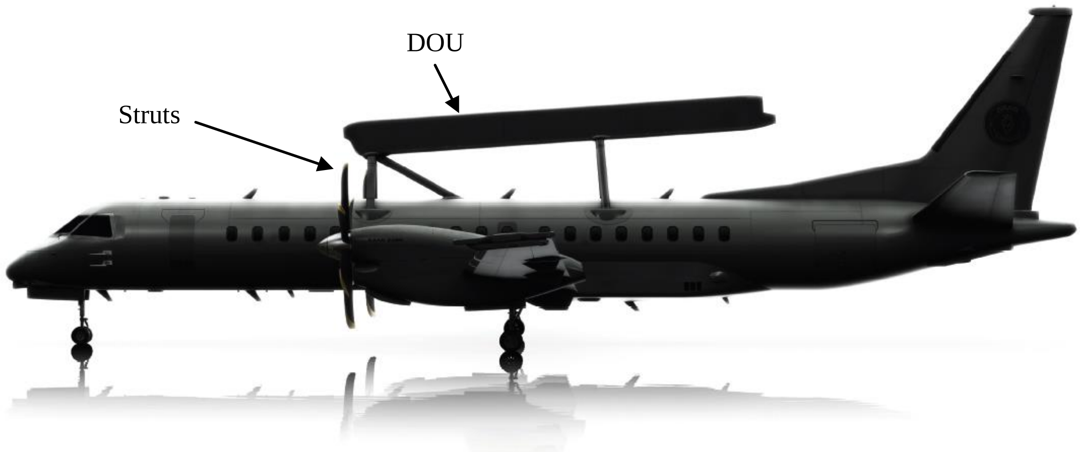


Figure 13 - ERIEYE AEW&C overall view.

The part mounted on top of the aircraft constitutes the Dorsal Unit (DOU), a 10 meter rectangular box, including the structure and all enclosed radar components. The structure is a lightweight design, made mainly out of glass fiber composite that works as a compartment for the radar equipment that needs to be placed on top of the aircraft. These include the components responsible for the transmission and reception of radar signals and the amplifying antenna plates on each side of the DOU. To enable the radar signals to emit out of the structure, the walls are made transparent to radar waves, while functioning as a structural and weatherproof enclosure. For cooling purposes, the DOU is also equipped with an air intake in the front and a diffuser in the back along with air channels through the compartment, which allows the enclosed radar components to be cooled by Ram air.

To connect the DOU to the aircraft fuselage there are six rods, also known as struts, four in the front and two in the rear part. These struts are protected from corrosion and mechanical damage by aerodynamic fairings, which also protect the cables that supply the DOU with power and connection to the aircraft, placed at the rear struts.

The remaining radar equipment and power supply of the whole radar system is placed inside the aircraft, due to their heavy weight and because they do not require to be mounted on top of the aircraft. Similar to the DOU equipment, these components are all air cooled but rather than natural flowing air, this is done by installed fans or ambient air.

As mentioned in chapter 4.1, product requirements can look quite differently for airborne solutions compared to land based equipment. For instance, the temperature can change rapidly due to the variation of altitude, which puts very specific thermal requirements on components. Similar to the ground units, the ERIEYE has to cope with heavy rain but also resist rain erosion because of the high velocities. Heavy vibration is another important issue to consider, and require testing to verify that the components do not fail. The lifetime of the ERIEYE is 15 years, due to the high fatigue stresses on the whole system and extreme aerodynamic loads on each strut. Moreover, as there is always a risk of bird collision, the equipment is tested to withstand a major bird strike.

4.5 PS-05/A Airborne multi-mode radar

Although this compact, lightweight radar system is specially designed for the JAS 39 Gripen Fighter, it can be modified for integration into any standardized avionic platform. Due to its air-to-ground and air-to-air modes with support for Beyond Visual Range (BVR), meaning that the target is visual on radar before it can be seen by the pilot, the radar system qualifies for multi-role applications. This is also why the Gripen Fighter is often considered for reconnaissance missions.

The rack mounted sub-units are mechanically and electrically autonomous, creating a modular architecture for easier maintenance and exchange of components. A value for the predicted mean time between failures specifies the service intervals to 250 hours of air operation. Through the Travelling-Wave Tube (TWT) transmitter, the power consumption can become as high as 10 kW, requiring a liquid cooled system. The weatherproof, aerodynamic cone in the front of the aircraft, also known as the radome, is designed to protect the system from environmental influences while at the same time enabling radio signals from the radar to pass through, see Figure 14.

Figure 14 - The PS-05/A radar system mounted in a Gripen Fighter.

4.6 LASER

Unlike the products mentioned earlier this product is not related to radar systems, but instead is a solution that works as a distance meter or range indicator. The main function is performed by emitting short pulses of light and measuring the “time-of-flight” to and from the target, providing a range of up to 20 km. The LASER is always attached to a scope with a sensible tracker and is mainly used as support for anti-aircraft systems, but other applications include installations on helicopters or aircrafts.

Although there are many different models, the structural components are largely the same, with a transceiver unit equipped with several optical lenses that aim the emitted light beams. For most models the transceiver unit is cooled by air, in a sealed system, and is placed in the same case as the power unit.

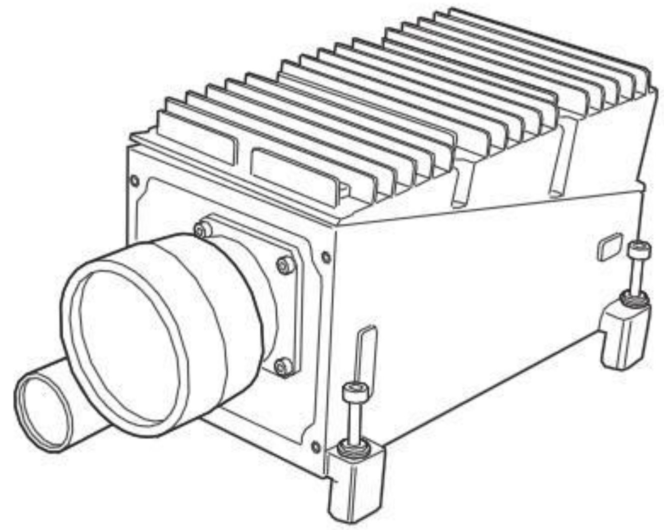


Figure 15 - LASER model.

5 Concept development

The methodology of how concepts are formed within this project is described in chapter 2. To come up with good concepts, a lot of knowledge is required, in this case, both about existing products and properties of a wide range of nanomaterials. To make sure that focus will be put on areas where it creates most value for SAAB EDS, the development work is starting wide and is quickly limited to a few concepts that can be thoroughly analysed. These concepts will be divided into briefly- and fully developed concepts, to make an even clearer separation between high and low value. Starting from an idea these development processes are defined as follows:

Idea: Concerns any product related idea involving nanoscience that could create value for SAAB EDS.

Briefly developed concept: Regards properties of a nanomaterial that could be used to improve a product at SAAB EDS. These concepts are presented in Appendix B.

Fully developed concept: Based on a briefly developed concept, focused on a specific component at SAAB EDS to be improved by a thoroughly investigated nanomaterial. The following parts should be covered:

- Theory
- Application
- Material
- Verification

5.1 Generated ideas

As information is gathered about the nanomaterial properties during the literature study, promising ideas emerging from brainstorming session are compiled as follows:

Nanocomposites

- Stiff, lightweight design through CNT reinforced aluminium matrix.
- Efficient cooling pipes with CNT dispersed in copper matrix.
- Self-cleaning glass by adding titanium-oxide nanoparticles.
- Enhanced ductility and lower brittleness of ceramics through reinforcement of silicon-carbide or zirconium-oxide nanoparticles.
- Strong and conductive polymers with dispersed CNTs.
- CNT reinforced polymers to achieve anti-static equipment.
- Layered silicate particles in polymers for improved gas barrier properties.

Nanocrystalline materials

- Super hydrophobic surfaces for water and dirt rejection.
- Nanocrystalline cobalt-based coating to replace chromium.
- Hard and wear resistant surfaces by coating with nanolayers of hard metals.
- Create transparent conductive surfaces on, for instance, glass by indium tin oxide.

Porous nanomaterials

- Molecular selective filtering by tailored zeolite membranes.
- Polymeric nanofilters to purify water.
- More efficient catalysts through zeolite membranes.

Nanofluids

- Enhanced properties of liquid cooling through dispersion of nanoparticles.

5.2 Created concepts

Bringing forth the generated ideas and presenting nanomaterial properties in a workshop, as described in chapter 2.4.1, using it as a forum to discuss concepts with employees, a Pick chart with existing and new concepts is achieved, illustrated in Figure 16. Involving the employees opinions and utilizing the Pick chart as a first evaluation, ensures to choose the ideas with highest value for further investigation.

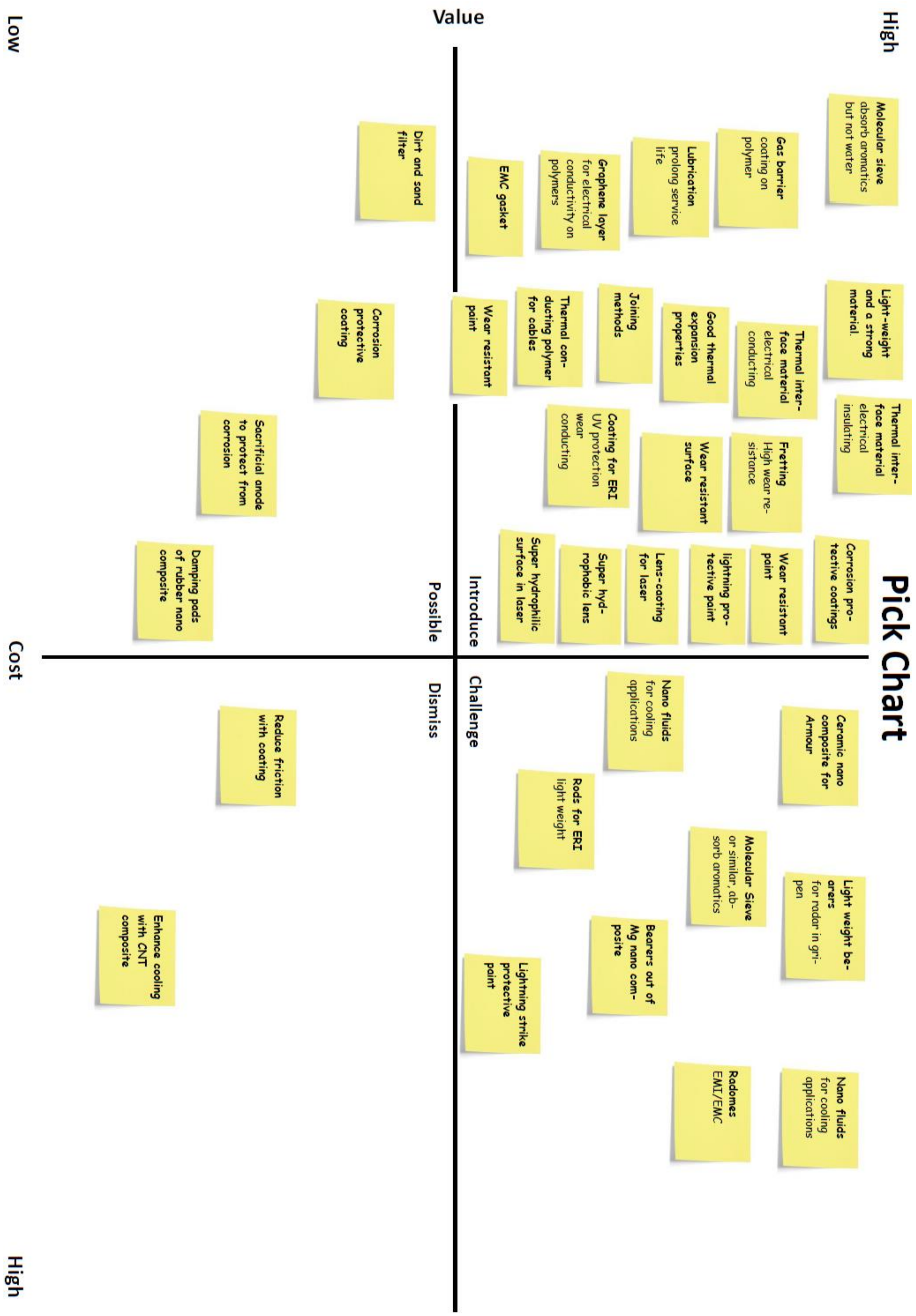


Figure 16 - Pick Chart

Adding on more information about a specific application and specifying proven material properties, transforms the chosen ideas into briefly developed concepts.

5.3 Concept evaluation

To be able to distinguish value between the briefly developed concepts, all concepts are put together in an Evaluation chart, accompanied by information on each concept intended to be comparable entities. As seen in Table 1, each field has got points from one to four where one is poor and four is high. The following five different areas are graded:

- applications at SAAB
- company/institution
- properties proven in lab
- manufacturing possibilities
- commercial timeframe

Summing up these graded areas into a total value score for each concept, this is used as a help to decide which concepts should be taken to the next level and further developed. Again, as part of the process, employees at SAAB EDS are consulted to choose the concepts that show the highest potential, basing the decision partly on the Evaluation chart. As a result, nine concepts are chosen to become fully developed concepts and are marked as orange in Table 1. The remaining concepts are not further developed, although still interesting and realistic, short descriptions along with a motivation to why they are not further analysed is given in Appendix B.

Table 1 - Evaluation chart, continues on next page.

Properties / Materials	Main task	Material used today at SAAB	Application at SAAB		Company/Institution	
Nano composites						
CNT reinforced Aluminium alloy	Strong and light with good heat conductivity	Aluminium alloy	Bearer of electrical components	4	Bayer materials, bioneer and smart high tech AB	4
CNT reinforced Magnesium alloy (AZ91D)	Strong and light with good heat conductivity	Aluminium alloy	Bearer of electrical components	4	'Bayer,Germany/bioneer	4
Mg /Al reinforced with boron and lithium	Strong and light	Aluminium alloy	Bearer of electrical components	4	powdermet inc	3
Polymer matrix with metal nanocrystalline coating	Ultra light weight	Aluminium alloy	Bearer of electrical components	4	Integran	3
CNT Ceramic composite	Penetration protection	n/a	Ceramic armour	3	Lian Gao, Linqin Jiang (IBD deisenroth?)	4
CNT in Polymer	Conducting, Stronger and lighter parts	Aluminium alloy	Bearer of electrical equipment	4	Nanocyl	3
CNT in Elastomer	Conducting gaskets	Metal reinforced elastomer	EMC/EMI gaskets	3	Zyvex technology	3
Film of nanolayers of nickel and aluminium	Joining of metals	salt bath brazing	Alternative for welding and glueing	3	Indium corporation	4
Graphene-MLG in polyurethane	Thermal conductive, electrical insulation	n/a	Thermal interface material/Cable insul.	4	Sky Spring Nanomaterials Inc.	3
Sandwich construction with epoxy/nanoclay (Cloisite 93A)	Frequency selective surface, lightweight, stiff	n/a	Stealth radome	2	Southern Clay Products Inc. Kukdo chemical Co.	3
Sandwich construction with CNT	Radar absorbing, lightweight, stiff	n/a	Stealth radome	2	Korea Advanced Institute of Science and Technology	2
Nano fluids						
Nanosized particles in lub.	Prolonged service time, reduce friction	Mineral/synthetic engine oils	power plant of the ARTHUR WLS	4	Apnano	3
Cupper nanoparticles in cooling liquid	Increase CHT (critical heat transfer)	none	Cooling of electronic	3	NanoHex	4
Porous nanomaterials						
Zeolite molecular sieve	Adsorb VOCs(volatile organice compounds)	Zeolite (unknown)	Filter outgassing products(vocs) in Laser	4	NeoZeo AB	4
Hollow polymer fiber membranes	Filter VOCs(volatile organice compounds)	Zeolite (unknown)	Filter outgassing products(vocs) in Laser	4	PoroGen	3
Surfaces						
Layered silicate barrier	Prevent outgassing of polymers	none	Seal polymers in Laser	4	Inmat	3
Lotus leaf resembling coating	Water/dirt repellent properties	Various coatings	Erieye radome	3	Sto corp./P2i	3
Nanocrystalline (Titanium,Silica,carbon)	Wear resistant contact coating	Layers of Gold and Nickel	Electrical contacts to prevent fretting	4	Impact coating	4
CNT in polymer	Conduct heat and electricity	n/a	lightning strike protection	2	Advanced Materials IFAM in Bremen/hanwhananotech	3
Nickel/tungsten alloy	Corrosion resistance, wear resistant	Chrome alloy	Corrosion- and wear-intensive surfaces	3	Xtalic/Xprotect	3
Nanocrystalline Cobalt	Corrosion resistance, wear resistant	Chrome alloy	Corrosion- and wear-intensive surfaces	3	Integran/ Enduro industries	3
Sprayed on nano capacitors	Mobile antenna system	None	Various antenna applications	4	Chamtech operations	2
Deposited ZnO on Al and Cu	Conduct heat	None	Cooling of electronic	4	Terry J. Hendricks, Shankar Krishnan	1
3D nano-structured coating	Protect substrate	epoxy based or Bolicoat	IFF antenna	3	Nanovere	4

Properties proved in lab		Manufacturing today		Commercial timeframe		Total value(points)
Tensile strength 7.1% increase, 81% increase in heat conductivity on micro scale	3	Advanced alloying	2	New methods explored which can be scaled up 1-2 years	2	15
Tensile strength 388 Mpa(230MPa) E-modul 55 Gpa(45GPa)	3	Special methods	2	Technically proven	2	15
80% of the density, high strength/stiff.-to-weight ratio	3	Special methods	3	Available	4	17
weight 40% less Compareable strength	4	Possible to manufacture	3	Available	4	18
0.1wt% CNT 1.6 times higher fracture thoughness Al2O3 from 3.7 to 4.9 MPam1/2	2	Possible to manufacture	3	Available?	4	16
Fracture thoughness 100% better, improved strength over 15% from 90-45 degress of fiber direction	3	Possible to manufacture	2	Available	4	16
improved tear strength by as much as 50% and conductive	3	Possible to manufacture	2	Available	4	15
Reaction temp. 1350°-1500°C	3	vapor-depositing	4	Available	4	18
approx. 14 W/mK ρ ≈ 1,4 x 10^9 Ω-cm	4	Liquid-phase-exfoliation technique	2	Technically possible. Further development needed	3	16
Resonant freq: 8,5 GHz, Max. transmission rate: 80%, Bandwidth for -1dB: 0,6 GHz, Flexural strength: 40 MPa	3	Composite sandwich construction.	1	Technically proven	2	11
EM absorption rate: max. 97%, min. 84%, Bandwidth -10 dB: 3.3 GHz, Peel strenght: 2,0 kN/m	3	Composite sandwich construction.	1	Technically proven	2	10
reduces friction, wear and temperature	4	Possible to manufacture	3	Available as additive	4	18
40% better cooling	4	Possible to manufacture	2	Pilot projects finished within 2 years	3	16
Biogas seperation	3	Possible to manufacture	3	Available	4	18
Removal of VOCs from process streams	3	Possible to manufacture	3	Available	4	17
Permaebility, cc-mm/m2-day-atm = 2.5-3.5	3	Possible to manufacture	3	Available	4	17
Superhydrophobic(contact angle >150°)	3	Possible to manufacture	3	Available	4	16
Low friction, low resistivity, high heat resistance och good wear resistance	4	Possible to manufacture	4	Available	4	20
Better electrical conductivity of plastics	3	small scale manufacturing	3	further development needed 5-10 years	3	14
10 times better corrosion resistance then chromium applied on steel	4	Possible to manufacture	2	Available. Applied through Electroplating	4	16
Reduced friction and sliding wear, 4 times better corrosion resistance then hard chrome	4	Possible to manufacture	2	Available. Applied by Electrodepositioning	4	16
Better effieciency (RFID tag from five feet to almost 700 feet)	4	Small scale testing	2	further development needed 1-5 years	3	15
Heat transfer coefficient 23000 W/m2K	4	Deposition methods	1	Need further developing	2	12
self cleaning, reduces water drag with 50 %, Erosion resistant	3	Possible to manufacture	4	Available	4	18

5.4 Fully developed concepts

The concepts described in this chapter are all chosen from the Evaluation chart, see Table 1, due to their potential to create value for SAAB EDS. To form fully developed concepts, the intended application and material will be described in more detail. Furthermore, since it is desirable to verify some of these concepts through tests, the procedure to perform these tests will be explained. Additionally, to better understand the material and application some background theory is provided as well.

5.4.1 Highly thermal conductive aluminium heat sink

This concept is based on an aluminium alloy reinforced with CNTs. Due to the material's efficient heat conducting properties compared to conventional aluminium alloys, it has potential to increase the performance of a heat sink holding heat generating electronics and where lightweight is desired. This material did not achieve a high total value score in the evaluation chart partly because it is not yet commercially available. However, it is of great interest to investigate further what effects this material could have on an existing components.

Theory

Heat can be transferred conductively through interaction of atoms, by emitting radiation of heat or by convection which involves mass transfer in fluids (Frank M. White, 2008). In this concept it has been focused on the conductive heat transfer which is the ability of energy to move within a medium, in this case an aluminium bracket. Heat conductivity is described with Fourier's Law,

$$\vec{q} = -k\nabla T \tag{1}$$

This law describes how heat flow perpendicular to heat gradients, T, and that the heat flux is proportional to the steepness of the gradient. This means that more heat is transferred in regions where the difference in temperature is high. How much heat that is transferred is also dependent on the thermal heat conductivity constant, k, and is specific for all materials.

Heat transfer through convection is complex, but an effective way of transporting heat. It involves mass transfer that occurs both on large and small scale. On small scale it is diffusion processes that drive the movement and on large scale currents are formed of which mass is transported. It is difficult to model the movement of fluids and therefore also how the heat is dissipated.

Thermal radiation is how the suns energy reaches the earth. The power of which a body is emitting thermal radiation can be estimated with Stefan Boltzman's law,

$$P = A \cdot \varepsilon \cdot \sigma \cdot T^4 \tag{2}$$

where P is the total amount of power that is emitted, A the surface area, ε the emissivity, σ the Stefan–Boltzmann constant and T the temperature. In many engineering applications this addition of heat can be cancelled because of being insignificant in magnitude compared to conduction and convection.

Application

As part in a bearer application of electronics an aluminium bracket is used to mechanically hold mounted electronics and be a good thermal conductor in order to dissipate heat. The heat sink, see Figure 17 has heat generating electrical components mounted that are represented by small squares extruded from the surface of the plate. The heat generated, is transferred into the aluminium that itself is cooled actively through its long side.

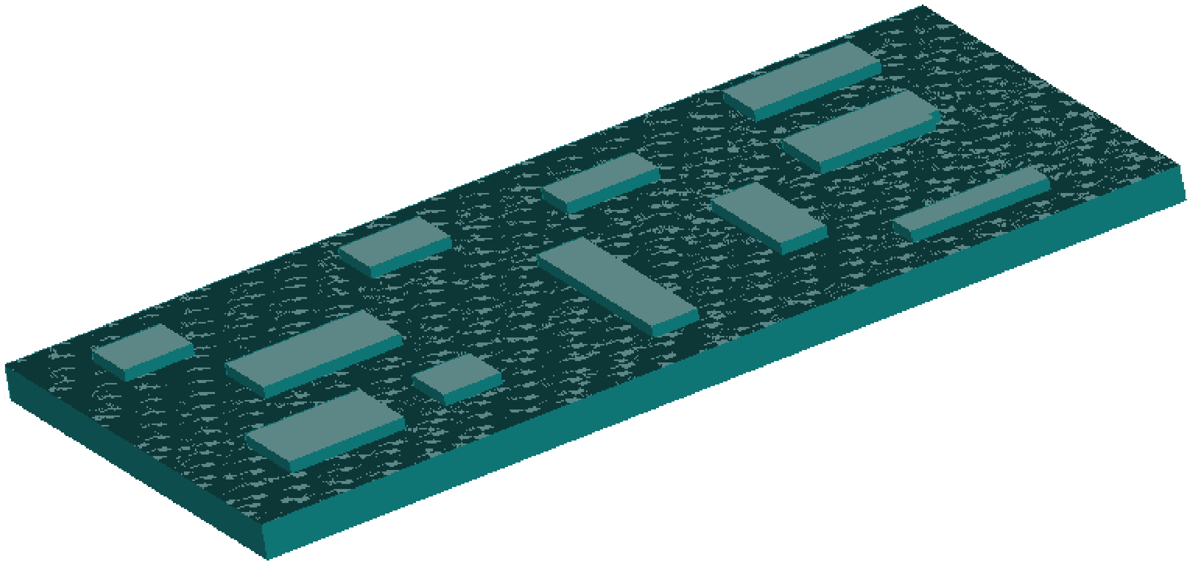


Figure 17 - 3D model of the heat sink.

This project is not to design components but only consider properties of materials and what effects they can cause, therefore approximate measures are used. The bracket is 40cm long, 20cm wide and 1cm thick and should lead away heat trough its side width an area of 40 cm^2. The temperature of the electronics is not allowed to be any warmer than 80°C in order to prevent damage to the electronics. The mount is cooled through convection with a water based cooling liquid that constantly holds a temperature of 10°C. The electronics generate a total power of 500W.

Material

10 wt% CNTs have successfully proven to increase the heat conductivity in an Al-Si matrix (Srinivasa R, et al. 2010). However the increase is only significant when the CNTs are uniformly dispersed, else the heat conductivity decreases due to agglomerates that show less heat conductivity than the Al-Si matrix. This is a major problem when in most CNT composites agglomerates are present. Still, it has been shown on micro range that the heat conductivity can be improved with as much as 81%. However when the analysis is conducted over a larger area the CNT composite shows a decreasing heat conductivity with 35% (Srinivasa R. et al. 2010). This clearly states that if better methods would be developed that better dispersed the CNTs; a significant improvement in heat conductivity would be reachable.

Verification

To verify the improvement of performance a thermal finite element analysis of the heat sink is carried out to determine what the steady state temperature will be at in different regions. These calculations are compared with existing design and the weight of the bracket is strived to be reduced with maintaining of temperature levels.

5.4.2 Simplified joining method with nanofoils

With a welding film based on a fully developed nanomaterial it is possible to join metals in an easier way. The concept got a high total value score in the Evaluation chart because of great potential to replace existing more complicated joining methods at SAAB EDS.

The concept involves a nano structured film that is put between two metal parts and activated with a pulse of energy to where it emits an immense heat to which the parts melt together.

Theory

The exothermal reaction of RMNFs (Reactive multilayered nano foils) is a critical factor when using them as a joining film. How fast the reaction propagate is controlled by the thickness of the of the Ni and Al layers, and can vary between 25-90nm. Innojoin specifies the exothermal reaction to release up to 1250 J/g without generating any gas compounds. A reaction temperature gain of up to 1567°C is derived from Equation 3 where all heat is assumed to stay within the foil because of a very fast reaction speed. Where T is the temperature gain, W/m represent released energy per kg and C_p the average heat capacity of the Ni and Al layers.

$$T = \frac{W}{m \cdot C_p} \tag{3}$$

This temperature is slightly higher than what Innojoin specifies because the heat transfer from foil to the remaining goods is not taken into account in this model.

Application

To transport radio waves effectively in an antenna system so called wave guides can be used. It is a hollow tube like structure to which waves are transported, see Figure 18. The shape of the structure is critical to not affect the waves in any negative ways and therefore they have an advanced design and special manufacturing methods are required to get the shape required. In the creation of these wave guides a rare joining method is used that involves joining of a machined profile with a sheet of metal to close the open structure. This method is complicated and it is not many manufacturers using this method.

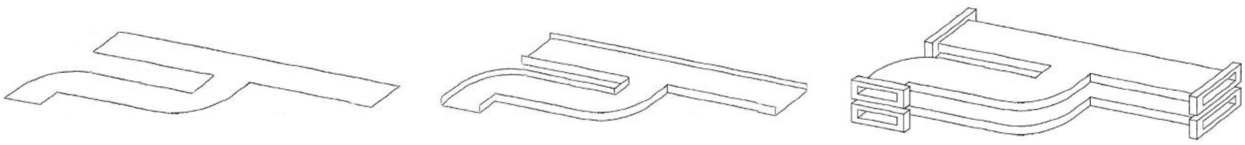


Figure 18 - Illustrative picture of wave guides, fully assembled to the right.

The new idea is to use RMNFs as a welding agent. The shape of the foil is tailor made to suite the machined profile which constitutes the wave guides, see Figure 18, then the sheet of metal will be placed on top and pressed together carefully. When an electric pulse is sent trough the foil the foil reacts and melts the surface treated aluminium part so they get joined together.

Material

RMNFs is the accepted name for this class of material. They are made up of thousands of alternative nanolayers of metals and react exothermally when activated. Innojoin has developed a nanofoil that consists of Aluminium and Nickel. The foil is manufactured with vapour deposition techniques and can be made with a thickness of 40-150µm. Because of the

RMNFs ability to react exothermally they can be used as a joining agent between two metal parts. The foil can reach temperatures up to 1350°-1500°C which is enough to weld many metals. At SAAB EDS the welding procedure concerns two aluminium parts that should be joined together.

Verification

To verify that this foil could be used as a replacement for the current more complicated joining process some factors needs to be considered. First of all, it needs to be tested if the adhesion of the joint created by the nanofoil is sufficient, besides that the following factors should be investigated:

- Electrical conductivity of the joint
- Complexity of welding technique
- Suppliers

To review the complete test procedure and results, see chapter 6.2 respective 7.2.

5.4.3 Enhanced oil lubrication in power generator

As a means to reduce wear in a power generating diesel engine, this lubrication related concept acquired a high rating in the Evaluation chart, see Table 1, and thus is chosen for further development.

Theory

Engine oil quality is influenced by many factors of which temperature is regarded as a main factor, because heat severely affects oil life. Another important issue that also affects the oil quality, concerns the iron particle concentration in the oil, as a result of wear and friction between engine components. Thus, these effects should be minimized, since the oil serves as a lubricant and with a high concentration of dispersed iron particles, friction and wear increases. (Brad Buecker, 2009)

The definition of friction (resistance to sliding) gives some indication to the function of oil lubrication. By creating a thin oil film between metal surfaces which otherwise would slide on each other, so called hydrodynamic lubrication is achieved and friction is virtually removed. In order to obtain the resulting frictional force F, the law for solid friction provides the following correlation

$$F = f \cdot P \tag{4}$$

where P corresponds to the load perpendicular to the frictional force F and f is equivalent to the coefficient of friction. To be noted is that the relationship is independent of the contact area and sliding speed of the components. Solid friction regards the friction between two solid surfaces at dry conditions, without lubrication. (Yukio Hori, 2006)

Application

The 3x230/400V, 50Hz power plant of the ARTHUR WLS, constitutes the primary power supply for the whole radar system, therefore considered a vital part for the continues operation and function during mobile military applications. Thus, the reduction of service intervals is essential, which requires an efficient and low maintenance lubrication system. As for most mechanical engines, the lubrication of the physical engine parts is done by standardized motor oils. For normal environmental conditions, specified in chapter 4.1, SAAB EDS uses 15W-40 mineral oil, a standard established by Society of Automotive Engineers (SAE), stating the viscosity grade and W for Winter-application. However, if the temperature drops below -15°C, no mineral oil can be used, forcing SAAB EDS to use the less preferred 5W-30 synthetic oil. But the main issue addressed here, concerns the frequent service intervals, every 250 hours during continuous operation, partly caused by polluted engine oil. Hence, a solution is sought that can extend the service intervals by reducing the required oil changes.

Material

Through the study of available nanomaterials, it was observed that normal motor oil is significantly improved by adding dispersed nanosized particles. According to specification, this nanofluid related lubricant (see chapter 3.8), manufactured and commercialized by the company ApNano Materials Inc, reduces wear and friction in engines, potentially prolonging service intervals (ApNano, 2012). The specific product is called NanoLub® RC-X, which is a solution made out of mineral oil and nanosized particles, to be mixed with conventional motor oil in a certain concentration, varying between 2 - 7%. The dispersed nanoparticles in the lubricant constitute a fullerene-like nanoparticles (see subheading under chapter 3.3.1) of tungsten disulfide (WS_2), denominated NanoLub® RL by the developer ApNano. By delivering the nanopowder dispersed in oil as a carrier, with a viscosity of 98 – 115 cSt at 40°C, the problem of agglomeration between nanoparticles is solved. Thus, by just adding a small amount of this additive to the host oil, which works fine even when the viscosities are rather different, the wear and friction is significantly decreased, minimizing maintenance and extending engine lifetime. The effect of reduced wear and friction is illustrated in the following chart, Figure 19, published by ApNano.

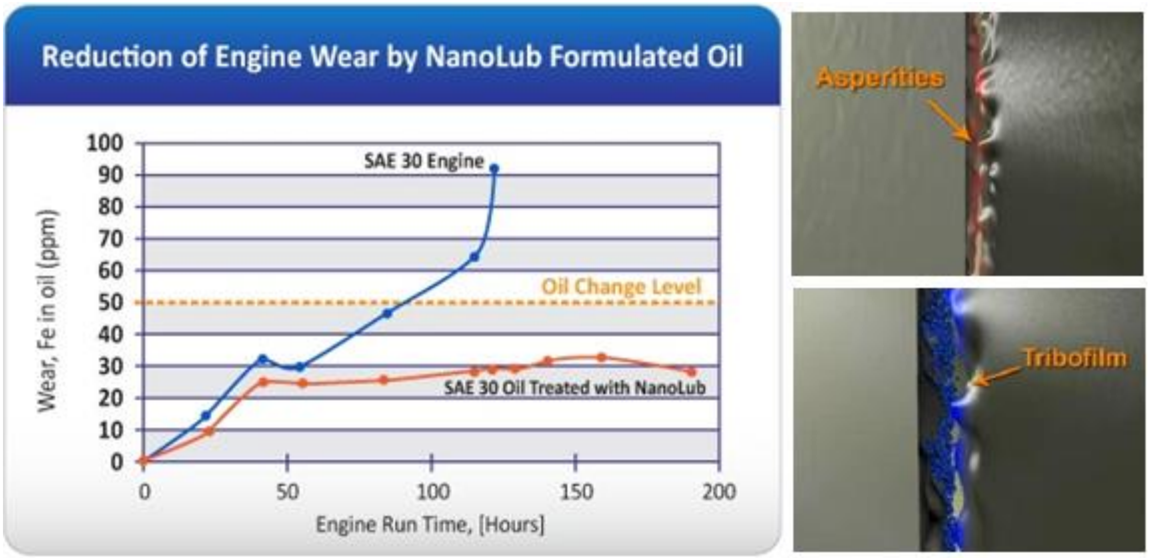


Figure 19 - In the table to the left the correlation between reduced wear and increased service intervals is illustrated. The upper right picture shows surface asperities causing friction while the picture underneath depicts the effect of NanoLub and the reinforcing Tribofilm. (ApNano Materials, 2012)

Verification

To compare the performance of the conventional motor oil with the new solution mixed in mineral oil, a test rig with an electric engine connected to the shaft of a combustion engine can be used. By running the electric engine at different speeds, towing the combustion engine, and measuring the power consumption, the idea is to prove that the oil with additive to a greater extent reduces friction and wear than the normal oil. While this test relates to a tribology test (“the science and technology of interacting surfaces in relative motion”) it does not provide a wear measure for the engine. Nevertheless, a closer analysis of the lubricant after the test might tell which oil contains less metal particles, giving an indication on the wear extent. Considering the temperature issue, the intended test does not provide any results on an increased resilience against heat neither does it state a decrease. Still, this might be an interesting property to analyse, although a separate test is needed, since the combustion engine in this test is not running by itself and therefore does not generate any heat.

Hence, in order to take on the lubricant for further examination, the performed test should prove to fulfil the following requirements:

- Clearly decrease wear and friction between engine components.
- Manage to be exposed to high temperatures.
- Improve engine lifetime and oil life.

5.4.4 Improved liquid cooling with nanofluid

More efficient cooling systems is a large research area since data centres gets bigger and power of electronics increases to which all requires efficient cooling. In many cases the cooling liquid itself can be the limiting factor because of insufficient heat conductivity. Recent science has shown that nanoparticles dispersed in the cooling liquid can strongly increase the heat conductivity in a cooling liquid. For SAAB EDS it would be of great interest to be able to increase the cooling efficiency in order to reduce weight and increase power in components. Therefore the nanofluid cooling liquid got a reasonably high score in the evaluation chart, even though no recognised manufacturer exists. However since this technology is said to be close to a commercial breaktrough and the potential at SAAB EDS is high it is chosen to be fully developed.

Theory

There are no existing model explaining the significant increase in heat conductivity by adding nanoparticles into a liquid (Liqiu Wang & Xiaohao Wei, 09). The increase can not only be explained by the increase in effective heat conductivity that the nanoparticles would give rise to. Many models are developed trying to explain this, where most theories suggest that the thermal boundary layer is affected in a way that heat is conducted much more efficient. The following factors are proposed to be additional reasons for an enhanced thermal conductivity:

- Vastly increased particle area.
- Particle migration could cause a non-uniform distribution of heat conductivity and reduce the thermal boundary layer thickness (Dongsheng Wen & Yulong Ding, 2004).
- Flow properties could be affected, creating turbulent flow on a very small scale (A. Mokmeli & M. Saffar-Avval, 2009).

Application

Nanofluids main applications are within cooling as a substitute for conventional cooling liquids such as water or glycol. SAAB EDS do always want to increase the capacity of their radars and for that more energy is needed. This always generates excessive heat that must be led away and that is done both with air and by fluids in present applications. With an ever increasingly demand for better radar performance new cooling technologies needs to be developed.

In this concept it is chosen to focus on cooling of a circuit board inside radar that is mounted in its ends where heat needs to be dissipated quickly to cool the circuit board. The equipment is placed within an airborne radar system which makes weight an important property. All heat is generated on the circuit board and all the cooling is carried out in its ends where it is attached to the holder.

Because it is not possible to cool the whole circuit board that generates heat evenly distributed over the board's surface, efficient cooling in its end is critical and governs the amount of power the radar is allowed to consume. With a nanofluid as cooling liquid more heat can efficiently be dissipated and the power of the electronics can be increased which raises the performance of the radar system.

Material

There are many different kinds of nanofluids where both the dispersed particles and fluid can consist of different elements. Underneath are some stated examples found in scientific papers where nanoparticles enhances the heat conductivity in a fluid:

- 10nm Copper nanoparticles in ethylene glycol are proven to increase the heat conductivity with as much as 40% with 0.3% volume fraction of copper particles.(Eastman et al. 2001)
- Alumina nanoparticles increase the heat conductivity with 12% at 3% volume fraction in water. (Wang et al. 1999)
- MWCNT with an average diameter of 25nm and a length of 50μm increases oil fluids heat conductivity with 250% at a volume fraction of 1% CNT. (Choi et al. 2003)

With these examples it is hard to understand why nanofluid coolants are not in wider use. However in the examples above factors like stability is not considered, which is one of the largest issues concerning nanofluids. It is important that nanoparticles have more repellent forces between one another than attractive forces in a suspension in order to prevent clogging because of agglomeration. This is today done with surfactants that serves as dispersants and changes the surface tension of particles. The stability of a suspension is normally described by how often particles collide with each other and what the probability is for cohesion when they do collide (Wei Yu & Huaqing Xie, 2011).

Verification

To verify the performance of the concept with nanofluids compared to conventional cooling liquids such as water and glycol advanced models can be used to numerically estimate the power of cooling. Another way is to adopt the results obtain on heat conductivity from various published articles and analyse how higher heat conductivity increases the power of cooling and decreases temperatures in the intended application.

The best verification method would be a physical test where properties as viscosity, stability over time, toxicity and heat conductivity would be investigated.

5.4.5 Prevent gas pollution from outgassing polymers

Two different concepts to improve air quality inside lasers were developed. Both got a good total score in the Evaluation chart, see Table 1 and since tests already exist in-house to prove their performance and are possible to buy they were chosen to be further developed. In one of the concepts a nano porous material is used to adsorb gas compounds selectively, the other concept regards a dense coating on parts inside lasers that releases unwanted compounds.

Theory

To analyse how different elements in gases react, diffuse or dissolves it is of importance to know the partial pressure. The partial pressure is the pressure a compound in a gas would give rise to if it was secluded and put in a vacuum chamber of the same volume.

$$p_i = x_i \cdot p \qquad (5)$$

Equation (5) shows how the partial pressure of a specific compound, p_i, in a gas is equal to the mole fraction, x_i, of the same compound times the total pressure, p, of the gas mixture. This is for example of importance concerning gas penetration of thin films and how gases react with surfaces.

Application

SAAB EDS have many different lasers designs, thus we have chosen to focus on lasers in general. The laser is described in chapter 4.6 where general information about all SAAB EDS lasers are covered.

Inside a laser it is very critical to have a clean environment because lenses are sensitive to get contaminated with dirt. Some of the maintenance work with lasers has to be done in a cleanroom and unwanted gases or particles inside lasers are not desirable at all and can reduce the performance. For some temperatures inside lasers polymer components can gas out. These gases can when exposed to a laser beam be burned onto the surface of the lens. This can harm the laser and over time even damage the optics severally, see Figure 20.

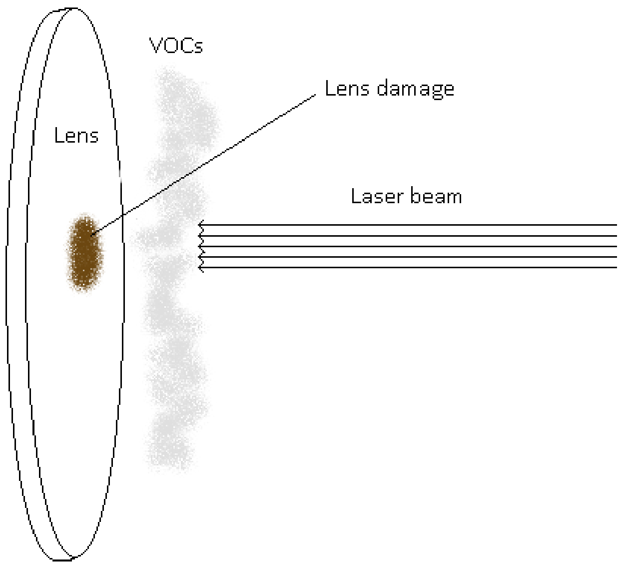


Figure 20 - Illustration of how polluted air damage lens in a laser.

It has been tried to reduce these gases also known as VOCs (volatile organic compounds) with zeolite adsorbents but not without also adsorbing water in the air. This reduces the effectiveness of the zeolites. Therefore two alternative solutions will be presented that solves the problem in a better way preventing the lenses of getting damaged.

Adsorbent material

One way to keep a clean atmosphere inside lasers is by using adsorbents that effectively attract unwanted molecules. Adsorption is not to be mixed up with absorption which acts more similar to a sponge. Adsorption on the other hand collects matter by reacting with molecules so they get stuck on the surface of the material. Materials with a vast surface area compared to its volume are preferable used as adsorbents. This makes it possibly to manufacture rather small but effective adsorbents. Zeolites that are described in chapter 3.6.1 are an excellent alternative to use. A company specialized in zeolites is the Swedish company NeoZeo AB that work with tailor make zeolites as to pore size and surface reactivity properties concerned. Most zeolites are hydrophilic and adsorb water which in the lasers is not desirable.

NeoZeo claims they can produce a hydrophobic zeolite that still could work to attract VOCs such as aromatics but repel water. If this is proven to be correct it could be of great interest.

Barrier material

Instead of adsorbing compounds in the air as the zeolites material do, this concept can be used to seal components that normally gas out so the air never gets contaminated in the first place. This is done with a nanomaterial consisting of layered silicate particles dispersed in an elastomer being coated on affected polymers. Layered silicate nanocomposites have been known for roughly 20 years now (Kojima et al. 1993) and show good barrier properties. Many sources confirm remarkable barrier properties with just 5wt% layered silicate dispersed in polyimide, polyester and epoxy matrices (Chunsheng Lu & Yiu-Wing, 2007). However other properties are also improved such as stiffness, thermal stability, wear resistance and strength (Chunsheng Lu & Yiu-Wing, 2007).

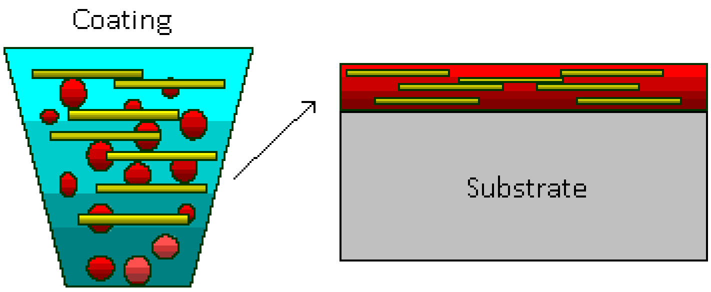


Figure 21 - Illustration of Nanolok™ barrier.

A company called Inmat deals with layered silicate composites and are specialised in barrier properties. They have a number of different barrier composites but one is particular interesting which is the Nanolok™ film, see Figure 21, that can be applied through spray or dipping processes. This material is advantageously coated on a PET substrate and has an oxygen permeability value of only 0.2-0.6 cc-μ/m2-day-atm. The coating does not contain any VOCs itself and meet many demanding toxicity requirements since it is used in food packaging industry.

Verification

The adsorbent zeolite should be able to efficiently adsorb aromatics such as toluene and naphthalene and not adsorb any water. The test will be divided in two parts, first a water adsorbent test will be carried out by measuring the weight increase of the zeolite after a specified time, temperature and a controlled humidity inside a closed space. If the zeolites weight has increased it has adsorbed water which is not desirable. The second part will be carried out in the same way but with aromatics added. This time it is possible to compare the results with the first test and through that estimate if any aromatics have been adsorbed.

The barrier concept will be verified with a different method since this material does not adsorb any gases but cleans the air by preventing polymers from gassing out. How well it seals outgassing materials will be measured with a FTIR (Fourier transform infrared spectroscopy) that can estimate concentration and what elements are present in a specific specimen. A polymer is with this test coated with the barrier material and put in a small closed space where it will be heated up to a temperature to which the underlying polymer normally gas out. If the FTIR equipment can not detect the same elements that are present in a reference sample without any coating the barrier has worked efficiently. If new elements are detected that are not present in the reference sample the seal itself has given off compounds. It might also be necessary to conduct the same test but keep the specimen heated inside the chamber a longer time to obtain aging effects.

5.4.6 Efficient antenna application with nanocapacitor spray

This concept goes under the label unclassified nanomaterials and did not get many points in the evaluation chart, see Table 1. Despite that, this concept was chosen among the high value concepts because of SAAB EDS interest in antenna systems which is their main business. The reason for its low score in the evaluation chart is mainly because there are no commercially ready products and the technology is still in its infancy.

Theory

An antenna is a device that can convert oscillating electrical currents into electromagnetic waves. Most antennas today are made of conducting metals such as copper, aluminium, steel and magnesium depending on the environmental requirements (Blake Lamont V & Long Maurice W, 2009). The frequency range of radio waves that have practical use lies within 10 KHz -100 GHz, however, in radar applications the range normally lies around 1-30 GHz (Blake Lamont V & Long Maurice W, 2009).

$$\lambda = \frac{v}{f} \tag{6}$$

The relationship between frequency f, wave propagation speed v and wave length λ is showed in (6). The propagation speed for electromagnetic waves in the earths atmosphere are close to the speed for vacuum and is therefore in most cases set to 299,79 km/s which is the speed of light.

Application

Even though the antenna was invented over 200 years ago today’s antennas still remain based on the same technology. This technology involves a copper wire that is wound in different configurations to obtain certain properties. One drawback with this system is that to get the antennas to send and receive signals power is needed and conventional antennas consume a lot of energy. Consequently heat is created that needs to be led away which becomes the limiting factor of how long range an antenna can have.

Material

What the company Chamtech operations have found is that with a material that consists of small nanocapacitors applied to a surface can do exactly what antennas do. This material is applied to any surface to which nanocapacitors align themselves in a pattern that allow them to take up charge and discharge extremely fast. This is done without generating any noticeable heat. The material can be sprayed on almost any surface and has been successfully tested with results being as efficient as the best antennas on the market.

Unfortunately Chamtech has exclusive right to this material and therefore it is difficult to evaluate properties of such antennas, but it should be mentioned that it is not a novel idea. The idea of a spray on antenna system has been thought of in the defence industry a long time (Kenyon, Henry S, 2001). Also recent papers proves that nanomaterials with special dielectrical propeties advantageously may be used in antenna applications (Atul Thakura et al. 2010), which strengthens the fact that Chamtech has developed and found an applications for these very new nanocapacitor composites.

Verification

When no possibilities exist to do tests and verify the properties of this material this chapter still serves its purpose to keep this material in mind for the future.

5.4.7 Rain erosion resistant coating

Based on the high value obtained in the Evaluation chart, see Table 1, the coating for erosion resistance was found to be worthy further examination, especially considering the very clear application in mind at SAAB EDS.

Theory

The underlying problem of rain erosion damage and the theory is quite complex. To accomplish an erosion resistant coating, there are many different factors to take into account, whereas the most important ones are hardness of the material's surface (resistance to plastic deformation due to indentation, measured in Vickers) and the impact velocity of the water droplets. However, other factors such as the bonding between coating and substrate and angle of incidence of the drops (angle relative to the surface direction of movement, usually set to 0°) as well as the material density and E-modulus should all be considered influential. (H. Busch et. al, 1966)

Comprehensibly, all the constituents mentioned above cannot be anticipated all at once while some may not even be estimated in theory. Yet, since rain erosion occurs when small water droplets strike a surface at high speeds, the most convenient situation to analyse in theory is the moment of impact of a water droplet, see Figure 22. (G.H. Jilbert, 2000)

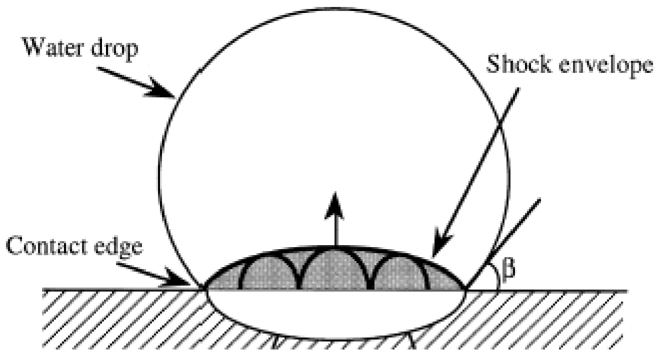


Figure 22 - Initial situation a short time after impact of a water drop on a solid surface. (G.H. Jilbert & J.E. Field, 2000)

Due to compressible effects occurring in the liquid at impact, so called “water hammer” pressures cause damage to the material’s surface. With the anticipation of a rigid surface, this specific pressure can be calculated in theory by

$$P = \rho \cdot C \cdot v \tag{7}$$

where ρ equals the material density and v refers to the impact velocity. The shock velocity C, relates to the acoustic velocity ($C_0 \approx 1500$ m/s for water) and can be determined as

$$C = C_0 + k \cdot v \tag{8}$$

with the constant $k \approx 2$ for water at velocities of v up to 1000 m/s. (G.H. Jilbert, 2000) While this theoretical pressure may not indicate whether a material is erosion resistant or not, it provides an indication on what forces a rain erosion resistant material has to sustain.

Application

Due to the harsh operation environment of the IFF Blade Antennas (Identification Friend from Foe), placed on top of the DOU (ERIEYE), puts tough requirements on the coating. In particular, the erosion resistance is essential since the antennas are exhibited to heavy rain and snow at a TAS (True Air Speed; the aircrafts speed relative to the airmass in which it is flying) of approx. 128 m/s when airborne. Furthermore, most of the remaining requirements conform to the ones already stated in chapter 4.1, as for instance the temperature and pressure, including extreme values and swift changes, as well as the average solar radiation. Electromagnetically compatible (EMC) with components installed outside the DOU, the equipment is supposed to retain its structural integrity even when subjected to a lightning strike. Finally, since the antenna is transmitting signals, it should be ensured that the coating does not interfere with this function.

Material

The Vecdör X-SC Nanocoating, manufactured by the company Nanovere Technologies, proved to be the most interesting alternative for the intended application, with a product already in use and available on the market. According to the company, the coating is specifically developed for aerospace applications with good self-cleaning properties, 50% lower water drag resistance and significantly reduce ice adhesion. Additionally, due to the environmental requirements, the coating is specified to conform to a temperature service interval between -54°C to +177°C and provides improved UV-resistance. Most importantly, Nanovere also stresses that the coating has passed Boeings challenging tests of scratch, chemical and rain erosion resistance. Furthermore, the coating has also been subjected to several ASTM standard tests, including salt spray for 3000 hours, abrasion resistance and impact resistance (Nanovere, 2012).

Since this is a nanomaterial, it is the utilization of nanotechnology that provides these desired properties. But unlike most nanocoatings, using dispersed nanoparticles as the enhancement element, the Vecdör X-SC Nanocoating has a 3D nano-structured architecture that lends it unique physical properties. Nanovere claims that they have created a harder, more flexible and scratch resistant material from the original material.

Verification

To verify the credibility of the above mentioned erosion and abrasion properties, mainly taken directly from the company’s specifications, the project should strive towards performing an erosion related test similar to the once already done for the coating in use today. These former tests were conducted at SAAB's rain erosion test rig in Linköping, illustrated in Figure 23 below. It comprises a rotating arm, to which in the outer end the sample is attached, and 6 rain drop generators exposing the sample to rain like conditions, thus enabling a very realistic test simulation. In order to perform this test, identical samples have to be prepared in disc like shapes of 5 cm in diameter, one treated with the present coating while the other is covered with the suggested substitute material Vecdör X-SC. One by one these samples are then fastened in the test rig and by accelerating the outer end of the rotating arm to speeds of up to 300 m/s while subjecting the sample to 2 mm raindrops, potential erosion damage might occur after a specific period of time. Afterwards, the coated samples are compared and thoroughly examined for erosion damage and analyzed on a microscopic level if necessary.

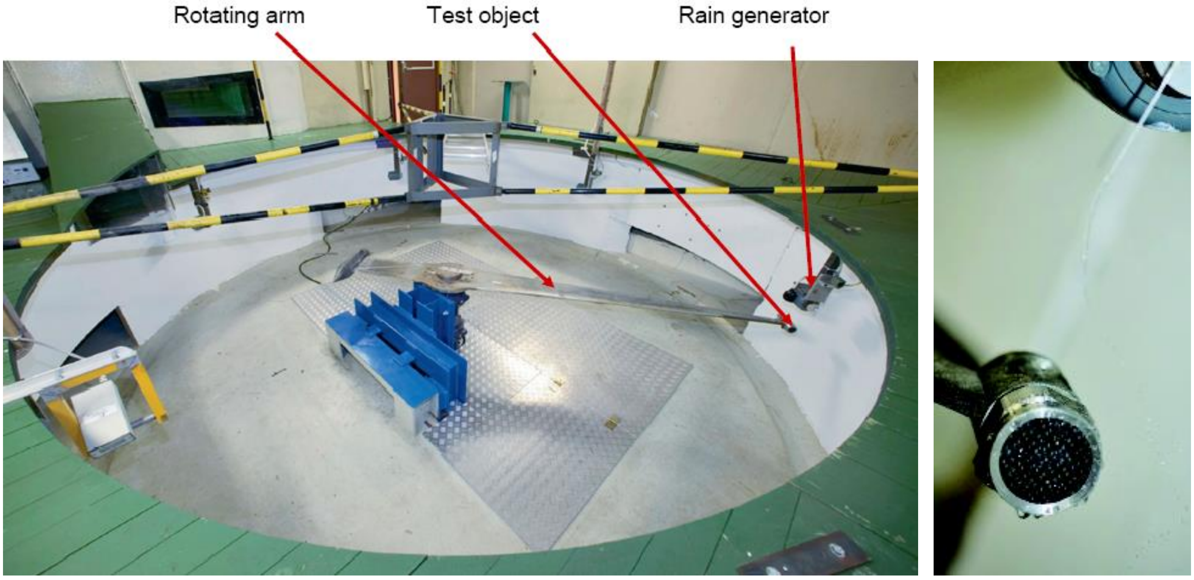


Figure 23 - The left picture depicts the rain erosion test rig and the right picture shows a detailed view of the sample attachment with a black test specimen.

Due to the importance of compatibility with other components, it would also be advisable to carry out an EMC-test for verification as well as a test to measure the coatings shielding properties, since it is covering an antenna. Both these tests may be performed at SAAB EDS with present test equipment.

5.4.8 Electrical contact coating to prevent fretting

As this concept received the highest rating in the Evaluation chart, with a clear application at SAAB EDS, good material properties and manufacturing availability, it is an evident candidate to take on for further examination.

Theory

Fretting is a common problem associated with electrical contacts subjected to high frequency vibrations and thermal expansion, resulting in increased contact resistance and possible failure. Initially, before the fretting problems occur, the contacts will form so called a-spots, metal-to-metal contacts with low contact resistance, by plastically deforming surface asperities (Michael D. Bryant, 1994), illustrated in Figure 24.

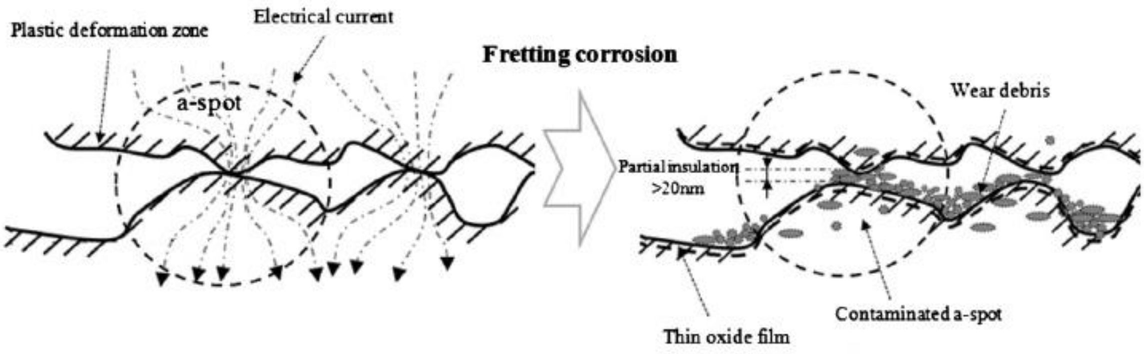


Figure 24 - The left picture depicts the forming of a-spots and the right shows the fretting process. (Kang Yong Lee et al, 2011)

Yet, after some time fretting failure takes place (Hong Tian et al. 1990), may be divided into fretting wear, fretting corrosion and fretting fatigue. At the wear stage, contact surfaces are slowly worn down due to the friction caused by vibrations, although not significantly influencing the conductivity and only filling some of the cavities, as illustrated in the right picture of Figure 24. But as the protective surface is worn down exposing the more corrosion sensitive substrates, fretting corrosion will further increase contact resistivity. Ultimately, as vibrations continue and therefore also the friction between surfaces, wear debris and oxide particles accumulate and form an insulating layer that eventually may cause connection failure. Concerning fretting fatigue, it is referred to the situation when a considerably high friction coefficient and contact pressure leads to fatigue cracks. (Hong Tian et al, 1990)

Theoretically, it is hard to analyse the fretting properties of contacts and few reliable calculation methods exist. However, there are available computational methods to anticipate the electrical resistance of a fretted contact, recognised as an accepted measure of a material's fretting properties. (Hong Tian et al, 1990)

Application

As the application areas at SAAB EDS were discussed, the company mentioned backplane board contacts located in high frequency exposed vehicles, on which fretting resistance could be improved. Temperature requirements of the contacts are set to 1000 hours at 125°C. Furthermore, regarding the more important fretting related requirements, the solution should be able to cope with a Random Vibration of approx. 0.6 G^2/Hz, since this is determined to be the main fretting cause. Even though the contacts used today, comprised of a gold coating on a nickel alloy substrate with a copper core by far exceed the performance in contact resistance, a more fretting resistant solution is sought.

Material

A thin alloy coating, associated with ceramic nanocomposites, see chapter 3.4.3, is composed of the elements titanium, silicon and carbon (Ti_3SiC_2) evenly distributed showing nanocrystallinity. Hence, a harder and more ductile surface is obtained, compared to hard gold plating, yet providing similar corrosion resistance and electrical conductivity. It is commercially available for production through the company Impact Coating, under the label MaxPhase film and is produced through physical vapour deposition in vacuum. Additionally, MaxPhase can be applied on large volumes at low cost and fortunately enough also has very good adhesion properties to all metal surfaces, including nickel on which it is usually applied. The coating thickness is generally between 0.5 µm to 2 µm and has a metal grey colour tone.

Testdata shows that the electrical contact resistance for the coating against silver was measured to 15 microohms (Babyak, 2010), which although higher than silver against silver (7 microohms) still provides a very satisfying electrical conductivity considering the electrical requirement. Furthermore, tests in a corrosion chamber, exhibiting the coating to corrosive gases at 70% humidity and 30°C for 27 days, showed that the contact resistance was not influenced at all. The hardness was obtained from tests as 5 - 10 GPa, a rather good value compared with hardened steel.

Due to the relatively high hardness, it was anticipated that the MaxPhase coating would prove to have good fretting resistance compared to for instance gold. Unfortunately, a dialog with the supplier Impact Coating revealed the contrary, making a test to analyse this property unnecessary. According to them, an unofficial fretting test showed that the material, regardless of its high hardness, is not suitable for vibration intensive applications due to low fretting resistance. Thus, all the excellent properties specified for the MaxPhase coating, it lacks the ability to handle the most important requirement and is therefore not taken into further consideration.

However, there are other interesting coatings that might work better considering fretting purposes. One particular coating is the thin gold film with dispersed zirconia nanoparticles as strengthening mechanism, which points at improved fretting resistance. (Jesse Robert Williams, 2008) Unfortunately, this material is still in the research stage but could be interesting to investigate in the future.

Verification

To be able to measure the fretting resistance of the contacts, coated samples may be fastened to a test rig placed on a vibration table. Due to the correlation of corrosion as a result of fretting, it would be preferable to place the whole equipment in a corrosion intense environment. After a reasonable period of time, the contacts are removed from the rig for examination and by measuring the contact resistance and analyzing the fretting sensitive areas with a microscope, potential weaknesses might be revealed.

6 Design of tests

Although most of the fully developed concepts are provided with a verification method, only two have been chosen to be evaluated and verified through tests, due to the limited timeframe and cost. The performed tests differ in the way they are conducted, one being physically tested while the other is done numerically, yet both focus on the improvement properties that the new materials might lead to. In the following sub-chapters, the test designs are thoroughly described, while the test results are presented in chapter 7.1 and 7.2.

6.1 Finite element analysis of heat sink

A numerical thermal analysis of an aluminium plate to which electronics are mounted, is performed through a finite element simulation, using Nastran/Patran analysis tools. Optimizing the aluminium plate for lowest weight, as discussed in chapter 5.4.1, both a conventional aluminium alloy and aluminium with dispersed CNTs are analysed and compared. All variables required for the analysis, related to the products environment and dimensions, are estimated but correspond to reality.

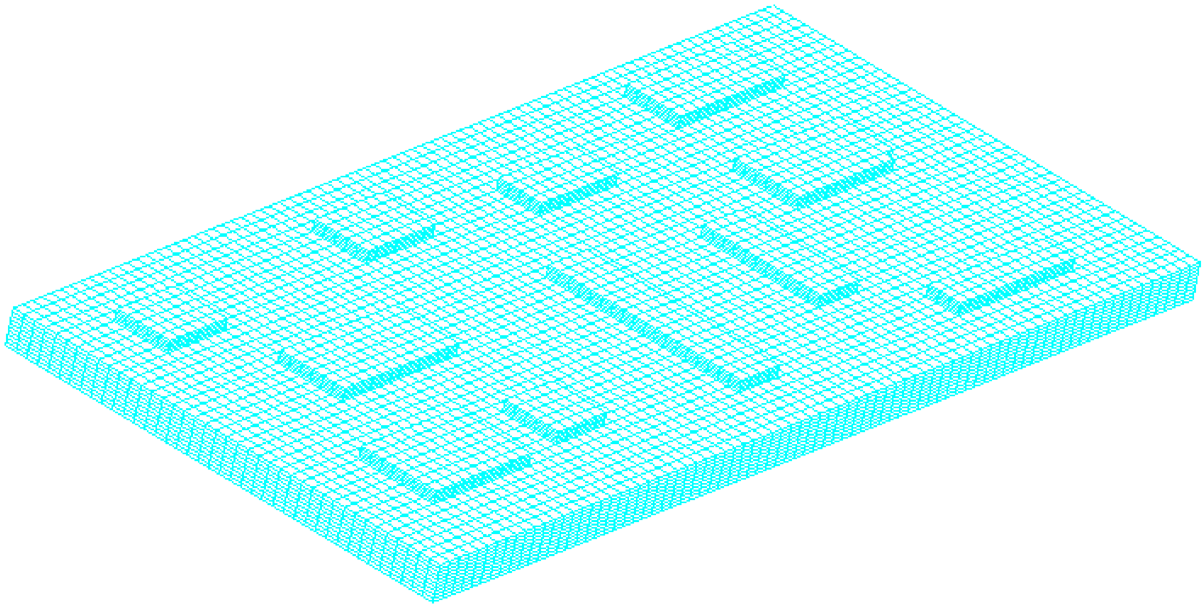


Figure 25 - Mesh of the heat sink.

6.1.1 Objective

This tests main objective is to estimate the achievable weight reduction, when an 81% increase in heat conductivity is adopted for the aluminium heat sink.

6.1.2 Procedure

The main geometry and mesh is defined in the computer aided design software Patran and consists of more than 32000 quad elements, see Figure 25. The model is analysed with Nastran, a finite element analysis program, where it is divided into the three main parts, bracket, thermal interface material and heat generating electronics, all with specific attributes assigned to them.

Table 2 - Material data.

Materials	Heat capacity [J/(kg·K)]	Heat conductivity [W/(m·K)]	Density [kg/m^3]
Aluminium	900	237	2700
Aluminium with CNTs	900	429	2700
Silica (interface)	700	Interface 10(148)	2330

Table 3 - Part information.

Part	Dimension [mm]	Material	Thermal Load
Bracket	200·400·20	Aluminium	Convection: 400[W/m^{2}K], Cooling liquid temp. 10°C
Interface material	Thickness 2	Silica	-
Electronics	Various	Aluminium	Total heat, 500W

First, in order evaluate the concept a reference bracket is analysed with dimensions specified in Table 3, where the cooling is simulated as described in chapter 5.4.1. As a result, a temperature gradient figure is obtained, also displaying maximum and minimum temperatures.

The same is carried out for the aluminium with dispersed CNTs, which provides a separate temperature gradient figure. Now, by reducing the thickness of the aluminium-CNT bracket until the two gradient figures are similar, it is possible to estimate how much the thickness and thus the weight, which should be optimised, can be lowered without reducing the performance.

6.2 Verification of nanofoil joint properties

The following chapter describes objectives, preparations and test procedures necessary to proper evaluate the potential to use nanofoils for welding. In chapter 5.4.2 the intended application and nanofoils are thoroughly described.

6.2.1 Objectives

By performing tests on joints made with nanofoils, the following properties are to be evaluated:

- Tensile and shear strength of the joint.
- Electrical conductivity.
- Microstructure after welding.

6.2.2 Material

Aluminium 6082 was chosen as substrate material since this is used in the waveguides today. Furthermore, due to the adhesion properties of the joint, the surface finish is set to Ra 3,2 and requires a coating of 1-2 µm nickel covered by 2-5 µm tin, as recommended by Innojoin.

6.2.3 Dimensions

The dimensions of the aluminium test samples, illustrated in Figure 26, are accustomed to the limitations set by the tensometric test rig, both considering dimensions of available test equipment and maximum allowed load case due to the joint area. The nanofoils, illustrated to the right in Figure 26, depict the original dimensions of the samples.

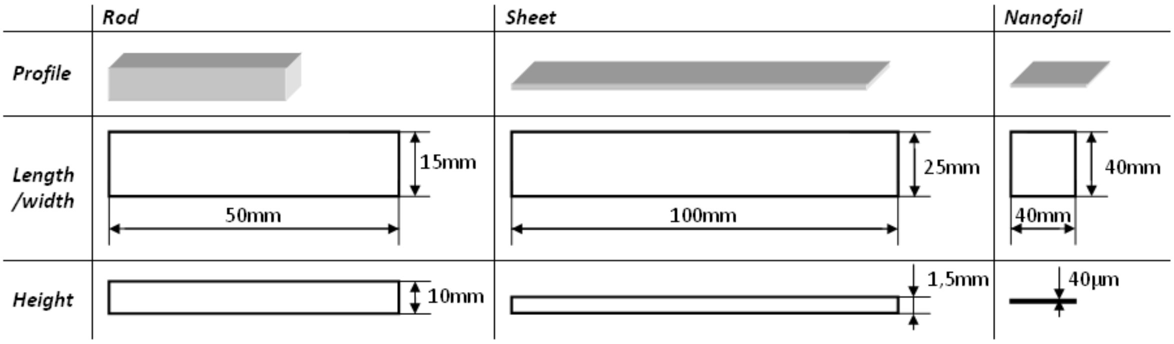


Figure 26 - Test sample dimensions.

As mentioned above the sample dimensions are set according to the allowed joint area, which in turn is controlled by the maximum load case of the test rig. Thus, through a dialog with the responsible test engineer, specifying the properties of the test rig, the joint areas are set as seen in Figure 27.

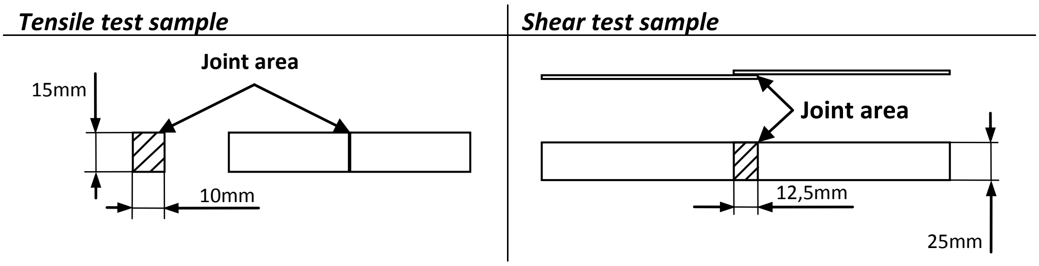


Figure 27 - Joint area of test samples.

6.2.4 Preparations

With specific dimensions set, the samples have to be prepared before the actual tests can be commenced. As necessary precautions, safety googles and gloves should be worn at all times when handling the highly reactive nanofoils. Now, as a first step the original nanofoils are measured and cut to dimensions corresponding to the joint areas, using a pencil, ruler and glasscutter as seen in Figure 28. Furthermore, in the instant of welding a pressure of approx. 0,34 MPa (specified by Innojoin) on the samples is essential to make sure that the surfaces are in full contact with the foil and ensure a good adhesion. Hence, a weight is used to put pressure on the shear samples while a vice fixture provides the pressure needed for the joining of the tensile samples, illustrated in Figure 28.

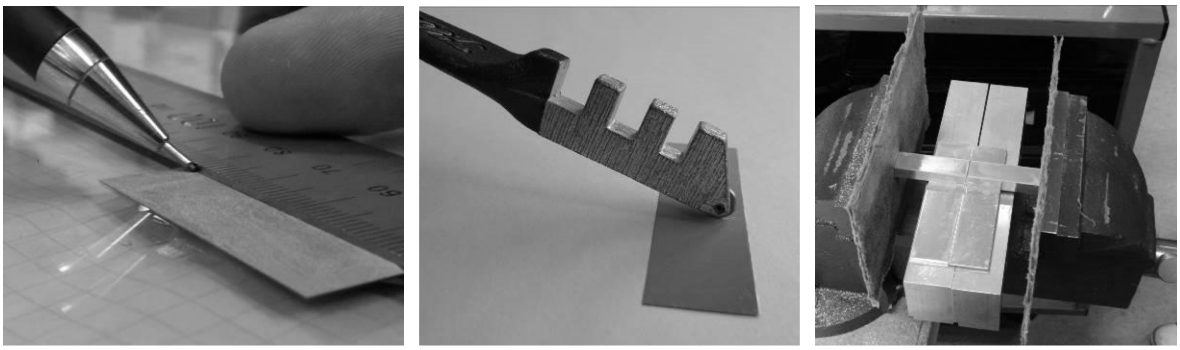


Figure 28 - From left to right: marking on a nanofoil; a glasscutter; vice fixture.

Now, to activate the foils an electrical pulse is applied by short circuiting a 9V battery against the protruding foil side, initiating an instant reaction, as seen in Figure 29.

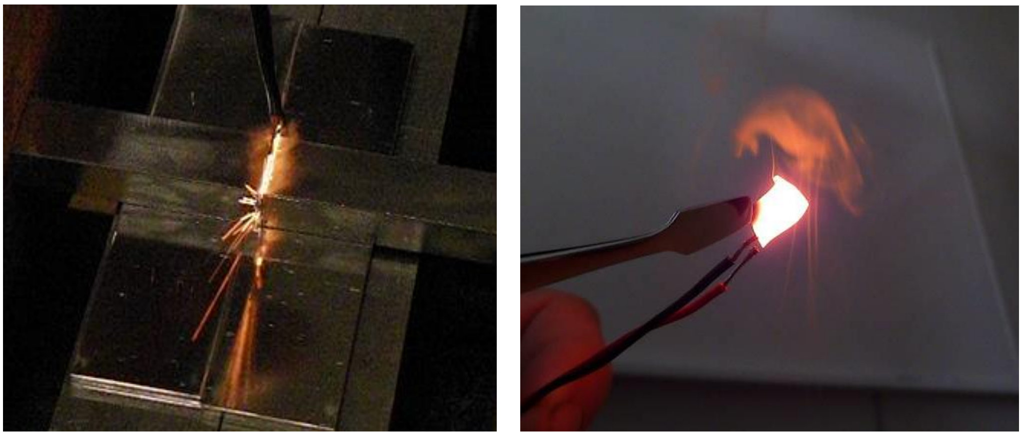


Figure 29 - Activate nanofoil by short circuiting a 9V battery.

6.2.5 Electrical conductivity

To ensure that the joint provides adequate electrical conductivity, the resistance is measured. This is done by using a micro-ohm meter with connected point probes held to the rods/sheets on each side of the joint, see Figure 30, after the welding process.

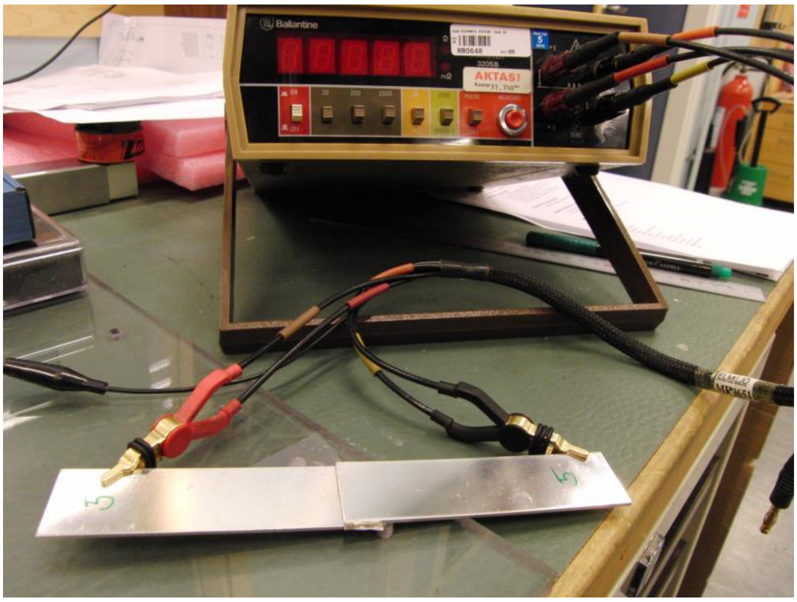


Figure 30 - Measuring resistance over joint with micro-ohm meter.

6.2.6 Strength analysis

After the welding process, separate load tests to measure the tensile and shear strength are performed in a tensile test rig at SAAB EDS, to analyse the mechanical properties of the joints. At a speed of 2mm/min the machine, model Alwetron TCT50 by the company Lorentzen & Wettre, pulls the joint samples apart, continuously measuring the applied force as well as the elongation until failure. To produce reliable test results, five joint samples are used for each strength analysis, see Figure 31.

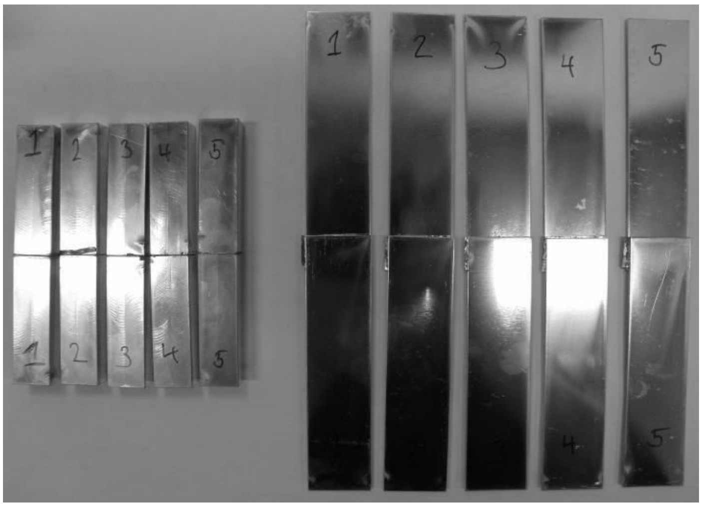


Figure 31 - Joined test specimen, 5 rods to the left, 5 metal sheets to the right.

Tensile stress test

For the tensile stress test the tensile samples are mounted into the fixture of the test rig, as illustrated in Figure 32.

Figure 32 - Fixture of tensile test rig with tensile sample.

Utilizing both the measured force, *F*, and the cross-sectional area, *A*, the tensile stress, *σ*, can be derived from the definition of tension in equation (9) (Hans Lundh, 2008):

$$\sigma = \frac{F}{A} \qquad \textbf{(9)}$$

Apart from the applied force, the test rig also measures the elongation, i.e. the extension of the sample. However, converting this length unit into percent elongation, *ε*, and combining it with the tensile stress measures, enables the plotting of a stress-strain curve as well as calculating the modulus of elasticity, *E*, for the joint, through Hooke's law:

$$\sigma = E \cdot \varepsilon \qquad \textbf{(10)}$$

The E-modulus gives a measure on the stiffness of the joint, provided that the elongation has not reached plasticity. (Hans Lundh, 2008)

Shear stress test

As for the tensile test procedure, the samples for the shear stress test are assembled with the same joining method. In this case the sheets from Figure 26, are joined as illustrated in Figure 27 and subsequently mounted into the test rig, as seen in Figure 33.

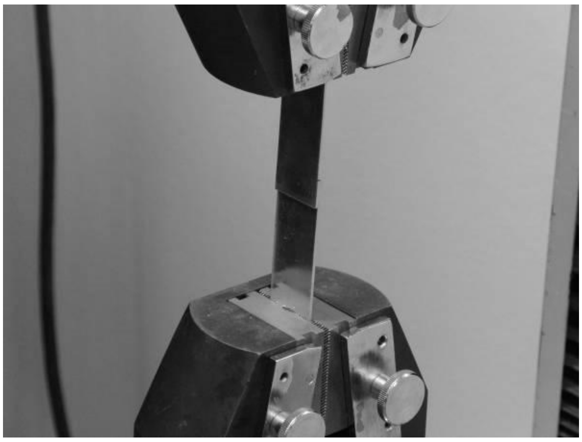


Figure 33 - Shear strength test samples mounted in tensile test rig.

For this load case, a similar definition of Hooke's law for shear stress τ, states

$$\tau = G \cdot \gamma \qquad \textbf{(11)}$$

where G is designated the shear modulus and γ corresponds to the shear strain of the joint. (Hans Lundh, 2008)

6.2.7 Microstructure analysis

While the stress tests provide important measures on the strength properties of the joint, it might also be interesting to look at the microstructure, to determine how well the nanofoil merges two aluminium specime

n on a microscopic level. With a cross-sectional cut through a prepared sample, using a metal cutter, it is possible to analyse the interface microstructure between nanofoil, coating and aluminium sheets. Based on the starting point of the nanofoil reaction, the cutting direction is set parallel as well as perpendicular to the propagation direction. To achieve a good microscopic image quality of the interface, the surfaces need to be polished using sandpaper of different roughness. This polishing process is divided into four different levels, going from fine to very fine papers. However, before the polishing is initiated the samples are moulded in an epoxy polymer in order to provide a stable grip, see Figure 34.

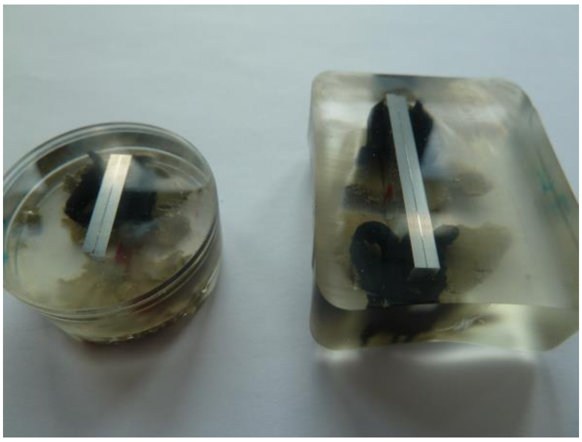


Figure 34 - Joined aluminium sheets moulded in epoxy.

By first analysing the samples with an optical microscope, special characteristics of the joint such as faults, cavities, irregularities and other visual information can be observed and help to evaluate the performance of the joint. Different magnifications are used to adjust to what is observed.

To receive clearer topographical images, the same samples are analysed with Scanning electron microscopy (SEM). Although the main purpose of this alternative observation is to determine what substances are to be find in the joint, by analysing the characteristic x-rays emitted when electrons are aimed at the surface. This is possible with energy dispersed x-ray spectroscopy that captures the emitted x-rays, and since all elements have different spectra the different substances in the joint can be determined.

7 Results

To refer back to the idea of value creation for SAAB EDS, many concepts have been refined and compared. After a thorough investigation of the concepts presented in chapter 5.4, more information was gathered that could either strengthen the potential of a concept as well as reduce potential. Therefore, the fully developed concepts are divided into three different categories based on potential for implementation. The result of this categorisation is presented under chapter 7.3, 0 and 7.5, where emphasis is put on the potential of each concept to be used in future applications within SAAB EDS.

The results of the two tests described in chapter 6 are presented in the following subchapters, including data from the numerical analysis of a heat sink as well as the physical tests of a nanofoil joint.

7.1 Aluminium heat sink test results

The thermal finite element analysis shows that an increase in heat conductivity of the aluminium heat sink, described in chapter 5.4.1, clearly lowers the temperatures in the material.

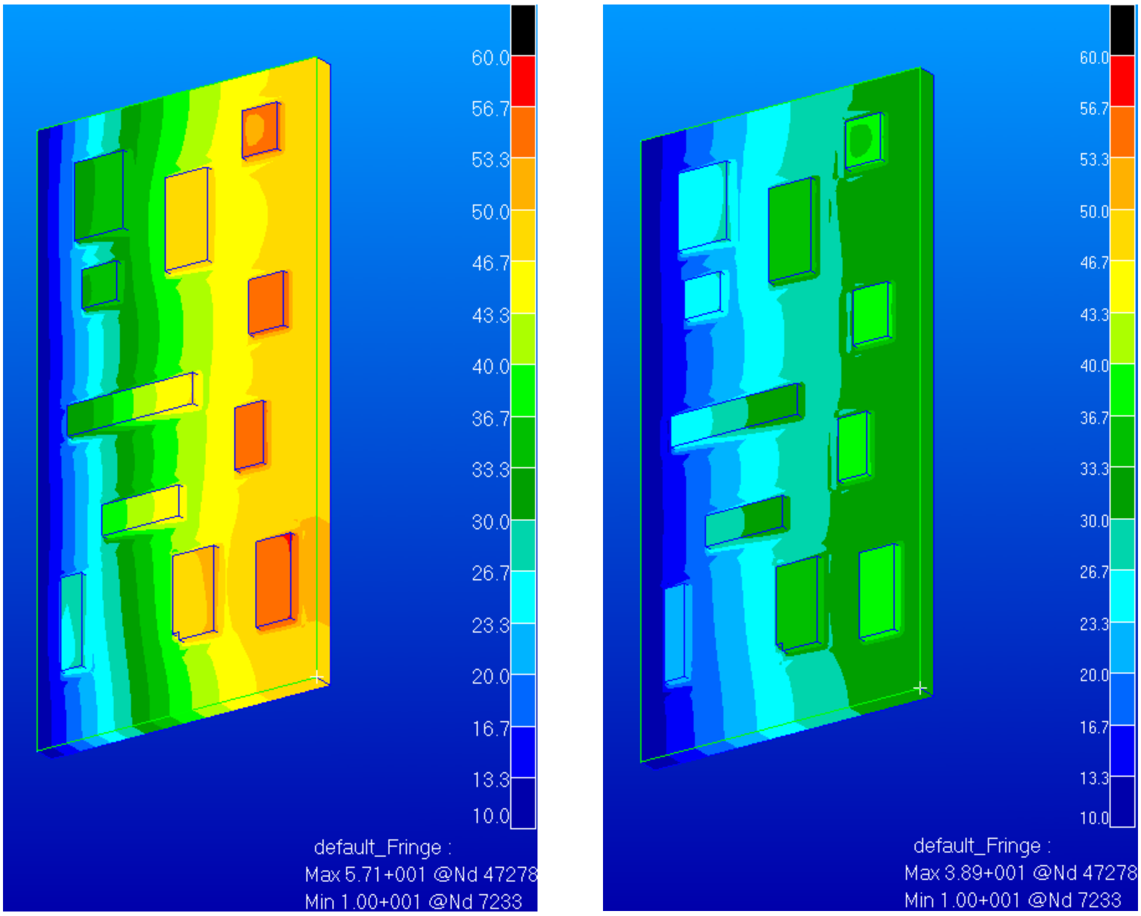


Figure 35 - Temperature gradients [°C], (a) Aluminium, (b) Aluminium with CNT.

Figure 35 shows two dimensionally equal heat sinks where (a) consist of aluminium while (b) has additional CNTs dispersed in aluminium. The temperature gradients are between 10°C and 60°C, displayed in a colour plot. The highest obtained temperature with solely aluminium is 57.1°C, corresponding to the orange-red fields in Figure 35 (a), compared to 38.9°C, marked as light green fields in Figure 35 (b), for the aluminium plate with CNTs. This difference is achieved by an 81% increase in heat conductivity due to the dispersed CNTs.

Evidently, the temperature fields have shifted further away from the cooled side, seen as blue in Figure 35 (b), for the CNT dispersed aluminium plate compared to Figure 35 (a). Hence, while the temperatures closest to the cooled side are quite similar, the more noticeable temperature difference between the two analyses is achieved further away from the cooled side.

By matching the temperature plot in Figure 35 (a) with the high heat conductive CNT dispersed aluminium, a plate with half the thickness is obtained, as seen in Figure 36.

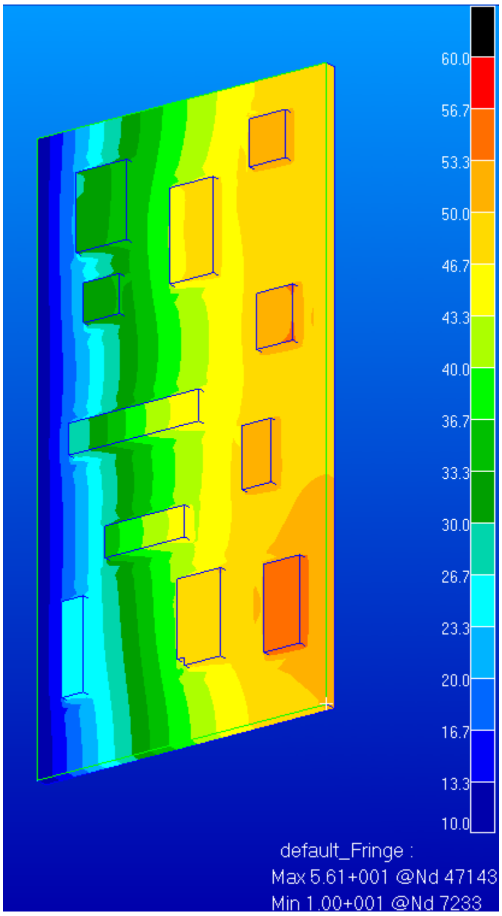


Figure 36 - Temperature gradients [°C], CNT dispersed aluminium plate with a 50% decrease in thickness.

The maximum temperature in Figure 36 differs only 1°C from Figure 35 (a). However, half the thickness of the heat sink compared to the original leads to a weight reduction of 50%, corresponding to -1.08 kg for the intended concept.

7.2 Nanofoil joint test results

As described in chapter 6.2, three tests are performed in order to verify the performance of the nanofoil joint. The tests comprise verification of conductivity, mechanical strength and visual evaluation of the joint in high magnification.

7.2.1 Conductivity over joint

The conductive properties of the sample joints seen in Figure 31, measured with the micro-ohm meter, are compiled in Table 4 and Table 5. All values are given in micro ohm.

Table 4 - Resistance over nanofoil joint with sheets of aluminium.

Sheet resistance [μΩ]	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Close to joint (ca. 1cm)	0.030	0.032	0.027	0.031	0.033
At the ends	0.173	0.181	0.177	0.178	0.171

Table 5 - Resistance over nanofoil joint with aluminium rods.

Rod resistance [μΩ]	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Close to joint (ca. 1cm)	0.001	0.000	0.001	0.001	0.002
At the ends	0.000	0.000	0.001	0.001	0.000

Considering the aluminium sheets, the results indicate that the resistance is low close to the joint and increase at the sample ends. Looking at the resistance of the rod samples, this distance relationship is not as obvious since the resistance is close to zero for both cases, see Table 5. However, since only the third significant digit is changing the accuracy of the measures are quite uncertain, yet, it can be concluded that the joint has good conducting properties.

7.2.2 Tensile and shear strength of the joint

All values obtained for each of the load cases, tensile resp. shear stress, are plotted in two different charts, see Figure 37 resp. Figure 38, to visualise differences between test samples. The unit for the y-axis is Pascal, Newton per square metre, and the x-axis is specified as millimetre displacement of the test rig fixture, thus, correlates to the elongation of the samples.

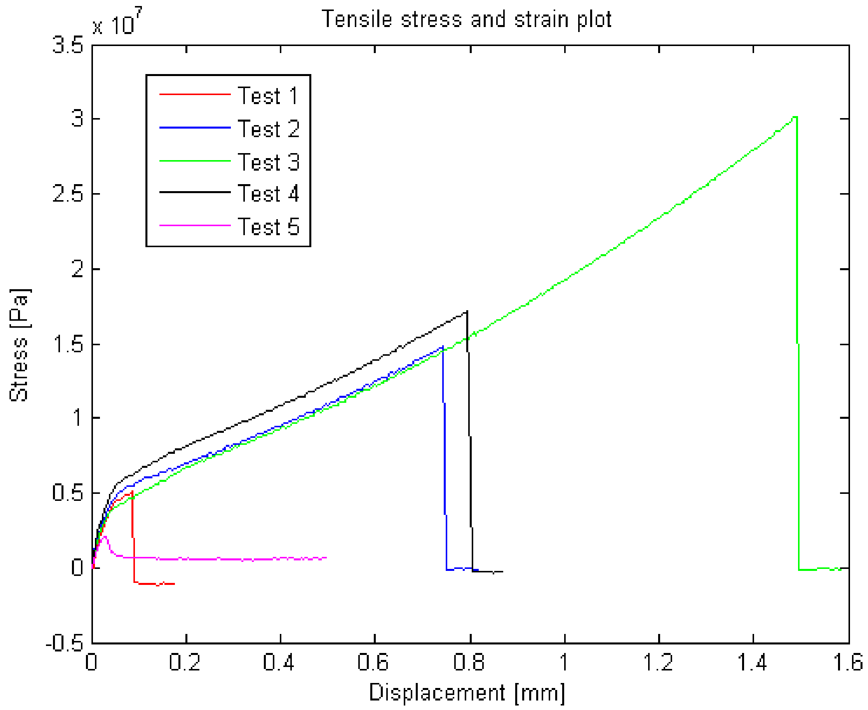


Figure 37 - Tensile stress and strain plot of aluminium rods.

As Figure 37 illustrates, the stress-strain curve obtained for each test sample vary significantly from one another. The maximum achieved stress is measured for test sample 3, reaching 30.1 MPa at failure. This value is far better compared to test samples 2 and 4, failing at approx. 15 MPa while the stress values for 1 and 5 not even reach 5 MPa.

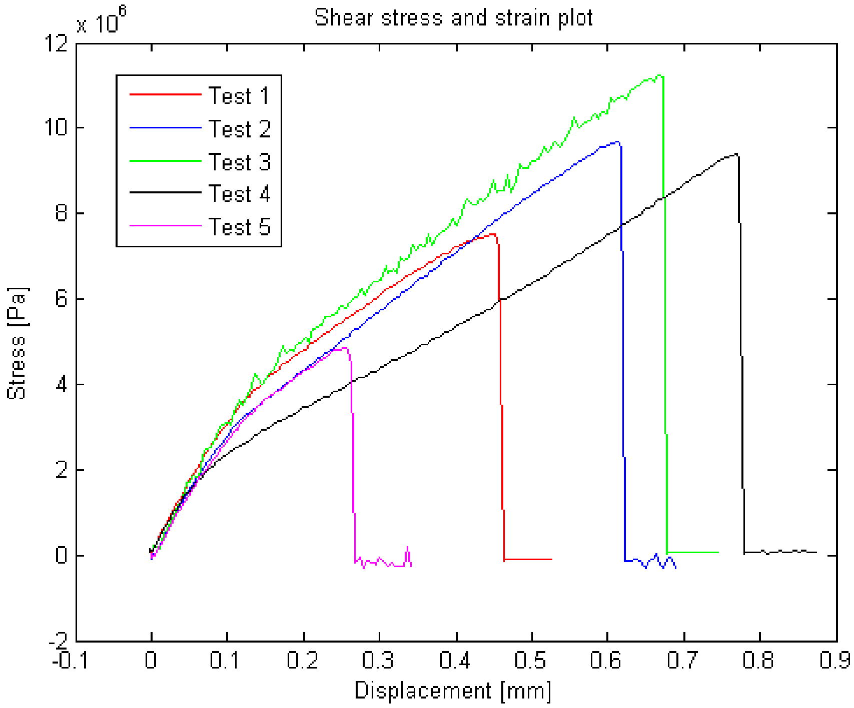


Figure 38 - Shear stress and strain plot of aluminium sheets.

Similarly to the tensile test results seen in Figure 37, the shear stress results at failure, displayed in Figure 38, are also widely scattered. Test sample 3 attained the highest shear stress at failure of 11.2 MPa.

7.2.3 Sample microstructure

Optical microscope

Explained in chapter 6.2.7, the joint sample is cut in two different directions for better analysis of the nanofoil reaction propagation. To enable a good microstructure analysis, both 20 respectively 50 times magnification is used, depending on what is observed.

In Figure 39 (a), cavities, merged areas and remaining foil is visible, while the more homogenous structure in picture (b) shows foil with solder on both sides. A quite frequent defect concerns small cracks in the remaining nanofoil, seen in Figure 39 (c). Finally, image (d) displays a severe crack area without any adhesion.

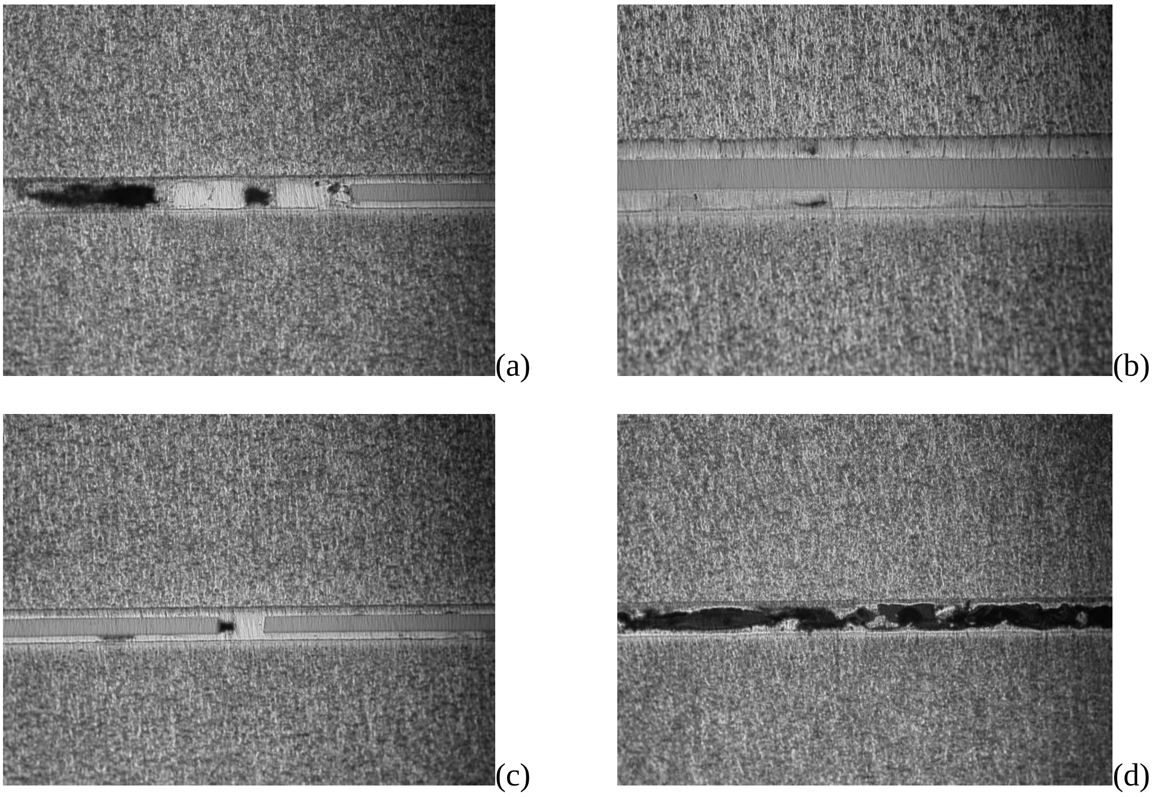


Figure 39 - Interface parallel to propagation direction of nanofoil.

All images in Figure 40 are magnified 50 times and show similar defects as in Figure 39. Only Figure 40 (d) differs, displaying an area where the tin solders are fully merged with no visible nanofoil.

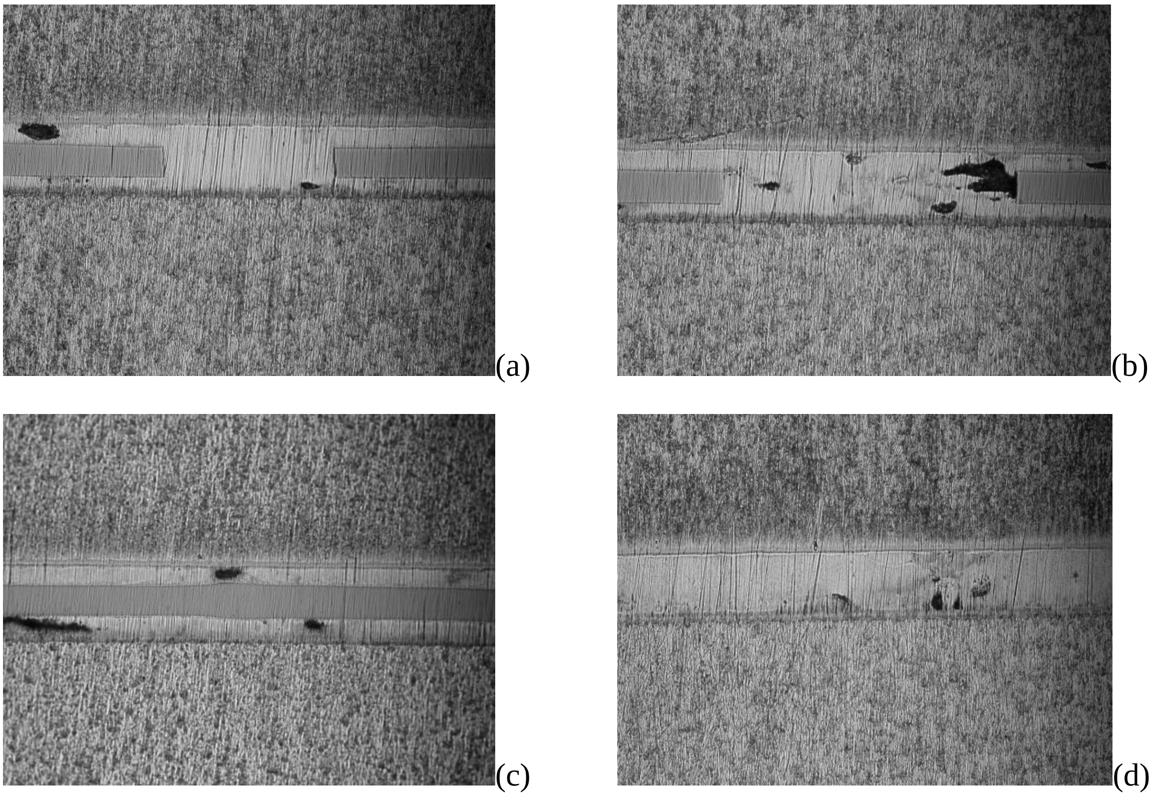


Figure 40 - Interface perpendicular to propagation direction of nanofoil.

Scanning electron microscope

As described in chapter 6.2.7, the results from the SEM analysis provide both highly magnified topographical images as well as information about the chemical composition of the sample.

By magnifying interesting spots of the cross-section observed with the optical microscope, the SEM-images can offer more detailed pictures on different phenomenon. For instance, Figure 41 clarifies that the observed cavity occurs in the tin layer. Another reoccurring defect concerns cracks in the nanofoil, as seen in both Figure 42 and Figure 43. However, as tin fills the cracks no cavities are formed except for small ones. According to the measure in Figure 43, the width of the foil after joining is 41.48μm.

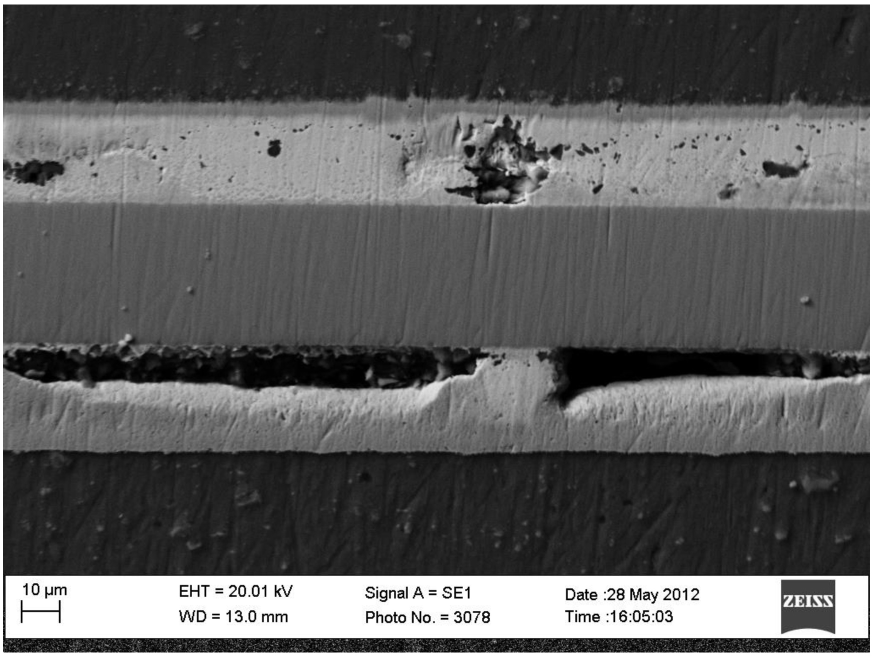


Figure 41 - Cavity in tin layer.

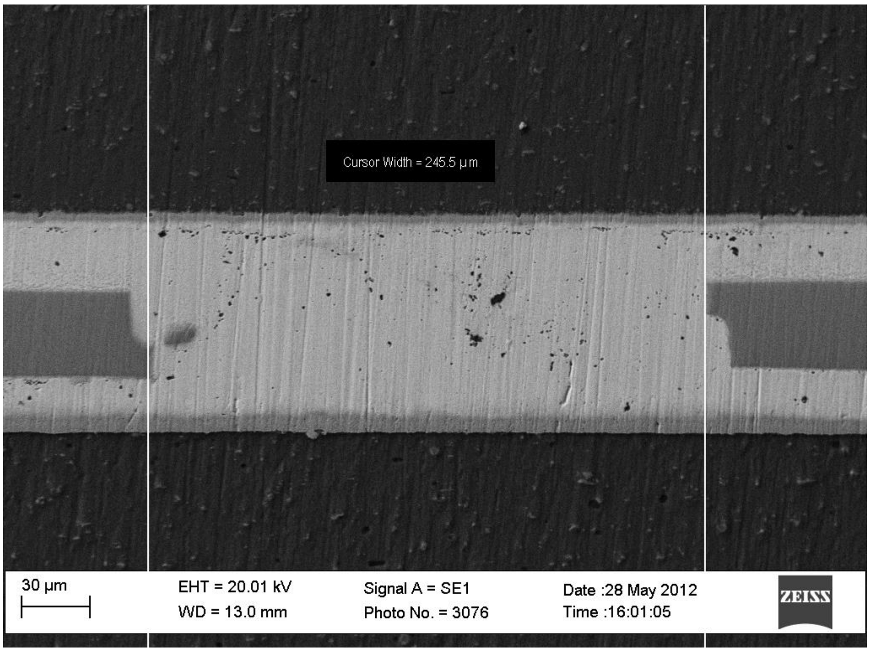


Figure 42 - Nanofoil crack.

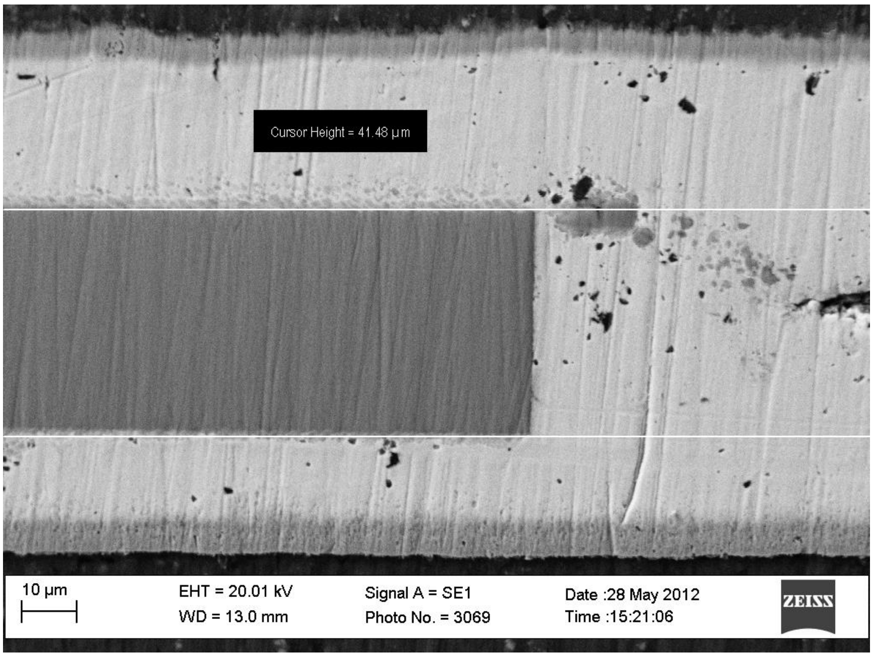


Figure 43 - Width of nanofoil.

Through a line-scan with energy dispersed x-ray spectroscopy, displayed as the yellow line in Figure 44 (a), values of intensity for different elements across the interface is obtained, seen as the different coloured lines. These intensities are also plotted in Figure 44 (b), (c) and (d), representing the different materials included. By examining the different layers it is clear that the nanofoil, represented as the red resp. cyan coloured lines, still remains $Al_{50}Ni_{50}$ even after reaction as specified by Innojoin. In Figure 44 (d) the curve shows the intensity of tin, also illustrated as the purple line in Figure 44 (a), which constitutes the coatings from both the aluminium sample and the nanofoil merged together.

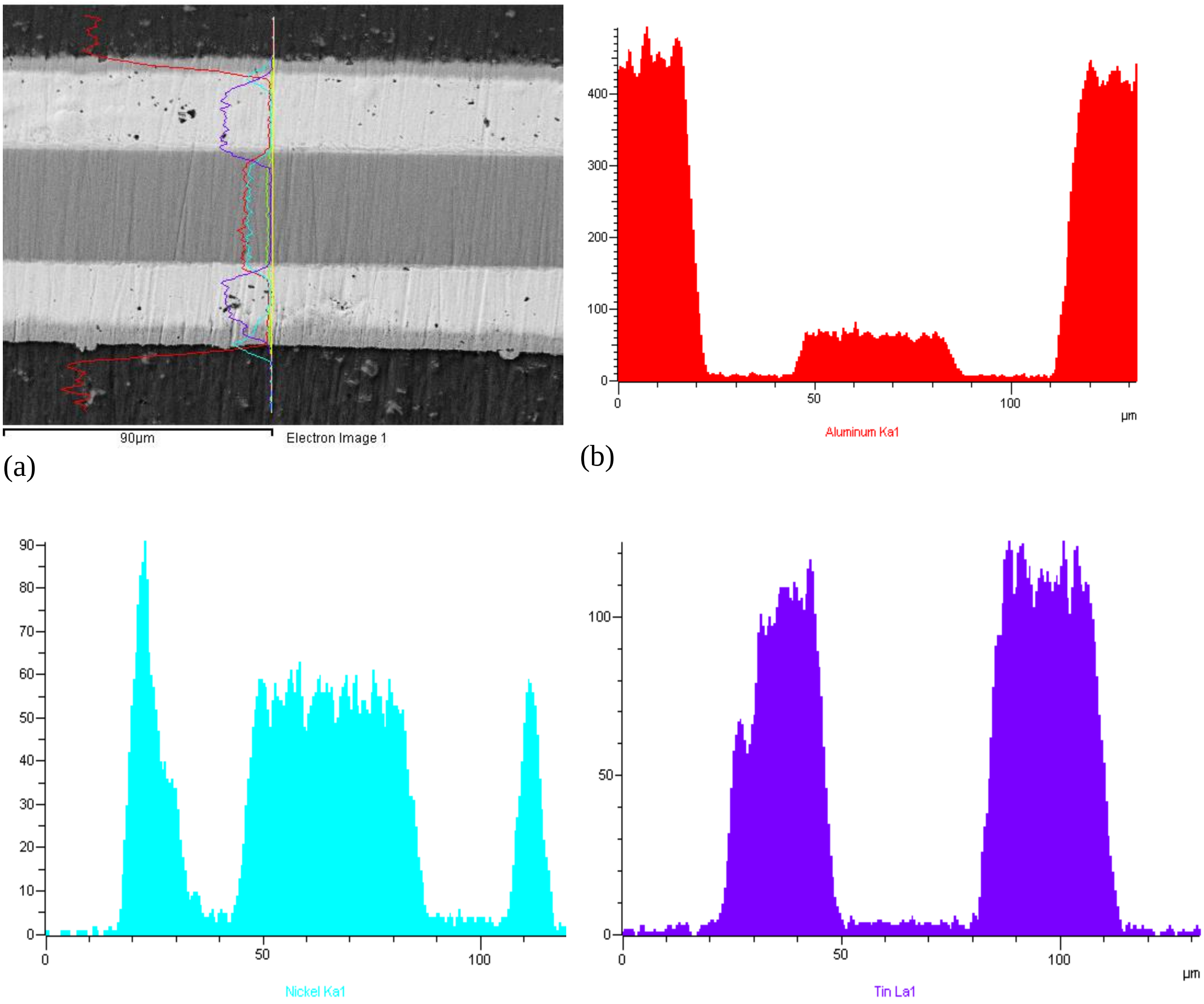


Figure 44 - Line-scan over joint interface, (a) Cross-section area, (b) Aluminium intensity, (c) Nickel intensity and (d) Tin intensity.

7.3 Concepts with high implementation potential

The following four concepts are potentially interesting to be implemented at SAAB EDS, chosen among many concepts as the most valuable.

Concept name	Description	Chapter
Improve gas quality inside a laser (2 concepts)	To improve air quality inside a laser two concepts were developed that intended to reduce pollution on laser lenses. Both concepts have shown good potential to be able to reduce concentration of aromatic compounds inside the laser.	5.4.5
Erosion resistant coating	This erosion resistant coating, based on a nano structured polymer, is considered interesting due to excellent rain erosion resistance. For instance the intended coating, sold by the company Nanovere, might be applicable on erosion exposed parts such as the IFF antenna on the ERIEYE.	5.4.7
Joining film for wave guides	Proposed as a substitute joining method, a foil with nano-thick layers of aluminium and nickel could be used to assemble wave guides for radars. By placing the foil between two metal parts and activating it by a pulse of energy, an immense heat is released that creates a joint in a simple way.	5.4.2

7.4 Concepts that require further research

Although all concepts developed within this thesis are based on existing properties of nanomaterials, there are a few concepts where the properties are only proven on a small scale. Hence, the three concepts presented here have high value for SAAB EDS, but need to be further developed to be implemented in an application.

Concept name	Description	Chapter
Highly conducting heat sink	Aluminium with dispersed CNTs has shown an increase in heat conductivity of 81% on a micro scale. If possible to achieve the same heat conductivity on a larger scale, the weight of a heat sink could be drastically reduced.	5.4.1
Nanofluid coolant	As efficient cooling of radars is essential, nanofluids that increase heatransfer might be interesting to use in order to enhance their performance. This technology will most likely enter the market within the next coming years.	5.4.4
Spray on antenna	Despite the very limited information about the technology behind this concept, it is an interesting concept that utilises nano capacitors to send and receive radar signals with less energy than existing radars.	5.4.6

7.5 Not recommended concepts

The concepts presented in this chapter were first chosen as high value concepts for SAAB EDS, yet after further refinement it was considered difficult to prove the expected high potential.

Concept name	Description	Chapter
Contact coating to prevent fretting	The aim of this concept was to find a material that could outperform gold in fretting exposed contacts. A nanocrystalline material consisting of Ti_3SiC_2 was very promising since it was already used in contact applications. However, after contacting the company it was found that their contact coating is used to replace gold coatings due to a cheaper price, not better fretting resistance.	5.4.8
Enhanced lubrication for reduced maintenance	Using a special engine oil that enhances lubrication, might prolong service intervals for a diesel power plant. With dispersed nanoparticles in the oil, friction and wear is reduced in the engine. But since high temperatures are the main cause for oil changes, an issue that this oil does not address, it is not recommended for the intended application.	5.4.3

8 Discussion

As the title of the thesis states, only nanomaterial applications have been investigated, even though interesting materials not related to nanoscience were found. With the vast amount of different nanomaterials available, the term had to be further limited, only concerning nanomaterials with engineering applications. This exclusion of materials was done rather early in the project, thus nanomaterials not mentioned in this report might still be valuable for engineering applications. However, since it is not possible to investigate all nanomaterials in one thesis, an early screening had to take place.

By following the project's methodology, the amount of interesting concepts has been limited in numbers after each evaluation. Yet, because concept drawbacks are more likely to be identified later in the evaluation process, time was spent developing promising concepts subsequently revealed not as valuable. This means that some fully developed concepts, not necessarily need to be more valuable for SAAB EDS than the briefly developed concepts. Nevertheless, in the results chapter all fully developed concepts are divided into three groups, depending on how to proceed with each one of them.

In the aim chapter, the importance of verification is explained, performing tests on the most promising concepts. Even though most of them would have been interesting to verify, only one concept was tested physically. In the end, the availability of the nanomaterial, communication with the responsible companies and time determined which concepts could be verified. With more time and resources it would be preferable to conduct more tests on promising concepts.

Regarding the thermal finite element analysis of the heat sink, the simplified analysis was made only to visualise properties for comparing purposes. As the model was comprised of estimated values, the gained information is only interesting when compared to the reference. Collecting more information about the specific application, might give more explicit results and a better indication on how much weight reduction can be achieved.

With the nanofoil joining method being the only physical test conducted, a great effort was put into achieving a good evaluation of the main properties. Although, the test setup did not resemble the intended environmental application of the joint, the acquired test results can still be used to analyse the performance of the joint. Thus, giving an indication on the value for SAAB EDS and what further investigation needed for implementation of this new joining method.

Especially through the strength test results, which were very scattered, it was realised that it is difficult to set an average strength value for this joining method. Furthermore, the joints seem to have a brittle character since failure takes place shortly after cracking sounds are heard. It is noticed that the tensile load properties are better compared to the shear load case, although the reason might be the different preparation methods used which could have caused different adhesion. Also, since the metal surfaces were not cleaned prior to joining, assuming that this was done by the coating manufacturer, it could have affected the strength of the joints. Hence, because of the uncertain analysis of the strength properties, trying different preparation methods and performing new tests would be interesting. But because of a limited timeframe it is not possible within this thesis.

From the microscopic images it is clear that the joints are not homogenous but show areas of cavities and defects. Additionally, some areas, where it is assumed that the nanofoil has cracked and disappeared due to shrinkage, are filled with the surrounding tin creating a homogenous tin solder. Consequently, no actual welding process takes place, but a reaction that melts the solders together, which constitute the joint and determines the strength. The visible cavities in the tin layers most likely reduce the performance of the joint and should be minimized for improved strength.

Concerning the application of the nanofoil, it might be more suitable as a substitute for conducting glues rather than the assembly of waveguides, as the joint shows very low electrical resistivity. With refined preparation methods better mechanical properties would most likely be achieved, improving the present test results in this report.

9 Conclusion

The purpose of this work was to identify where or if nanomaterials can be used in SAAB EDS products to enhance their performance. As a result, nine fully developed concepts and thirteen briefly developed concepts were created, all based on nanomaterials. In the end, four out of these concepts are recommended to be further investigated for implementation, showing high potential to increase product performances at SAAB EDS.

Performing tests on the nanofoil joining method revealed that it is characterised by a highly conductive metal joint, with enough strength to replace some conducting structural glues, but not to outperform the intended welding application. Moreover, the maximum strength results measured are not representative since the joints have highly scattered stress values, probably caused by microstructure defects in the joints. Thus, the joining process has to be improved to achieve a better adhesion.

For a material with 81% increase in heat conductivity there are many possible applications within SAAB EDS. By investigating the intended heat sink application, through a thermal finite element analysis, the overall potential of the material can be established. It was concluded that for this specific application, comparing the original model with this highly conducting aluminium composite, the weight could be reduced with 50% while maintaining the same temperature profile.

To improve the air quality in lasers, two separate concepts were developed, both showing great potential. By using either a dense coating on outgassing materials to prevent unwanted gases to reach sensitive equipment inside a laser or with a tailor made zeolite that adsorb the unwanted gases.

Finally, the possibility should be investigated to implement a nanostructured polymer coating that has excellent rain erosion properties, according to literature and product specifications.

Concerning the thesis work, it should be seen as a pre-study of nanomaterials, and serve as a basis to start up new projects involving nanomaterials in SAAB EDS products. During the whole process, the focus was set on creating value for the customer, using methods to compare concepts and stop further development of low value concepts. This practically meant that nanomaterials with excellent properties could be cancelled because no suitable application was found.

It is obvious that nanomaterials play a more significant role when it comes to engineering applications and should be considered in material selection processes, as manufacturing techniques are improved and prices become more affordable.

10 Recommendations

In order to simplify the work for SAAB EDS, taking on the results from the project, this chapter provides some recommendations based on what has been discovered.

Due to the limited timeframe of the project, some of the concepts considered ready for implementation, as stated in results, have not yet been verified. Thus, as a next step it would be necessary to perform tests on the concepts barrier spray and erosion resistant coating, since their properties seem very promising but have not yet been proven. Furthermore, the properties of the absorbing zeolite membranes also remain to be verified, yet, in this case it is recommended that cooperation with the responsible company NeoZeo should be initiated, to develop a customized zeolite tailored for SAAB EDS purposes. As the nanofoil joining method has already been verified and proven to be a very interesting substitute for salt bath soldering, SAAB EDS should investigate other suitable applications where nanofoils might be used.

Concerning nanofluids for liquid cooling applications, a discussion was held together with an EU funded project called Nanohex working on nanofluids and how it can be commercialised. As they were interested in finding companies to cooperate with, it is recommended to regain contact with them in order to receive information on the latest progress in the field.

The recommendation, concerning the concept of a more efficient heat sink with CNTs in aluminium, is to keep track of the technological progress on this field. Despite the excellent cooling properties proven in lab, a large-scale application is yet to be verified and might take a couple of years to achieve. Similarly, the capacitor spray concept is still developing and therefore not available for commercial purchase. However, even though published test results seem very promising, no suitable application at SAAB EDS was found. Hence, a decision has to be made considering weather this concept is still interesting and in which case the search for a matching application needs to be resumed.

Finally, since the field of nanoscience is a constantly developing, the most important recommendation to SAAB EDS is to keep an open mind and look for other solutions that might emerge from nano related technologies.

References

A. Mokmeli, M. Saffar-Avval, (2009) *Prediction of nanofluid convective heat transfer using the dispersion model*. International Journal of Thermal Sciences, Vol. 49, Num. 3, pp. 471 - 478, Elsevier Masson SAS

Ajayan PM, Schadler LS, Giannaris C, Rubio A (2000). Advanced Materials, Vol. 12 No. 10 pp.750-753

Apnano 2012, Reduction of enginer wear by nano lube formulated oil, <http://www.apnano.com/NanoLubRCX.html>

Atul.Thakura, Preeti. Thakurb, Jen-Hwa. Hsua, (2011) Novel magnetodielectric nanomaterials with matching permeability and permittivity for the very-high-frequency applications. *Scripta Materialia*, Vol. 64 No. 2 pp. 205-208.

Babyak, R. (2010). Better than gold?, *Connectors and Cords*, Vol. 58 No. 2 pp. 24, Troy, USA

Bakshi, S.R., Patel, R.R., Agarwal, A. (2010) Thermal conductivity of carbon nanotube reinforced aluminum composites: A multi-scale study using object oriented finite element method. *Computational Materials Science*, Vol. 50, no 2, pp. 419-428.

Blake, Lamont V. Long, Maurice W (2009) *Antennas - Fundamentals, Design, Measurement (3rd Edition), [E-book]*, SciTech Publishing

Brad Buecker (2009) *Maintaining lube oil quality, Vol. 113, No. 8 pp. 62, PennWell Publishing Corp, USA*

Bryant, M.D. (1994) Resistance Buildup in Electrical Connectors Due to Fretting Corrosion of Rough Surfaces. *IEEE Transactions on Components, Packaging, and Manufacturing Technology: Part A*, Vol. 17, no. 1, pp. 86-95.

Bundesanstalt für materialforchung und -prüfung 2012, Illustration of double walled carbon nano tube, <http://www.nano.bam.de/de/projekte/carbosafe.htm>

Cao, G. (2004). *Nanostructures & Nanomaterials*. [E-book] Imperial College Press, Seattle, ISBN(9781591249979)

Choi, S.U.S., Zhang, Z.G., Yu, W., Lockwood, F.E. and Grulke, E.A. (2001) '*Anomalous thermal conductivity enhancement in nanotube suspensions'*, Applied Physics Letters, Vol. 79, pp.2252–2254.

Colin R. Crick and Ivan P. Parkin (2010) Preparation and Characterisation of Super-Hydrophobic Surfaces, *Chemistry – A European journal*, Vol. 16 No. 12 pp. 3568-3588

Davis, Joseph R (2000). *Metals Handbook*, ASM International, Vol. 2 [E-book], Ohio: Materials Park, (ISBN 9780871703880)

Dejang, J., Limpichaipanit, A., Watcharapasorn, A., Wirojanupatump, S., & Niranatlumpong, P. (2010). Fabrication and Properties of Plasma-Sprayed Al2O3/ZrO2 Composite Coatings, *Journal of Thermal Spray Technology*, Vol. 20 No.6 pp. 1259-1268

Dongsheng Wen, Yulong Ding, (2004) *Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions*, International Journal of heat and mass transfer, Vol. 47 No. 24 pp. 5181-5188, Elsevier Ltd

Eastman, J.A., Choi, S.U.S., Li, S., Yu, W. and Thompson, L.J. (2001) '*Anomalously increased effective thermal conductivities of ethylene glycol- based nanofluids containing copper nanoparticles*', Applied Physics Letter, Vol. 78, pp.718–720.

Engineeringtoolbox 2012, heat transfer coefficient for water steam on a copper substrate that is 1160 W/m2K, <http://www.engineeringtoolbox.com/overall-heat-transfer-coefficients-d_284.html>

Frank M. White, (2008) *Fluid mechanics sixth edition*, Mcgraw Hill International Edition, University of Rhode Island

G.H. Jilbert, J.E. Field (2000), *Synergistic effects of rain and sand erosion, Wear, Vol. 243 No. 1 pp. 6-17*

Gao, L., Jiang, L., Sun, J. (2006) Carbon nanotube-ceramic composite. *Journal of Electroceramics*, Vol. 17, no. 1, pp. 51-55.

Gogotsi, Y. (2006). *Nanomaterials handbook*, CRC/Taylor & Francis

Grimes, C. A. (2001). Effect of purification of the electrical conductivity and complex permittivity of multiwall carbon nanotubes, *Journal of Applied Physics,* Vol. 90 No. 8 pp. 4134-4137

H. Busch, G. Hoff, G. Langbein (1966), The Royal Society, Rain erosion properties of materials, Vol. 260 No. 1110 pp. 168-181

Lundh, Hans (2008) *Grundläggande hållfasthetslära*, KTH Stockholm

Heggli, M. (2001). *Elastomeric Nanocomposites, Research Plan, Eidgenössische Technische Hochschule Zürich*.

Hendricks, T.J., Krishnan, S., Choi, C., Chang, C.-H., Paul, B. (2010) Enhancement of pool-boiling heat transfer using nanostructured surfaces on aluminum and copper. *International Journal of Heat and Mass Transfer*, Vol. 53, no. 15, pp. 3357-3365.

Hong Tian, Nanuaji Saka and Ernest Rabinowicz (1990), *Wear,* Fretting failure of electroplated gold contacts, Vol. 142 No. 2 pp. 265 - 289

Hori Y. (2006) *Hydrodynamic lubrication.* [E-book] Tokyo, Japan: Springer

Hosokawa et al., M. (2007). *Nanoparticle Technology Handbook. Osaka: Elsevier*.

Kaiser, J. (2000). Having *a bucky ball*, The American Association for the Advancement of Science, Vol. 287 No.5452 p. 387, Washington, USA

Kang Yong Lee, Dae Ki Jeong, Jae Hyung Kim (2011) Simulational study of electrical contact degradation under fretting corrosion, *Tribology international*, Vol. 44 No. 12 pp. 1651-1658,

Kenyon, Henry S (2001) Spray-on antennas make their mark, *Signal*, Vol. 55 No. 11 p. 23

Khan M. F. Shahil and Alexander A. Balandin (2012). Graphene-Multilayer Graphene Nanocomposites as Highly Efficient Thermal Interface Materials, *Nano letters*, Vol. 12 No. 2 p. 861

Kim, P.C., Lee, D.G. (2009) Composite sandwich constructions for absorbing the electromagnetic waves. *Composite Structures*, Vol. 87, no. 2, pp. 161-167.

Kim, P.C., Kim, G.H., Lee, D.G., Seo, I.S. (2008) Nanocomposite stealth radomes with frequency selective surfaces. *Composite Structures,* Vol. 86, no. 1, pp. 299-305.

Koch, C.C., Ovid'ko, I.A., Seal, S., Veprek, S. (2007). *Structural nanocrystalline materials-Fundamentals and Applications.* [E-book] Cambridge, United Kingdom: Cambridge University Press.

Kojima, Y., Usuki, A., Kawasumi, M., Okada, A., Kurauchi, T., Kamigaito, O. (1993) Synthesis of nylon-6-clay hybrid by montmorillonite intercalated with epsilon-caprolactam. Journal of polymer science part A-Polymer chemistry, Vol. 31, no. 4, pp. 983-986.

Lee, K., Lee, J., Hwang, Y., Cheong, S., Kwon, L., Kim, S. (2009) Performance evaluation of nano-lubricants of fullerene nanoparticles in refrigeration mineral oil. *Current Applied Physics*, Vol. 9, no. 2, pp. 128-131.

Li, Q., Rottmair, C.A., Singer, R.F. (2010). CNT reinforced light metal composites produced by melt stirring and by high pressure die casting. *Composites Science and Technology*, Vol. 70, no. 16, pp. 2242-2247.

Lu, C., Mai, Y.-W. (2007) Permeability modelling of polymer-layered silicate nanocomposites. *Composites Science and Technology*, Vol. 67, no. 14, pp. 2895-2902.

Meyers, M.A., Mishra, A., Benson, D.J. (2006) Mechanical properties of nanocrystalline materials. *Progress in Materials Science*, Vol. 51, no. 4, pp. 427-556.

Molina-Aldareguia, J.M., Elizalde, M.R. (2010) Metal Matrix Composites reinforced with nano-size reinforcements. *Composites Science and Technology*, Vol. 70, no. 16, p. 2227.

Monthious, M., Kuznetsov, V.L. (2006) Who should be given the credit for the discovery of carbon nanotubes? *Carbon*, Vol. 44, no. 9, pp. 1621-1623.

Nanovere technologies <http://www.nanovere.com/zyvere.html>

Prado, R.A., Facchini, D., Mahalanobis, N., Gonzalez, F., Palumbo, G. (2009) Electrodeposition of nanocrystalline cobalt alloy coatings as a hard chroem alternative. *NAVAIR.*

Pugno, N. M. (2006) High strength over density ratio invisible cables. Turin, Italy.

SAAB Group <http://www.saabgroup.com/en/About-Saab/Company-profile/Saab-in-brief/>

Shi, X., Dong, Y., Xu, F., Tan, Y., Wang, L., Yang, J. (2010) Preparation and properties of nano-SiC strengthening Al2O3 composite ceramics. *Materials Science and Engineering: A*, Vol. 528, no. 6, pp. 2246-2249.

Solve for X: Anthony Sutera on low power wireless everywhere [YouTube] <http://www.youtube.com/>, Feb 2012

Sridhara, V., Satapathy, L.N. (2011) Al2O3-based nanofluids: a review. *Nanoscale Research Letters*, Vol. 6, no. 1, p. 456.

The future of things 2012, Super water repellent, <http://thefutureofthings.com>

Wang, L., Wei, X. (2009) Heat conduction in nanofluids. *Chaos, Solitons and Fractals*, Vol. 39, no. 5, pp. 2211-2215.

Wang, X., Xu, X., Choi, S.U.S. (1999) Thermal Conductivity of Nanoparticle-Fluid Mixture. *Journal of ThermoPhysics and Heat Transfer*, Vol. 13, no. 4, pp.474-480.

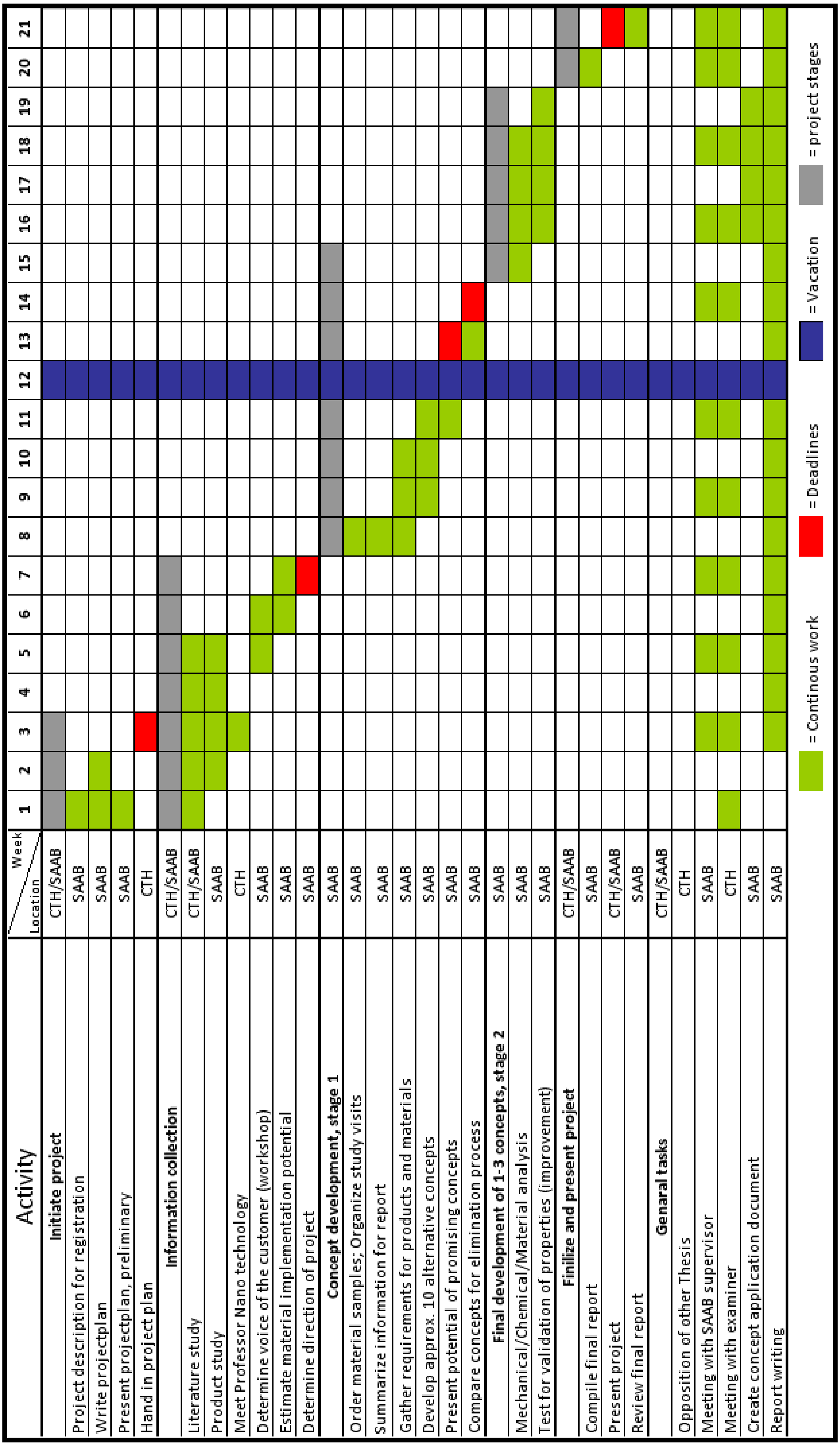
Wikipedia 2012, A*n open crystal structure of a zeolite*, <http://en.wikipedia.org/wiki/Zeolite>

Wikipedia 2012, Image to illustrate that 1 kg of particles of 1 mm3 has the same surface area as1 mg of particles of 1 nm3 nanoparticles <http://en.wikipedia.org/wiki/Nanoparticle >

Yu, M.-F., Lourie, O., Dyer, M. J., Moloni, K., Kelly, T. F., Ruoff, R. S. (2000) Strength and braking mechanism of multiwalled carbon nanotubes under tensile load. *Science*, Vol. 287, no. 5453, pp. 637-640.

Yu, W., Xie, H. (2012) A Review on Nanofluids: Preparation, Stability Mechanisms, and Applications. *Journal of Nanomaterials*, Vol. 2012, pp. 1-17.

Appendix A: Project plan as Gantt-chart



Appendix B: Briefly developed concepts

In this chapter, a short description will be given of the concepts that were not further developed due to low implementation potential at SAAB EDS. However, these concepts can still be of interest in other or future applications, which is why they are included in the report.

CNT reinforced magnesium

Magnesium is used in many light weight metal applications although it has slightly lower mechanical strength than other metals. However, scientists have successfully managed to disperse CNTs evenly in a magnesium matrix with a process called high pressure die casting, improving mechanical properties. For instance, the CNT reinforced magnesium had 20% better ultimate compression strength compared to the pure magnesium alloy (Qianqian, Rottmair, & Singer, 2010).

Because of the flammability of magnesium in addition to the fact that this material is still in its development phase and no proven results on improved tensile strength were found, the concepts was eliminated.

Improved properties of metals with nanoparticles

Magnesium or aluminium reinforced with boron and lithium nanoparticles results in a high stiff to weight ratio. The material is commercially available through the company Powdermet, basing their production method on powder metallurgy which makes it possible to enhance strength, hardness, wear and corrosion resistance.

Unfortunately, despite the materials high potential, no matching application at SAAB EDS was found. However, this material might still be interesting for future strong and light weight applications.

Light weight composite with metallic nanocrystalline coating on polymer

This interesting sandwich structured material, utilizes the advantages of both metals and polymers. A nanocrystalline metal surface is coated on a polymer substrate, which results in a lightweight composite with good mechanical properties and a surface that is both wear resistant and electrically conductive. Due to the nanocrystallinity of the surface a high corrosion resistance is expected.

Although this material is commercially available by the company Integran Technologies Inc. and could be used as a replacement for light weight metal parts, this concept had to be removed due to the lack of a suitable application at SAAB EDS.

Increased fracture toughness of ceramics with carbon nano tubes

A ceramic matrix with dispersed CNTs effectively increase the fracture toughness of ceramics with up to 3 times, mentioned in chapter 3.4.3. Fracture toughness is a critical property in ceramics and when improved the performance increases vastly. CNT reinforced Al_2O_3 can preferably be used in armor plates or for other hard, high strength and temperature resistant applications.

Since SAAB EDS already buy high tech armor plates, as well as the fact that armor is not part of SAAB EDS main product portfolio, it was chosen not to take this concept to the next elimination process.

CNT reinforced polymer

This nanocomposite has got a lot of attention concerning mechanical applications, since larger carbon fiber reinforced polymers provide great improvement of mechanical properties compared to normal polymers. Unfortunately, to this date no noticeable improvements of mechanical properties exist in CNT reinforced polymers. But the combination of a conductive polymer due to CNTs (see chapter 3.4.1) with average mechanical properties, still makes it an interesting material. For instance, it can be used in environments where EMC properties along with a good strength to weight ratio is important.

Despite the absence of improved mechanical properties, this material should still be kept in mind since a lot of research is being conducted in the field. The poor increase in mechanical strength mainly relates to the problem that the CNTs agglomerate, which can be overcome with better dispersion methods. But for now, this concept will not be investigated further.

Electro magnetic compatibility with conductive elastomer

Due to the somewhat mandatory EMC properties at SAAB EDS, this concept was developed since conducting gaskets are used at SAAB EDS today in order to enhance EMC properties. Elastomeric polymers that normally are used as gaskets between hatches or door must be conducting in applications at SAAB EDS which can be done by mixing conducting fibres or particles in an elastomer matrix. A problem with this method is that the conducting particles can be torn down at the surface because of abrasion. This leads to lack in conductivity over the gasket. With CNTs well dispersed in an elastomeric gasket it is believed to be more resistant to wear and will get good electrical properties with just a little amount of CNTs added.

This concept was not taking through to the next elimination round because potential in other concepts were higher. Also difficulties in finding suppliers exist.

Dispersed graphene improving thermal interface material

The large amount of electronic devices in SAAB EDS radar systems, calls for efficient cooling techniques. Therefore, this thermal interface material with dispersed graphene and multilayered graphene (MLG) particles was taken into consideration because of high thermal conductivity and electrical insulation. The material has excellent heat conductivity of approx. 2000 W/mK for MLG and the layered structure enables directional dissipation as well as electrical insulation. (Khan M. F. Shahil et al, 2012)

Though it is technically possible to manufacture, further development is still needed and because SAAB EDS already focuses a lot of resources on thermal interface materials, this concept is not examined further.

Frequency selective surface of electromagnetic waves

This nanocomposite stealth radome functions as a selective surface for transmission and reflection of electromagnetic (EM) waves. With a sandwich construction of flexible copper clad laminate as the frequency selective surface (FSS), covered by nanoclay-dispersed epoxy composite and an inner core of PVC foam, this concept represent an alternative weather protection with radio selective abilities for SAAB EDS many radar antenna applications. (Po Chul Kim et al 1, 2008)

Although the technology has a high potential of application at SAAB EDS, most of the information is derived from scientific articles and therefore needs to be developed further.

Electromagnetic wave absorbing structure

Similar to the FSS, this sandwich construction with CNT nanoparticles serves as a weather protective stealth system. But instead of a frequency selective radome this structure works as a radio signal absorbent, and hence cannot be used as a protection for the radar antenna. To provide the EM wave absorbing ability, the structure is covered with a nanocomposite made out of a combination of glass-fiber reinforced plastic, epoxy resin and CNT. This achieves an EM absorption rate from 84% to a maximum of approx. 97% in the X-band frequency range, which is quite high considering that only 3% of the reflected EM waves escape from the structure. (Po Chul Kim et. Al 2, 2008)

Considering the reason for elimination, these are somewhat identical to the FSS above. The technology is still under development and most of the company information is kept secret.

Gas absorbing nanoporous polymer membranes

First of all, nanoporous membranes are further described in chapter 3.6.2.

One way of enhancing the air quality inside a laser is by filter or by adsorb certain compounds on a molecular scale. That can be done with nanoporous polymers which was the idea with this concept.

For this problem three concepts were developed where this concept was considered having least potential to solve the problem even though porous polymers are used today as filters on a molecular scale.

Lotus leaf resembling super hydrophobic coating

Super hydrophobic surfaces are strongly water and dirt repellent, as the lotus leaf. Today it is possible to treat surfaces to make them super hydrophobic using sprays or other coating methods (see chapter 3.7.2). This surface could prevent ice from forming and keep surfaces clean longer or keep water away from sensitive equipment.

After discussion with personal at SAAB EDS it was decided not to take this material into the next elimination round. The reason for this was problems with making these surface effects last longer, also no applicable applications where found.

Wear resistant nanocrystalline metal alloy

Nanocrystalline materials have high hardness and tensile strength and are preferable coated onto a surface. A nanocrystalline cobalt, nickel and tungsten based alloy become very hard and wear resistant. On that basis this surface can be a good replacement for toxic chromium surfaces or other coatings exposed to wear. However at SAAB EDS the main task for chromium plated surfaces is to conduct electricity and therefore a more suitable material than the nanocrystalline material could exist.

Since no other applicable application for a high wear exposed part was found this concept was chosen not to be further developed.

Efficient cooling pipes with deposited zinc oxide

With a nanostructured surface consisting of ZnO particles deposited on Al or Cu, enhancement in boiling heat transfer has been measured due to changes in the surface structure. Tests have measured an increase in CHT (critical heat transfer) from 23.2 W/cm^2 to 82.5 W/cm^2 with water as fluid (Terry J. Hendricks, 2010). This corresponds to a heat transfer coefficient of 23000 W/m^2K which is a lot compared with the heat transfer coefficient for water steam on a copper substrate that is 1160 W/m^2K. This surface could advantageously be coated inside pipes where cooling liquid is flowing through to increase the cooling efficiency of electronics at SAAB EDS.

This rather new discovery is likely to be exploited if the good heat conductivity can be confirmed by others and good manufacturing methods can be developed. For uncertainty reasons it was chosen not to investigate this concept further. Still it can be of great interest to monitor these nanostructured surfaces to enhance heat exchange efficiency in the future which is clearly proven they can by Terry J and his colleagues.