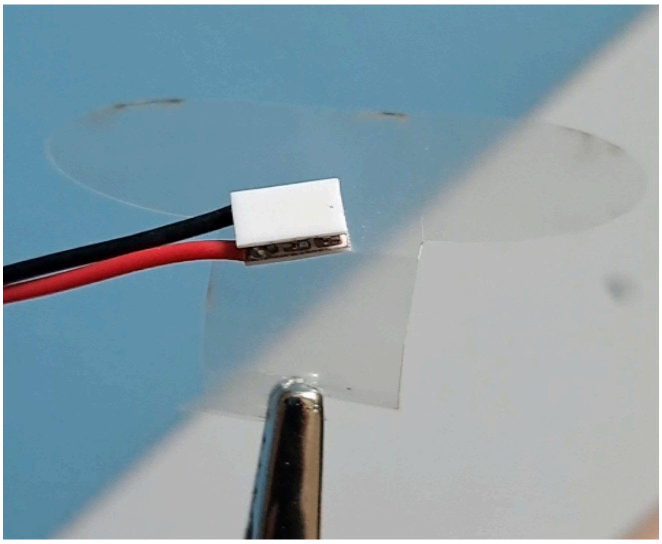

Robotic application for nanocellulose

Manufacturing and stimulus-response

Bachelor degree in Mechatronics Engineering

ELMEDIN SALIHOVIC

INSTITUTIONEN FÖR MEKANIK OCH MARITIMA VETENSKAPER
CHALMERS TEKNISKA HÖGSKOLA

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CHALMERS

Robotic application for Nanocellulose
Manufacturing and stimulus-response

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Abstract

Exposed to heat and moisture, materials react in different ways. One common material to be regularly used across the world is cellulose. Cellulose nanocrystal or CNC is plant based material with unique properties that can and have potential to be applied in the field of technology. The material reacts to temperature and moisture and plays an important role in the field of technology study. However, the material reacts differently according to format and shape. But also a lack of data on how it reacts during laser cutting. Here we show that different shapes respond differently with different exposed to chemical substances and how it reacts to laser cutting. We found that laser cutting the material works perfectly well, but a better treatment is required when placing it down and keeping it fixed. The most noticeable reaction when applying temperature and moisture to the material appears with round edges . The results demonstrate that the figures with round edges or shape tend to deform and react faster and reform back to their original state compared to figures with linear edges. We anticipate that the assay will be a starting point for future projects of CNC and CNC analysis.

Acknowledgment

I would like to express my gratitude to my supervisor Arion Pons, who works at Chalmers University as an assistant professor in fluid mechanics for his effort and time to guide throughout the project. I appreciate the materials, the work room and the electrical equipment for this project. I would also thank Gunnar Westman for producing the material needed for this study and the time he took to produce it. Lastly I wanna take my time to thank Mats Andersson for being my examiner for this project and having contact with my supervisor, constantly giving updated reports.

The time and effort to contribute to this study is appreciated and I thank again for the people that have been a part of this process.

Signature

Elmedin Salihovic

List of acronyms

Below showcase a list of acronyms that has been presented throughout this document.

CNC	Cellulose nanocrystal
Arduino	Arduino Uno R3
SME	Shape memory effect

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1 INTRODUCTION

1.1 Background

As technology and robotic usage have been starting to increase rapidly, so has the search for a more stable, environmentally friendly material that can handle qualities as more advanced technology starts to show up on our planet. Electronic devices are made of materials that are harmful for the environment, use the earth resources and are difficult to recycle. It is then important to find a material that can make good use of the planet's resources and withstand technological factors such as electrical, temperature and moisture.

Cellulose is found in plant cell walls and has started to be used in technological applications due to its huge affluence, properties and economic aspects. Cellulose has been studied to be used in the field of electronics. It has shown properties with good mechanical strength, flexibility and thermal stability[1]. Cellulose nanocrystals are materials that have been derived from polymers. The material is obtained from cellulose fibers that are biodegradable from nature. Nanocrystals are closely related to hydrophilics. Meaning it dissolves with water. They can be surface treated to meet different performance to strengthen the properties such as flexibility and temperature resistance [2]. One example is that it can be used as nanopaper and give out reactions of performance of electrochemical devices when performing with low voltage. The material can be used to implement technological application in devices without being harmful if taken care properly[3].

Nanocellulose has started to gain attention of how it can be used in the field of technology. CNC also showcases good biocompatibility, cytotoxicity, and mechanical properties such as low weight and flexibility. With those properties, CNC has started to be used in the biomedical field, especially as a drug delivery carrier. It has also been used to enhance batteries and sensors that rely on electrical response[4].

This part of the field has started a study at Chalmers University of Technology where a small group wants to develop a mini robotic look-alike fly to be used in forest and wildmarks for future development and projects. By studying the materials deformation with electrical properties and using a laser cutter to form the shape of the wings, it is a start to a next environmentally robotic future but potentially a manufacturing perspective.

1.2 Aim

The project aims to collect data for the CNC on how it reacts to through factors in regards to deformation. Information collected from practical electrical setup provides a scientific insight into applying the material to robotic application for a more environmentally friendly future.

1.3 Goals

The goal of the project is to determine how different shapes of CNC react to robotic properties in order to analyze the materials deformations. The deformations analyzed will be put through with electrical setup. The materials will be analyzed to see how it reacts to water drop as a moisture factor.

1.4 Limitations

In order to ensure that the main area will be analyzed and feasibility of this study, two main limitations will be addressed. The CNC that is being produced will be given to be analyzed with the amount of moles and will not be looking into the manufacturing methods. The other part will include only studying the materials active and the stimulus response properties and will not include the chemical structure why the reaction occurs.

2. Literature Study

2.1 CNC

The literature study brings up the theoretical aspects of this project in order to analyze and perform the goal of this study. This part consists of giving a deep understanding of the tools and material of the project.
CNC is in the same area as cellulose, but scaled down into smaller dimensions, nano dimensions. CNC is laboratory manufactured and can vary its properties due to its molecular dimensions. The material is very light thinned with a neutral transparent color. The material is drawn out from natural sources such as plantarial fibers and pulp made of wood. CNC have different properties and are uniquely dependent on what kind of cellulose is produced. For example there is sulfated nanocrystal Cellulose (S-CNC) and carboxylic nanocrystal cellulose (C-CNC) [5].

The samples are produced from Chalmers University of Technology in the department of Chemistry. The main product of the samples consist of 98 % of cellulose and the additive chemicals Triethanolamine, Sodium hypophosphite, Butanetetra-carboxylicacid, Ethylene glycol diglycidyl ether and Imidazole takes up around 2% of the weight of the samples. Four samples will be analyzed with each sample having a different amount of chemicals and being used with 30-60 micromol. They will be classified as CNC.

2.2 Shape memory effect

Shape memory effect (SME) is a method to change the material's properties when it reacts to temperature. It's often common within alloys, polymers and metals. SMEsimply follows that the material returns to its original shape when cooled down or heated up. This effect is very similar to elastic materials such as rubber, but the major difference is that elastic materials need to apply force in order for it to deform and come to its original shape. SME do not. The recovery of the materials is due to its internal structure. If the material is heated up it's called austenite. This means that the material can not be more deformed, while if you lower the temperature it's called martensit [6]. Figure 1 illustrates how the process works.

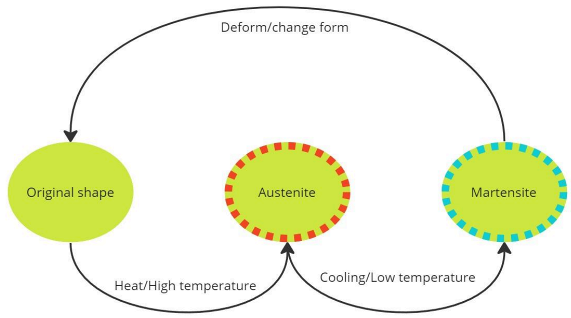


Fig.1. Illustration of how SME works ,reproduced from [6]

2.3 Thermal properties of CNC

When applying voltage to electrical components or any other devices, heat will generate. The measurement of CNC thermal properties vary in different methods according to different types of CNCs and experiments.

In thermal properties, thermal conductivity (k) is the material's ability to transfer heat. It is one of the three methods of transferring heat. The principle follows that two sides of a material are cold and the other side is hot. Heat will be flown throughout the material (Q) in the direction of where it flows, where it can be negative or positive. The temperature difference from each side with a distance (L) and how large a temperature side is (A). This method works also with placing the material in a liquid container and measuring it, figure 2 showcases an illustration of the how the principal works [7].

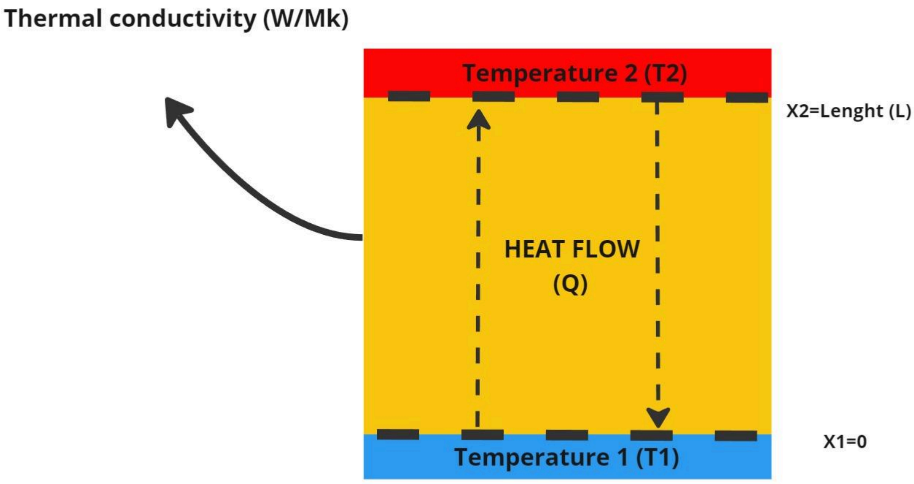


Fig.2. Illustration principle of how thermal conductivity works, reproduced from [10]

As all material, it can be heated up. In a bath experiment of a CNC, it showcases when heating up the water with a temperature 30-90 degree, it will give out a thermal conductivity of around 0,13-14 S/m. A prediction of how the conductivity would be compared to experimental shows a linear model. This means when temperature is rising, so will the conductivity for CNC [8].

2.5 Arduino Uno R3

The project will focus on using a microcontroller to implement the factors for analyzing the CNCs deformation. The microcontroller to be used is called Arduino Uno R3 and

consists of a board based on ATmega328P. Arduino Uno R3 consists of 14 input and output pins, 6 analog inputs, USB connection, a power jack and a rest button. The microcontroller has further different types of applications and components, but will not be implemented or focused in this part of study. To use the Arduino Uno R3, an Arduino software IDE provides a setup to implement code to communicate with the IDE and microcontroller.
The Arduino Uno R3 datasheet specifies requirements in order to operate and work in a safe manner. The board can only work with thermal limits of minimum -40℃ and maximum 85℃. It has a minimum input voltage of 6V and maximum of 20V when it comes to the maximum input voltage from Vin pad, while the USB connector can only take in a maximum input voltage of 5,5V [9].

2.5.1 Peltier module

[13].

The Peltier module for this project can handle a voltage direct current of max 1.4V, 800mA and a temperature difference of max 74℃. It has a black and a red string to connect the negative and positive input signal. The width is 6mm, length of 6mm and thickness of 3mm with a margin of 0.2mm on each side[10]. The datasheet explains how big the input voltage and ampere need to be in order to see the temperature difference.

2.6. Water interaction with CNC

Cellulose is a polymer with its habit of plant cell walls. One great aspect of cellulose study is its exposure to its interaction with liquid, especially water. When CNC was absorbed with 2-propanol (IPA), it has similar properties to water H20, no major change was observed for the mechanical properties. The interaction with liquid between water and CNC causes a SME (SME). [11]. The memory shape deformation causes the particle that is formed in a matrix-form shape to lose up when wetting it. The particles would stretch out, making the CNC to deform and elongate. When letting the material dry out, with less amount of liquid, CNC starts to reform to its original shape, but not 100% to its original form[12].

3. Method

3.1 CNC laser cutting testing

The laser cutting machine will be operated at Chalmers University of Technology with cutting each sample into different figures.

3.1.1 Laser machine model

The machine to operate the laser is called trotec speedy 400 and has been developed by the company trotec. Trotec speedy 400 is a machine that is mainly focused to be operated to cut, engrave and mark the materials according to your own intent of use. Trotec have designed a software called Trotec ruby that makes it possible and easier to control and use the machine. The computer needs to be connected to a LAN cable and within the same network for it to operate.

The machine has a length of 1428mm, width of 952mm and a height of 1072.5mm, giving a volume of 1458.01656 liters. It has a work velocity of 4.3m/s and an acceleration of 50m/s^2. The material that is planned for use can not have a lower temperature than 10 degree and not higher than 40 degree. The laser machine gives out an error accuracy of 5 micrometers when cutting a material.

3.1.2 Laser Cutting objective

The total area of a sample is 85cm. For this project 4 figures are cutted in one sample, where each sample has the same figures, area, and measurements. Trotecs software was used in order to design and cut the figures. Chart 1 showcases the measurements of each figure in one sample, while figure 3 showcases the program.

Chart 1
Measurements of the figures when using the trotec speedy 400.

Figure	Length	Width
Oval	21cm	29.7cm
Star (6 sides)	22cm	22cm
Square	20cm	20cm
Insect wings	7.5cm	6.5cm
Chalmers log	20cm	15cm

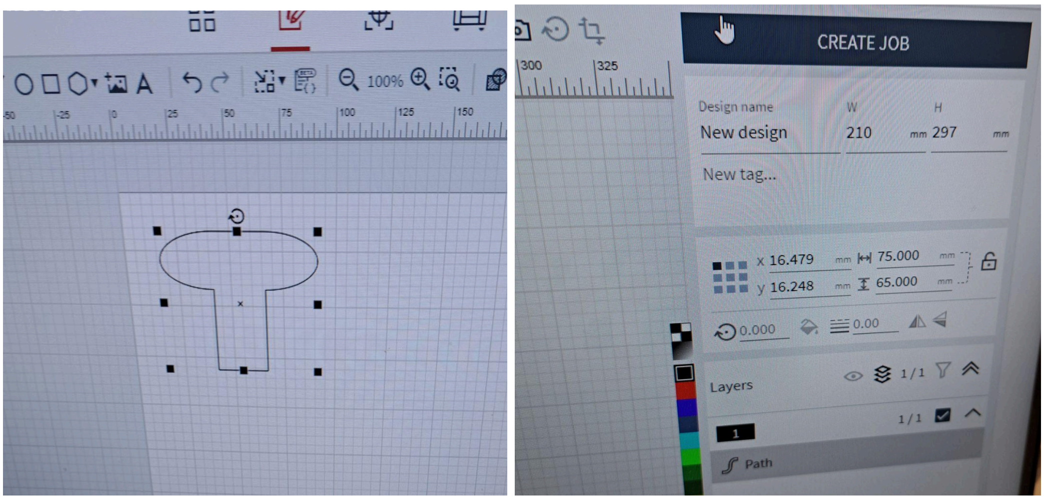


Figure.3. Trotecs software to design and cut the material into figures. The picture showcase the design of insect wings

Each sample was placed anywhere within the work area inside the machine. CNC is light, fragile and can be moved easily by force. To prevent failure and increase the accuracy, duct taped was used, The samples were cutted with a minimum period of 1s to a maximum of 3s with all figures combined.

3.1.2 The risk assessment CNC

The CNC is produced from Chalmers University of Technology in the department of Chemistry. The test materials consist of five different samples where each sample has different amounts of chemicals usage and amount of moles. The amount of moles in one sample can be seen at chart 2.

CNC is a wood-derived material of almost pure cellulose. Laser cutting the samples 1-4 is established to be safe for cutting wood. To give an insight of how precise estimation of how much the CNC and their additive chemicals would affect the laser cutter, personnel harm for the person operating but also the people in vicinity, data will be presented.

Chart 2:
The number of samples respective to their chemicals amount in micromol

	Main product	**Additive Chemicals**				
	SCNC	**TEDA**	**BTCA**	**SHP**	**EGDE**	**IMIDAZOLE**
Sample						
1	16.74μmol	30μmol	0	0	0	0
2	16.74μmol	30μmol	0	0	0	60μmol
3	16.74μmol	30μmol	30μmol	60μmol	30μmol	0
4	16.74μmol	30μmol	30μmol	60μmol	30μmol	60μmol

A microscope is used to see how each sample has its structure. Sample 1 and Sample 2 have the same amount of additive chemicals except that Sample 2 have instead 60 micromol of Imidazole. Sample 3 and 4 consist of the same TEDA, BTCA, SHP and EGDE, while Sample 4 has 60 micromol and Sample 3 does not have any substance of that chemical. The structure of each sample can be seen at figure 4.

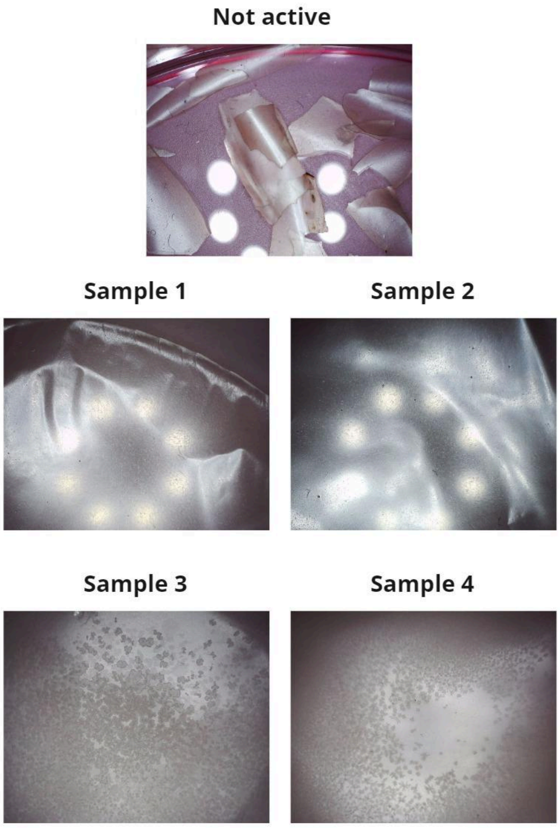


Fig.4. Microstructures for each samples for the CNCs used with a microscope

Sample 1 & 2 have a clean and transparent surface where the particles are close to one another. Sample 3 & 4 are the samples that have the additive chemicals BTCA, SHP and EDGE added compared to the two first. The particles are more separated compared to the two first. The chemicals EGDE and BTCA are covalently attached to the cellulose. TEDA forms then a strong ion-pair with a surface of the cellulose. This lead to the chemicals in the samples will have a small risk to evaporate when laser cutting

Each sample is in a circle safety glass box. The samples are disk shaped with a radius (r) of 4.25cm and a maximum thickness (t) of 0.1cm. Using the volume of the disk, an estimation of a sample volume can be seen at equation (1). The volume of the laser cutter area is estimated to be 1m on each side, giving a volume at equation (2)

$$\text{Volume of the disk (sample): } \pi * r^2 * t = \pi * 4.25^2 * 0.1 \approx 5.6cm^2 = 5.6mL \quad (1)$$

$$\text{Volume of the laser machine: Base*length*height} = 1 * 1 * 1 = 1m^3 = 1000L \quad (2)$$

The laser machine produces heat in order to cut the desired point of a material. Two scenarios could occur when cutting a material. **First scenario**: When cutting with a laser it leaves burn marks on the remaining area. **Second scenario**: The worst scenario, the material goes into flames. In normative scenarios, the material will leave behind burn marks. If the second scenario occurs, it is necessary to know how it affects the laser cutter machine and how it affects the person in order to operate a safe environment of work.

The concentration of the additive chemicals for the laser cutting machine under the second scenario can be computed by using the equation (3).

$$Amount\ \ additive\ chemical\ moles = Concentration * Volume\ of\ the\ laser\ machine \quad (3)$$

When working with additive chemicals in moles that are in a range of 30-60 micromol and finding the concentration for each chemical, two calculations are presented for 30-60 micromol in equation (4) respective equation (5). The data for each additive chemical for the concentration and molecular weight can be seen at chart 3.

$$Concentration = \frac{Amount\ \ additive\ chemical\ moles}{Volume\ of\ the\ laser\ machine} = \frac{30*10^{-6}moles}{1000L} = 30\ nmol/L \quad (4)$$

$$Concentration = \frac{Amount\ \ additive\ chemical\ moles}{Volume\ of\ the\ laser\ machine} = \frac{60*10^{-6}moles}{1000L} = 60\ nmol/L \quad (5)$$

Chart 3:
The data for each additive chemical and the weight of a molecular additive chemical

Additive chemical	The maximum molar concentration in the laser machine (nmol/L)	The molecular weight of a chemical (g/mol)
TEDA	30	149.19
SHP	60	87.98
BTCA	30	234.16
EGDE	30	174.19
IMIDAZOLE	60	68.08

By multiplying the data from chart 2 for each additive chemical and dividing by the volume of the laser machine, you get the maximum mass concentration in μg/L. This gives out data that is presented in chart 4.

Chart 4
Data for the maximum mass concentration of each sample

Additive chemical	Maximum mass concentration (μg/L)
TEDA	4.47
SHP	5.27
BTCA	7.02
EGDE	5.22
IMIDAZOLE	4.08

The data presented above showcases how much concentration it has in a space. To compute how much it will affect the person operating the laser machine when inhaling in the second scenario, you measure it in LD50 (lethal dose 50%). Equation (6) presents how to compute the maximum dose in grams. Chart 5 presents the data for how much maximum dose for a 50 kg adult is respectively an oral LD50.

$$Maximum\ dose = \frac{Maximum\ mass\ concentration * Volume\ of\ the\ laser\ machine}{Weight\ of\ a\ human} \quad (6)$$

Chart 5
The maximum dose of each additive chemicals for a adult with 50kg

Additive chemicals	**Max dose (mg)**	**LD50 maximum dose for 50 kg adult (mg/kg)**	**Oral LD50 (mg/kg)**
TEDA	4.47	0.055	2200
SHP	5.27	0.065	7640
BTCA	7.02	0.087	1720
EGDE	5.22	0.065	460
IMIDAZOLE	4.08	0.051	970

3.2 Measuring data with CNC movement

In order to know what to collect information out of the sample. The collection of data will consist of measuring the time out of each sample. The practical moment will consist of applying the factors of temperature, by using the peltier module, and a water drop test at the middle of each figure. Figure 5 illustrates each figure being applied by the factors and how it deforms.

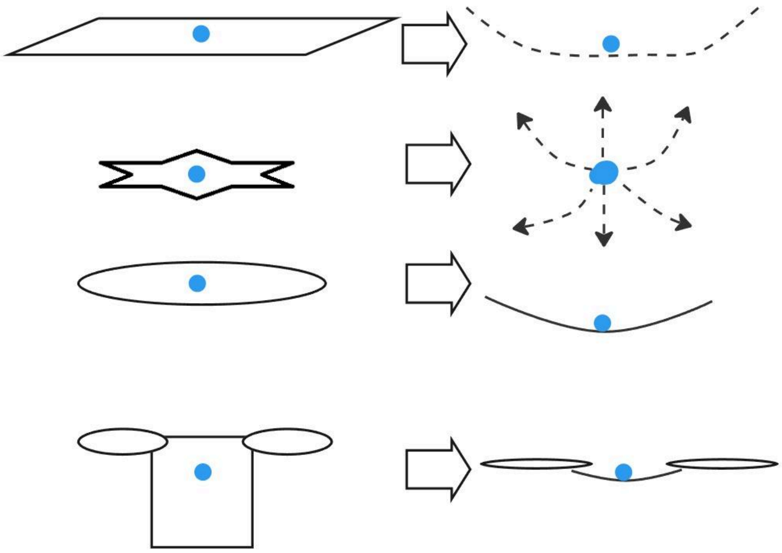


Fig.5.The placement of the experiment when doing the temperature and moisture. The blue color showcase the placement (placed at the center of each figure) and how the figures should move.

The figure above illustrates the desired deformation when doing the factors.The data will be collected when the material showcases slight movement. If no movement starts to occur, the material will be valued as 0. If a figure showcases movement but no deformation as the picture illustrates, the data collected will be instead when the material has stopped showing visible movement.

3.3 Temperature testing

For the CNC thermal properties, a peltier module was connected to the Arduino Uno R3 with a circuit design consisting of a 10k Ohm resistor to minimize the microcontroller and the peltier module damage. The peltier module was placed flat down, with the warm side facing to the CNC. One sample contained different figures that were cutted with the laser machine. One figure was placed on the peltier module starting with no temperature increase and starting from 0 degree. The peltier module would be heated up until it deforms or until it would start to leave burn marks. The temperature would be collected till one or both of the scenarios occurred. The voltage will start from 0.2V and 0.1A and slowly rise.

If a deformation has occurred, the voltage would then be shut down to see how long it takes for a figure to reach its original form. This process would perform 5 times.

3.4 Moisture testing

Compared to the temperature testing with the 4 figures on each sample, the moisture part will not test each figure for every sample. Sample 1 only will have the square, sample 2 without the insect wings, sample 3 have all the figures and lastly sample 4 has insect wings and square. All 4 samples have the square figure and will mostly be the main factor to be analyzed when doing the testing.

The testing consists of applying one small drop of hot water around 40 degrees with a small tip of an object as the instrument. Cotton swabs was used to reduce and remove the water. The process would be filmed within approximately 3 minutes. The water would stay and react in less or more than 2 minutes. Cotton swaps would be used as the cooling aspect to make it deform.

Figure 6 showcases how the process will work. The test will only apply the water drop around the middle area, with the theory, the material will expand in all directions where the drop lands.

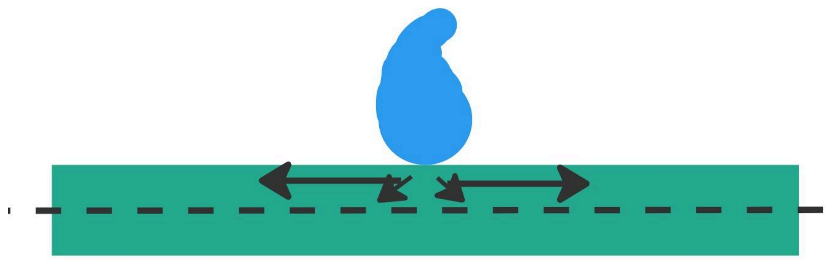


Fig.6. Illustration of the moisture experiment and how the expansion of CNC works

The data collected will be collected through video taping. The time of deformation will be stored after nothing happens after visible. After that the time of cooling down (using cotton swab) will be stored until the material does not react anymore.

4. Result

4.1 laser cut of CNC

Figure 4 showcases the figures cutted part. The cutting process was quick and efficient, without any necessary obstacles for the CNC to not be cutted. The software Trotec does not have a material called CNC in their data system when it comes to choose what material it needs to be cutted. Paper thinned material with a 0.11mm thickness was used due to the similar heritage of cellulose.

The laser's accuracy and precision to cut the material went without failure. No smoke or toxic gas was spread out. A small majority of the figures got small burn marks on a random area. This often occurs when the laser machine operates for a longer period. In this case, all three figures were placed together. The machine prioritizes the marked object that is the closest to the laser point. Figure 7 showcases the burned area of a cutted figure when finished. The burn marks occur on the edge of the CNC. The heat generated from the laser cutter causes the CNC to reach its melting point. Since the material is in fact low on the thickness part, brittle and transparent, it makes logical that some kind of burn marks will leave behind.

One cutted figure took 1 second each, while the Chalmers logo took 7s. Due to the limited space one sample had to have the figures and one extra sample needed to be produced in order to have all 4 pieces.

Fig. 7. Sample cutted part using a laser machine.

The chalmers log has also been cutted, chalmers log is a detailed log with multiple lines. By laser cutting all of it. The material is so detailed in a very small area, causing it to be a hole with the outer shape to have it form. The figure can be seen at figure 8. When cutting the material with only the text, it becomes more visible, clear, and time saving. The text for Chalmers can be seen at figure 9.

Fig.8 Laser machine cut with all the detailed Chalmers log.

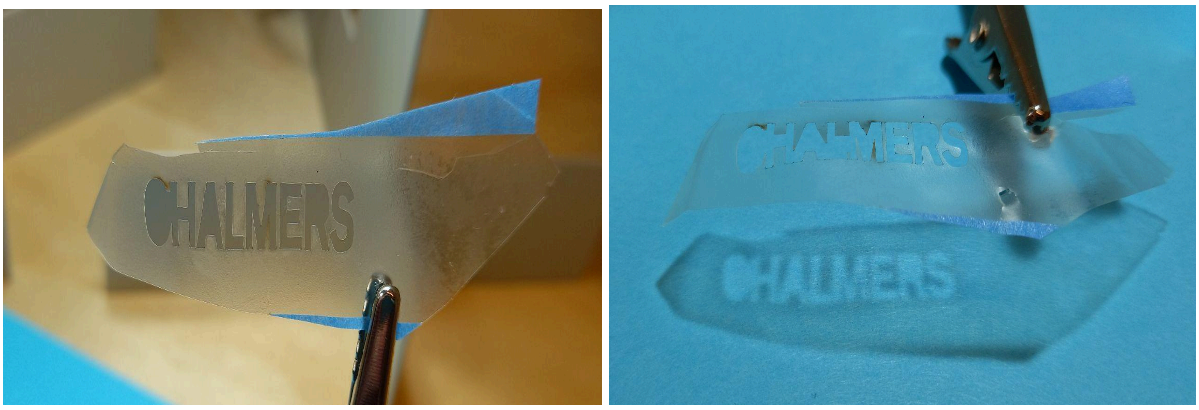


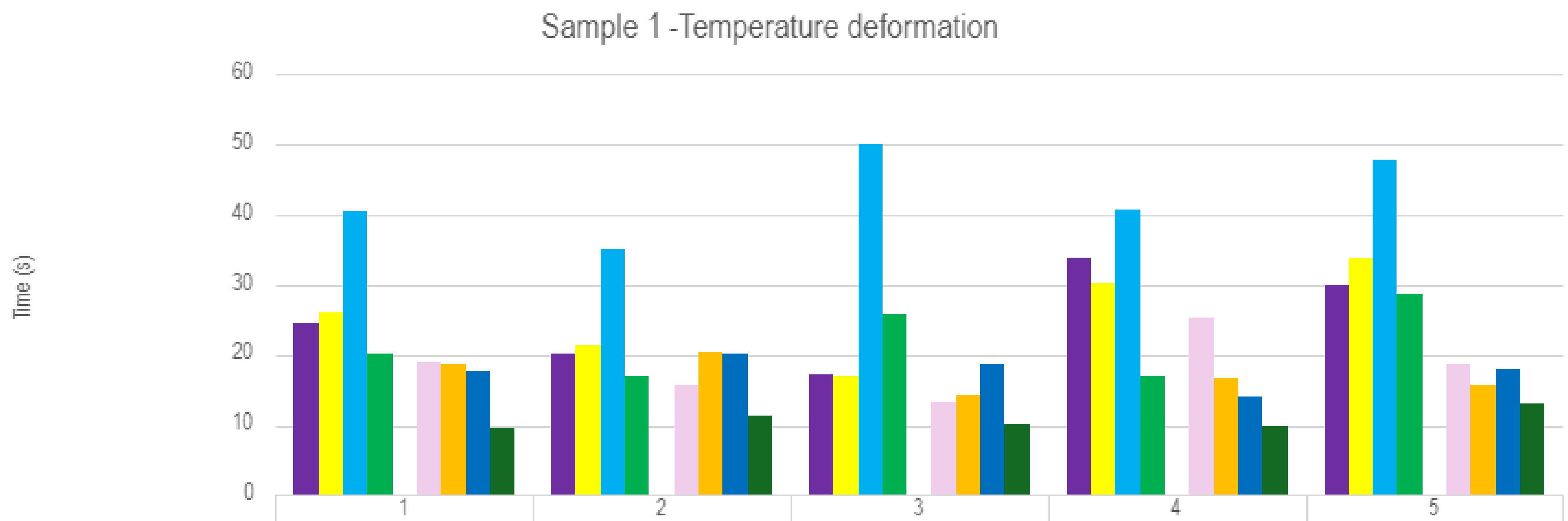
Fig.9 Chalmers text cutted using the trotec speedy 400.

4.2 CNC deformation with peltier module

An electrical circuit was setted up to start giving the thermoelectric cooler module voltage from a maximum voltage of 1.4V. Two input values were used. The first one being applying a voltage of 0.4V and a current of 0.2A. The second input value to be tested with a voltage of 1V and a current of 0.4V. Each sample consisted of 4 figures, with the same measurement.

The order of the figures to be tested was randomly selected, where each laser cutted figure got an input voltage of 0.4V and 0.2A. Each figure got tested 5 times, with a 3 minutes interval between the next session. When the figures were tested 5 times, an increase of voltage of 0.8V and an increase of current of 0.2A was applied, doing the same steps.

During sample 1 experiment, all figures showed signs of movement. The movement occurred differently for each figure. The movement followed that the figures bent upwards in a hastily direction towards where the heat was pointed at. The edges followed its path, but started to bend in all directions, making a design of being buckled. Figure 10 showcases the data of how long it took for each figure to bend. The square had the longest deformation time while the insect wings had the shortest. The poles showcase the 4 laser cutted figures and the data being the time in seconds till the CNC started to bend. The numbers 1-5 showcase the amount of times of the practical method.



	1	2	3	4	5
Oval (0.4V & 0.2A)	24.5	20.19	17.22	33.82	29.87
Star (0.4V & 0.2A)	26.09	21.3	17	30.21	33.87
Square (0.4V & 0.2A)	40.42	35.11	50.12	40.87	47.98
Insect wings (0.4V & 0.2A)	20.12	16.87	25.9	16.94	28.65
Oval (1.0V & 0.4A)	18.9	15.88	13.4	25.22	18.59
Star (1.0V & 0.4A)	18.68	20.31	14.2	16.76	15.87
Square (1.0V & 0.4A)	17.65	20.21	18.67	14.09	18
Insect wings (1.0V & 0.4A)	9.55	11.45	10.17	9.84	12.98

Voltage and ampere

Oval (0.4V & 0.2A) Star (0.4V & 0.2A) Square (0.4V & 0.2A) Insect wings (0.4V & 0.2A)
Oval (1.0V & 0.4A) Star (1.0V & 0.4A) Square (1.0V & 0.4A) Insect wings (1.0V & 0.4A)

Fig.10. The temperature data of experiment with sample 1.

For the first two test (1-2), there were signs of unsure deformation. The figures had a small margin of human contact, making it unsure if it was the temperature or the body moisture that affected the result. The figures did sometimes bend and did not, making the two first tests to not be fully analytical correct. Oval bend as expected from chapter 3.2 with a deformation measurement of 2mm upwards, while the other 3 buckled upwards in all directions. Around 1 mm.

When observing with the microscope for sample 1, the deformation for the oval is buckled till its point it can't be returned to its original state. Figure 11 showcases the sample 1 oval test experiment.

Fig. 11. Sample 1 oval test experiment with peltier module

With 0.4V and 0.2A, the CNC starts to deform quickly, making it buckle. No burn marks or major damage occurred for it to break or be unused for several more times. Increasing the input of voltage and current makes the oval figure buckle more, taking more than 1 minute for the edges to lower, and not be fully recovered to its starting point. Besides the oval figures' major deformation, the insect wings also occurred to deform. Figure 12 showcases the insect wings peltier module experiment.

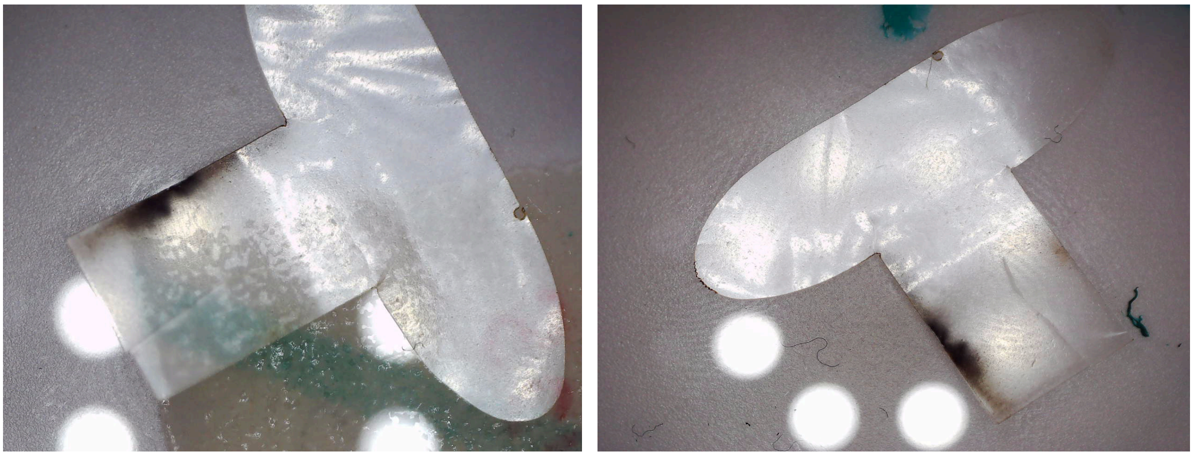
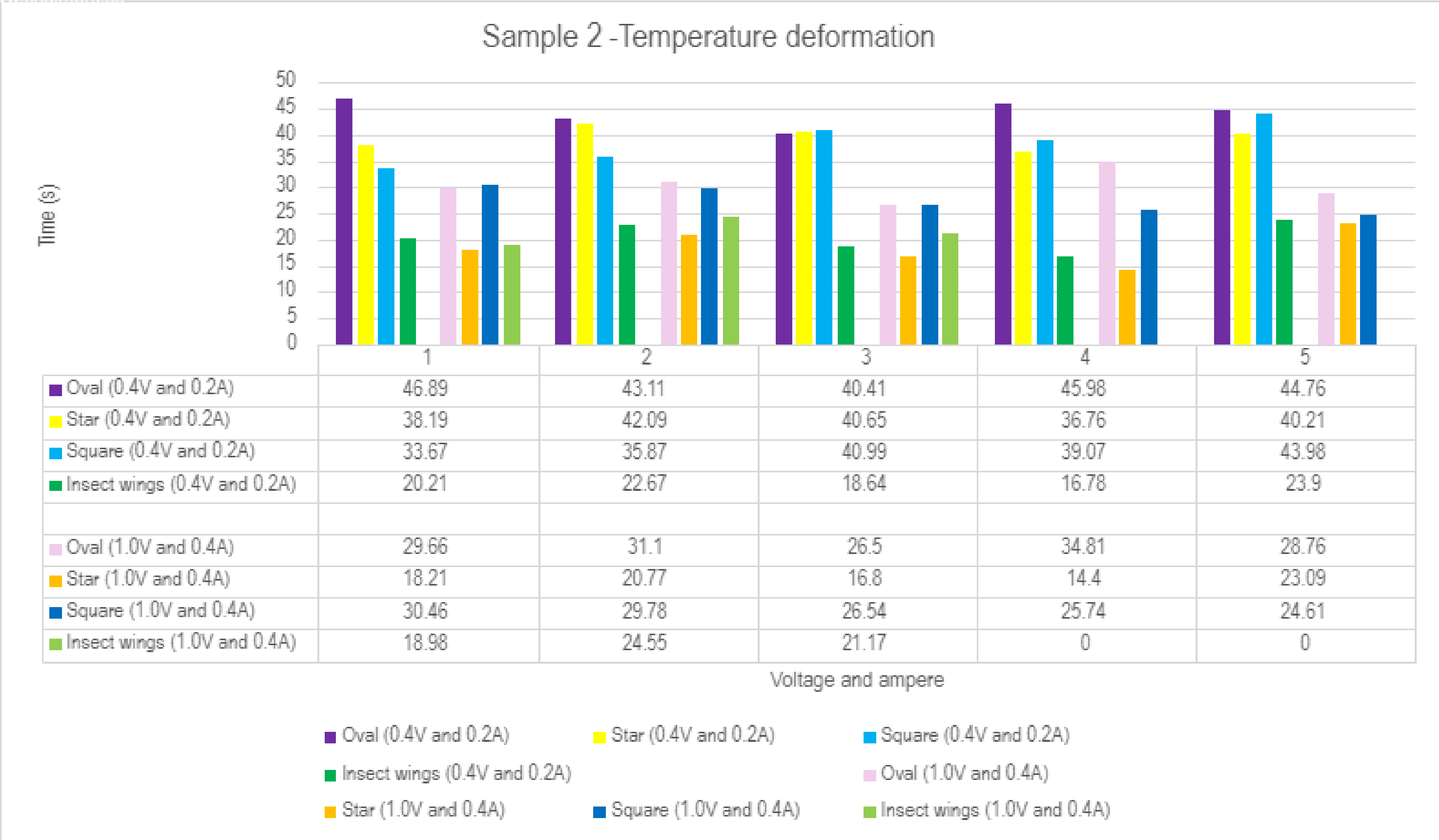


Fig.12. Sample 1 Insect wings test experiment with peltier module

Burn marks occurred on the bottom left side when doing the 0.4V and 0.2A input, but no major deformation occurred compared to oval. The deformation started to be more visible when increasing it. Instead of the expected result from figure 5, it deformed horizontal instead of vertically. A small portion of the area on the right side started to turn light brown, indicating that the material started to get burn marks. Within the 5th test, the material started to take a longer time to deform.

The other two figures can be seen at appendix 1 and appendix 2. Both have no damage and no deformation marks left when returning to its starting point. Both materials take longer to deform compared to the oval and insect wings, while the square has the longest. The sample 2 has a higher time to deform compared to the chart on sample 1. Figure 13 showcases the chart diagram for samples 2 temperature deformation with a peltier module. The number 1-5 is the amount of different times the experiment was tested on. For example, number one was the experiment performed for the first time, and the poles with different colors are the amount of voltage and current used for the experiment with respect to each figure (oval, square, star and insect wings).



	1	2	3	4	5
Oval (0.4V and 0.2A)	46.89	43.11	40.41	45.98	44.76
Star (0.4V and 0.2A)	38.19	42.09	40.65	36.76	40.21
Square (0.4V and 0.2A)	33.67	35.87	40.99	39.07	43.98
Insect wings (0.4V and 0.2A)	20.21	22.67	18.64	16.78	23.9
Oval (1.0V and 0.4A)	29.66	31.1	26.5	34.81	28.76
Star (1.0V and 0.4A)	18.21	20.77	16.8	14.4	23.09
Square (1.0V and 0.4A)	30.46	29.78	26.54	25.74	24.61
Insect wings (1.0V and 0.4A)	18.98	24.55	21.17	0	0

Fig.13. Time of deformation for CNC on sample 2 when using the peltier module

The square one has the most visible deformation compared to the other 3 figures. The movement was more clear and their was no time where the experiment ended in an unsure state, due to the material direct movement. The star had no major deformation and mostly stood still. There was sometime after around 10 sec each that the material started to move slightly in a wave form and stopped afterwards. Oval showed signs of movement in horizontal deformation with approximately 1 mm of deformation upwards. The edges moved upwards around 0.5mm.

Figure 14 shows the deformation after the 5th try. The 0.4V deforms in a diagonal form, and increases the buckle when on the right side of the picture. During the experiment, the insect wings broke.The picture can be seen at appendix 4, making the result having zero data when doing the 4th and 5th attempt.

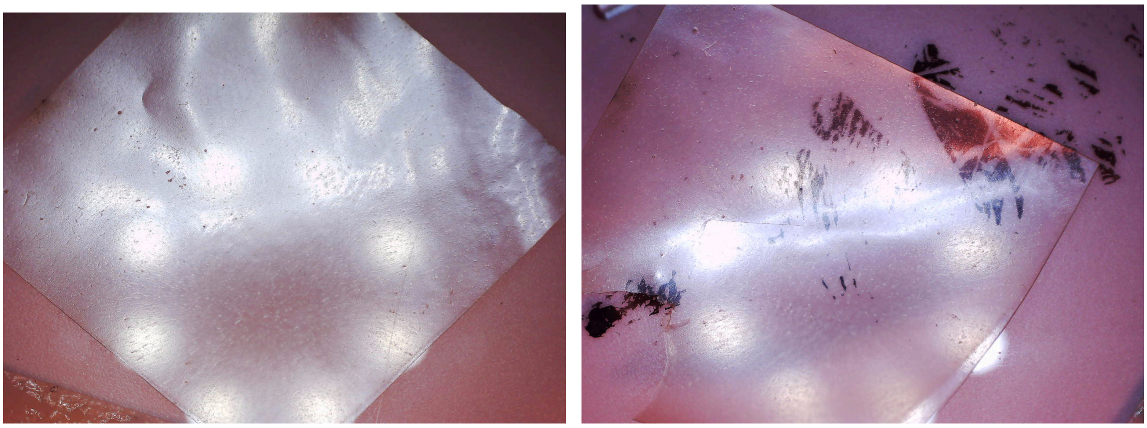
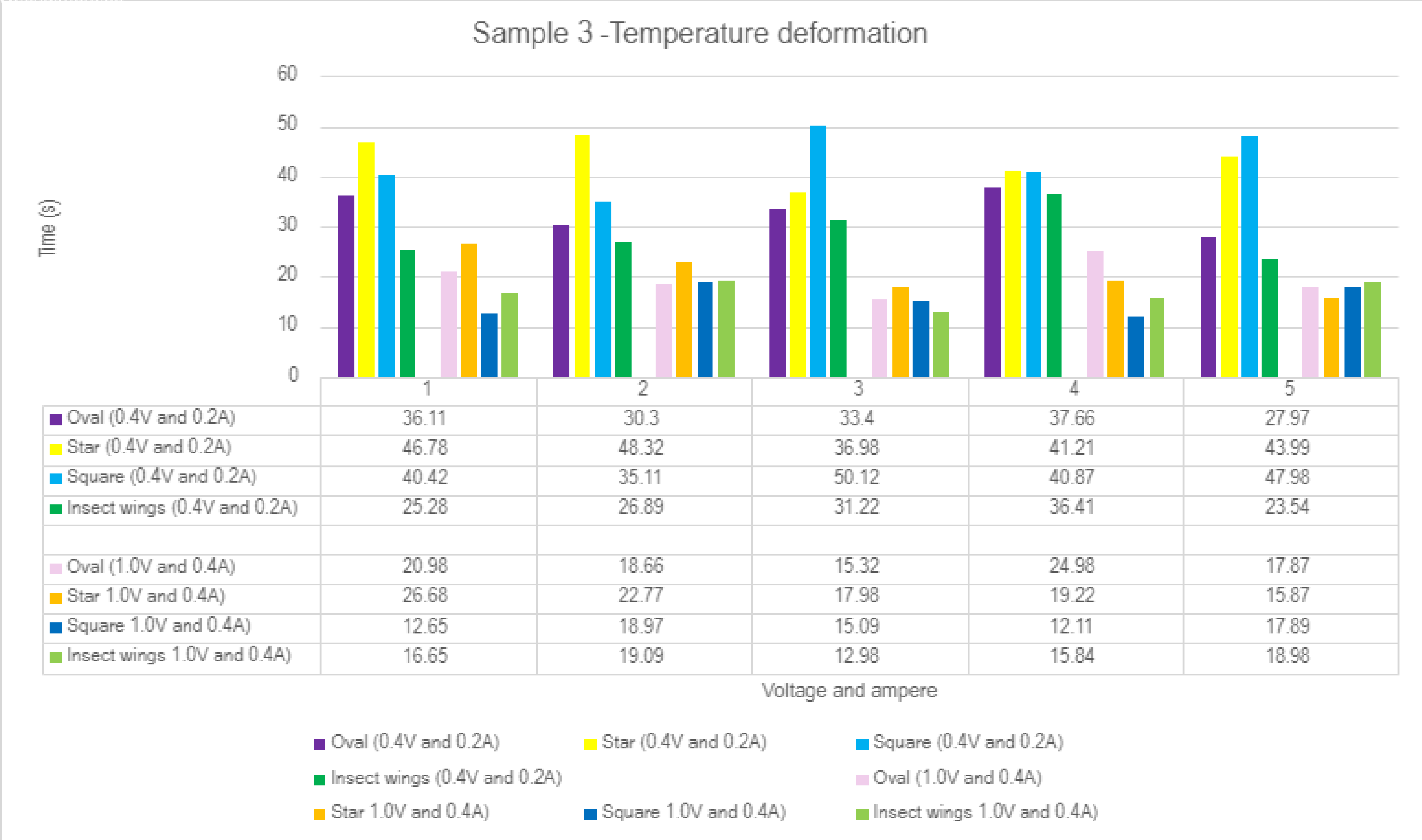


Fig.14. Sample 2 square test experiment with peltier module

Sample 3 has a faster average time compared to Sample 2. The test time for each figure, with respect to its input voltage and current can be seen at figure 15. The figure has the same protocol as the other two samples. The numbers 1-5 on the X-axis are the amount of tests used on the same figure. One test showcases two sections, one with 0.4V and 0.2A and the other with 1V and 0.4A. Y-axis is the time in seconds.



	1	2	3	4	5
Oval (0.4V and 0.2A)	36.11	30.3	33.4	37.66	27.97
Star (0.4V and 0.2A)	46.78	48.32	36.98	41.21	43.99
Square (0.4V and 0.2A)	40.42	35.11	50.12	40.87	47.98
Insect wings (0.4V and 0.2A)	25.28	26.89	31.22	36.41	23.54
Oval (1.0V and 0.4A)	20.98	18.66	15.32	24.98	17.87
Star 1.0V and 0.4A)	26.68	22.77	17.98	19.22	15.87
Square 1.0V and 0.4A)	12.65	18.97	15.09	12.11	17.89
Insect wings 1.0V and 0.4A)	16.65	19.09	12.98	15.84	18.98

Fig.15. Time of deformation for CNC on sample 3 when using the peltier module

Sample 3 was the sample with the least amount of visible movement when applying heat. Here it was very unsure what to collect data due to small visible deformation or movement shown for the figures. Instead of collecting data when the figures showed sign of movement, the time would stop when the material reacted instead. The reaction here would be that when it was heated, the material would move upwards with a measurement of less than 0,5mm.

During the experiment, none of the figures had major deformation, making it hard to do visible deformation. The figures would take more than 2 minutes for it to deform. Instead, when the figure reacted or started to deform the first it moved, then the test would stop. The most noticeable change was the oval. Figure 16 shows that the edge of the is brown, with a slight deform.

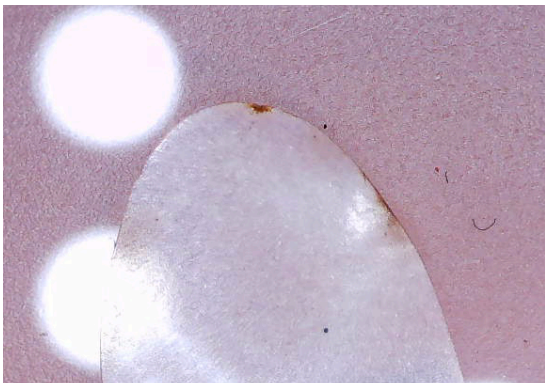
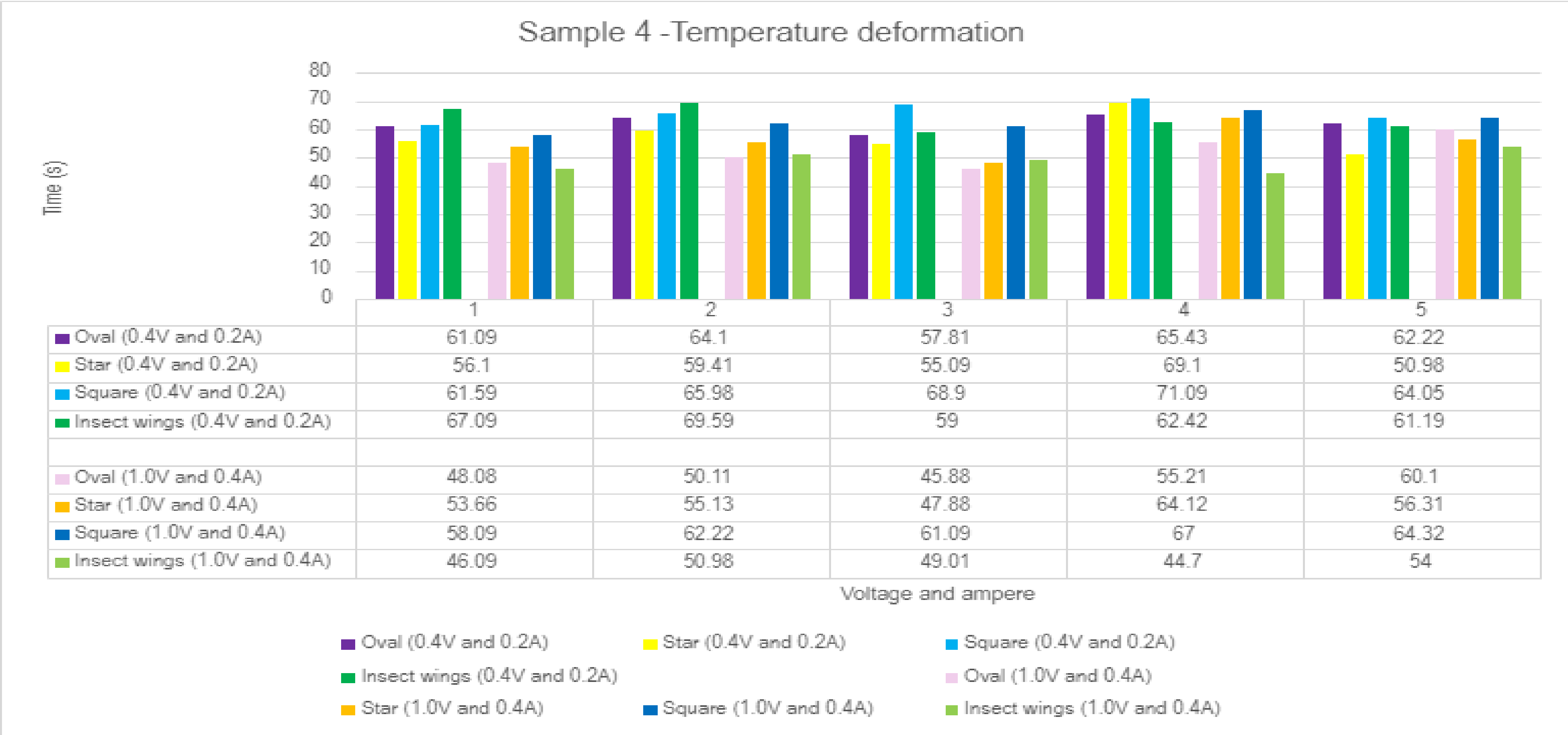


Fig.16. Sample 3 ovals test experiment with peltier module

The oval reacted and was most visible for the eye to see a deformation when performing with 1V and 0.4A. Only one side was starting to become brown, while the other figures did not. The figures reacted very slowly to the temperature and could take more than 3 minutes till it deformed as figure 5. The data instead was collected till a small movement occurred.

The last sample, sample 4 was performed with the same method. When performing with the 0.4V and 0.2A, the overall performance varies for each figure. When increasing the value, the patterns do not follow the same as the three previous samples. Figure 17 showcases the last sample 4 deformation time when performing the peltier module.



	1	2	3	4	5
Oval (0.4V and 0.2A)	61.09	64.1	57.81	65.43	62.22
Star (0.4V and 0.2A)	56.1	59.41	55.09	69.1	50.98
Square (0.4V and 0.2A)	61.59	65.98	68.9	71.09	64.05
Insect wings (0.4V and 0.2A)	67.09	69.59	59	62.42	61.19
Oval (1.0V and 0.4A)	48.08	50.11	45.88	55.21	60.1
Star (1.0V and 0.4A)	53.66	55.13	47.88	64.12	56.31
Square (1.0V and 0.4A)	58.09	62.22	61.09	67	64.32
Insect wings (1.0V and 0.4A)	46.09	50.98	49.01	44.7	54

Fig.17. Time of deformation for CNC on sample 4 when using the peltier module

Figure 18 showcases how the material reacted with the insect wings. When increasing the input of voltage and current, the average time is lowered, but the figures change its rank time of deformation. The insect wings reacted more hastily compared to the star and square. The movement was slightly better than the sample 3 insects' wings. The movement for the insect wing deformed tilted horizontally.

When doing the lower current and voltage, no signs of movement were shown, but the data collected was stored when the figures showed the first sign of reaction (movement). The reaction was that the figures that were oval and square buckled upwards in a vertical way but they changed sometimes to buckle vertically. The reason may be due to moisture being applied afterwards when heated, plus human contact from the fingers. Star showed no visible reaction except that the edges could tilt slightly upwards and then down. This occurred at random star edges in no particular order. There were uncertain times if the wind was a factor to cause the deformation. When doing the 1V and 0.4A, the movement stayed the same but had a more faster reaction.

Fig.18. Sample 4 insect wings test experiment with peltier module

4.3 CNC moisture

Sample 1 consisted of experimenting with the square figure. This is due to laser cutting causing the remaining 3 other figures to fall into a limited unauthorized area that could not be brought up or reached.

The experiment of the samples started with the first sample, sample 1. Chart 6 showcases the data collected through doing the sample 1 testing with water.

Chart 6
Sample 1 moisture data for applying and removing water.

Sample	Figure	**Water drop** Time until it does not react anymore	**Removing liquid** Time until it does not react anymore
Sample 1	Square	2 min 48s	46s

Sample 1 square figure took 2 min and 48 seconds to deform. The material reacted quickly at the first 50 seconds. The amount of reaction and deformation slowly began to slow down when the area did not spread anymore, until it did not deform more. Major portion of the liquid was removed after that. The time till it was restored to its original form took 46s. Figure 19 showcases the materials deformation during the experiment.

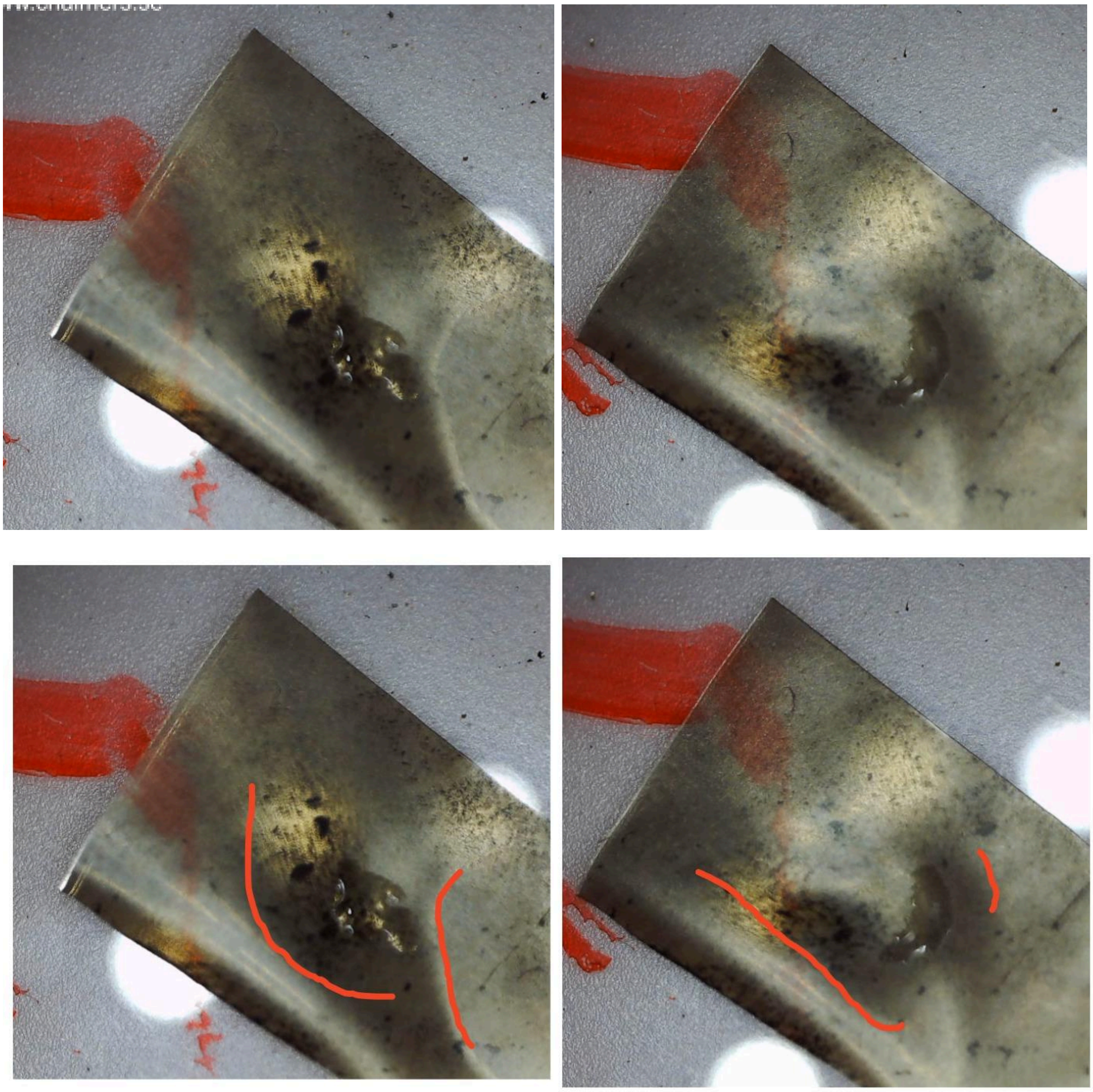


Fig.19. CNC reaction to water on sample 1 with the figure of a square.Red lines showcase where the movement most occurred. Left showcase material applied with water, Right showcase water removed.

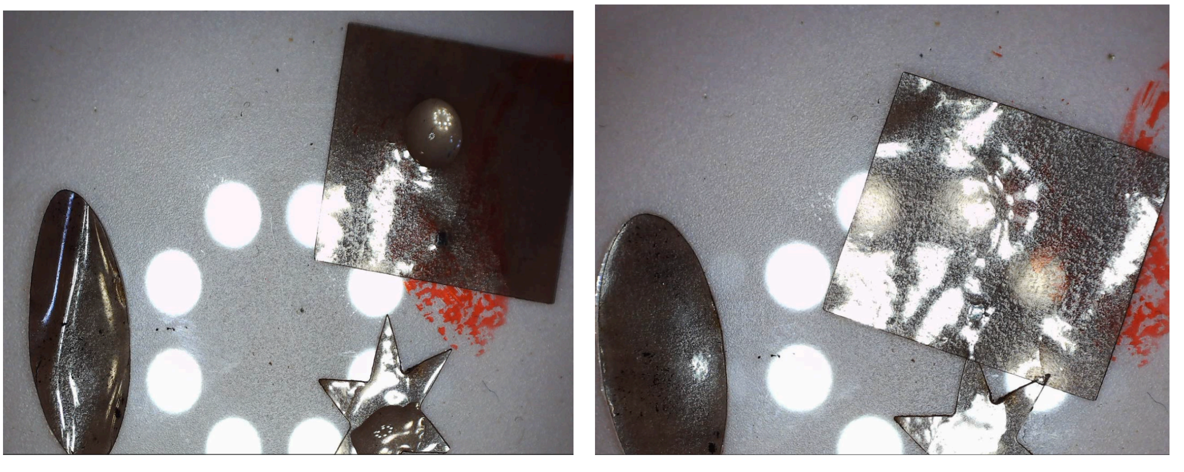
The picture on the left showcase has buckles at the center, making the rest of material follow its path. One side of the material moved up around 1mm while the rest did not move up. When removing liquid (picture on the right), the outer area still showcases buckles marks near the placement of the water. The edge of the material that deformed up with 1mm went down. It took approximately 15 seconds for it to fall down in a slow motion.

Sample 2 consisted of all figures except the insect wings. Chart 7 showcases the data for the experiment.

Chart 7
Sample 2 moisture data for applying and removing water.

Sample	Figure	**Water drop** Time until it does not react anymore	**Removing liquid** Time until it does not react anymore
Sample 2	Square	1 min 39s	2 min 02s
Sample 2	Oval	44s	35s
Sample 2	Star	1 min 6s	No reaction

Oval reacted quickest of all on this sample when applying water and had also the fastest time to deform back when removing the liquid. The square had the longest time to deform and to reform. Reforming took approximately double the time to get back to its original shape, while the figure of the star had around 30 seconds faster to deform with water but no reaction to deform back when removing the liquid. Figure 20 showcases the sample of the three figures when applying the liquid (left), and removing the liquid (right). Red lines show where the deformation most occurred.



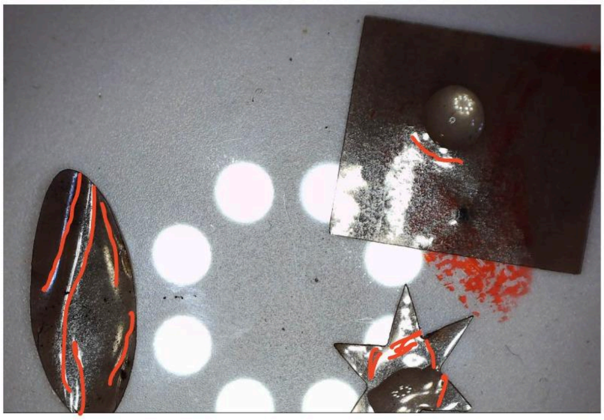
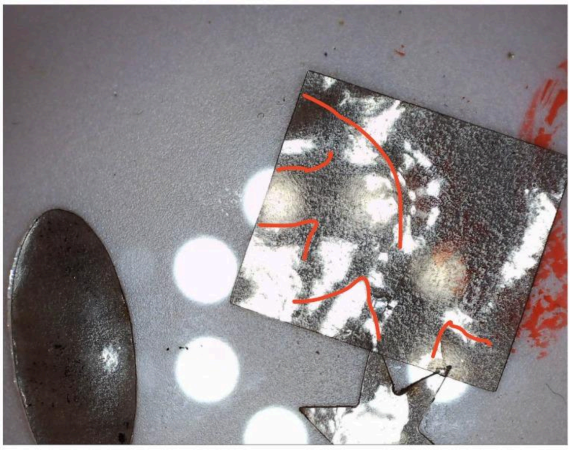
 

Fig.20. CNC reaction to water on sample 2 with the figures of a square, oval and star. Red lines showcase where the movement most occurred. Left showcase material applied with water, Right showcase water removed.

When applying liquid in the middle for the oval, the deformation occurred at almost every edge of the material. The oval moved upwards in all directions directly after applying. After 10 seconds, the material stopped deforming in upwards direction and instead moved down slowly until it stopped.   When removing it, the reformation occurred fast and left no buckles or damage. This can be seen in the figure above. Star had small bump marks after around 40s when applying the liquid. When removing it, the figure reacted with no movement and did not leave any buckles. The last figure, square, had a very slow reaction at the first 30 seconds but started to deform faster. When reducing the liquid until it has a small water drop left, the material instead did not reform at the start but instead deformed and reformed one after another, until it stopped.

The third sample, sample 3, had all four figures to be experimented on. The sample protocol follows as the other two samples. Chart 8 showcases the data for each figure on sample 3.

Chart 8
Sample 3 moisture data for applying and removing water.

Sample	Figure	**Water drop** Time until it does not react anymore	**Removing liquid** Time until it does not react anymore
Sample 3	Square	1 min 31s	2 min 37s
Sample 3	Oval	51s	2 min 10s
Sample 3	Star	1 min 6s	1 min 38s
Sample 3	Insect wings	1 min 52s	2 min 02s

By looking at the chart, oval and star have the fastest reaction and deformation when reacting with the liquid compared to the square and insect wings. The square and the insect wings have a total of 30s to 50s longer period time to fully stop reacting.

When removing the liquid, the square and the insect wings had more visible deformation but took longer. As for the oval, it reacted slower to reform back to its original state. Figure 21 and figure 22 showcase the area of deformation after applying the liquid and removing the liquid.

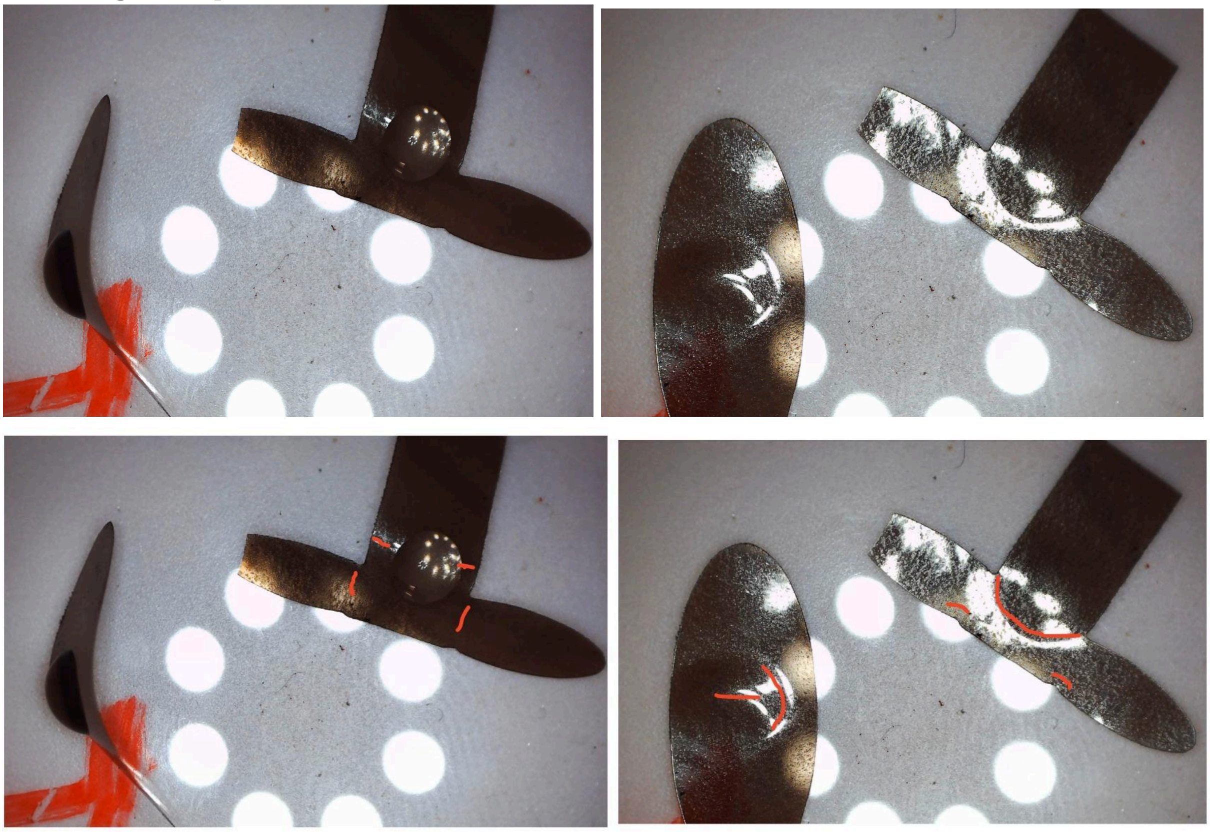


Fig.21. CNC reaction to water on sample 3 with the figures of oval and insect wings.Red lines showcase where the movement most occurred. Left showcase material applied with water, Right showcase water removed.

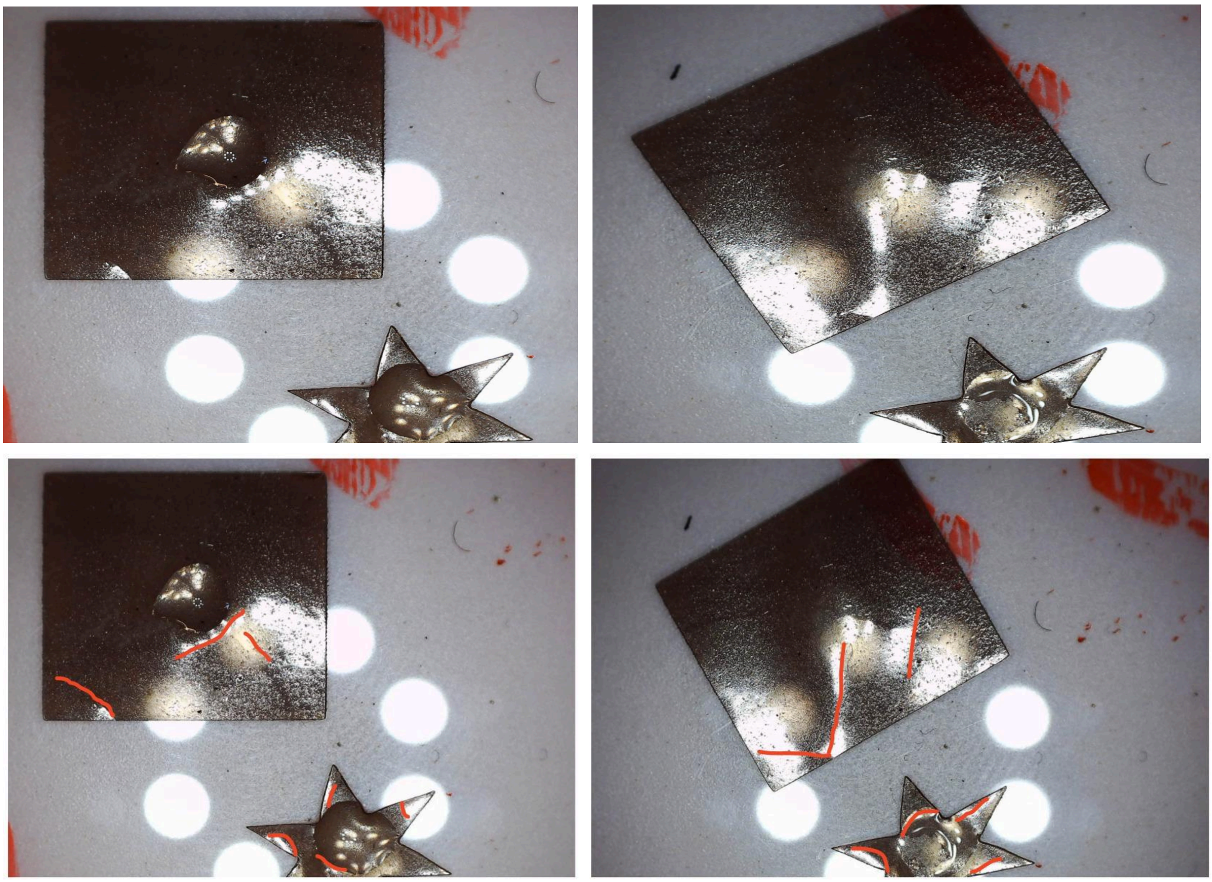


Fig.22. CNC reaction to water on sample 3 with the figures of square and star.Red lines showcase where the movement most occurred. Left showcase material applied with water, Right showcase water removed.

The most noticeable deformation after applying the liquid are the insect wings and the oval, due to drastic movement. Around 15s after the application, the oval reacted hastily and made drastically deformation compared to the insect wings shown in figure 20. After removing the liquid for insect wings and oval, the insect wings showed more reformation visibility around the edges compared to the oval. Both square and star showed similar deformation time and reaction time when applying the liquid, but square had slower reform time with 1 min.

The last sample to be tested with the moisture was sample 4. Chart 9 showcases the time until the deformation stopped after applying the liquid and the time when the CNC started to stop reform back to its original shape.

Chart 9
Sample 4 moisture data for applying and removing water.

Sample	Figure	**Water drop** Time until it does not react anymore	**Removing liquid** Time until it does not react anymore

Sample 4	Insect wings	2 min 48s	1 min 32s
Sample 4	Square	1 min 3s	1 min 50s

The insect wings have approximately three times longer to deform compared to the square which has approximately 1 min. When removing the majority of the liquid for both figures, the square had a longer time to reform back compared to insect wings with a margin of 20s. Figure 23 showcases the experiment for the two figures. The red lines illustrate where the majority of deformation occurred.

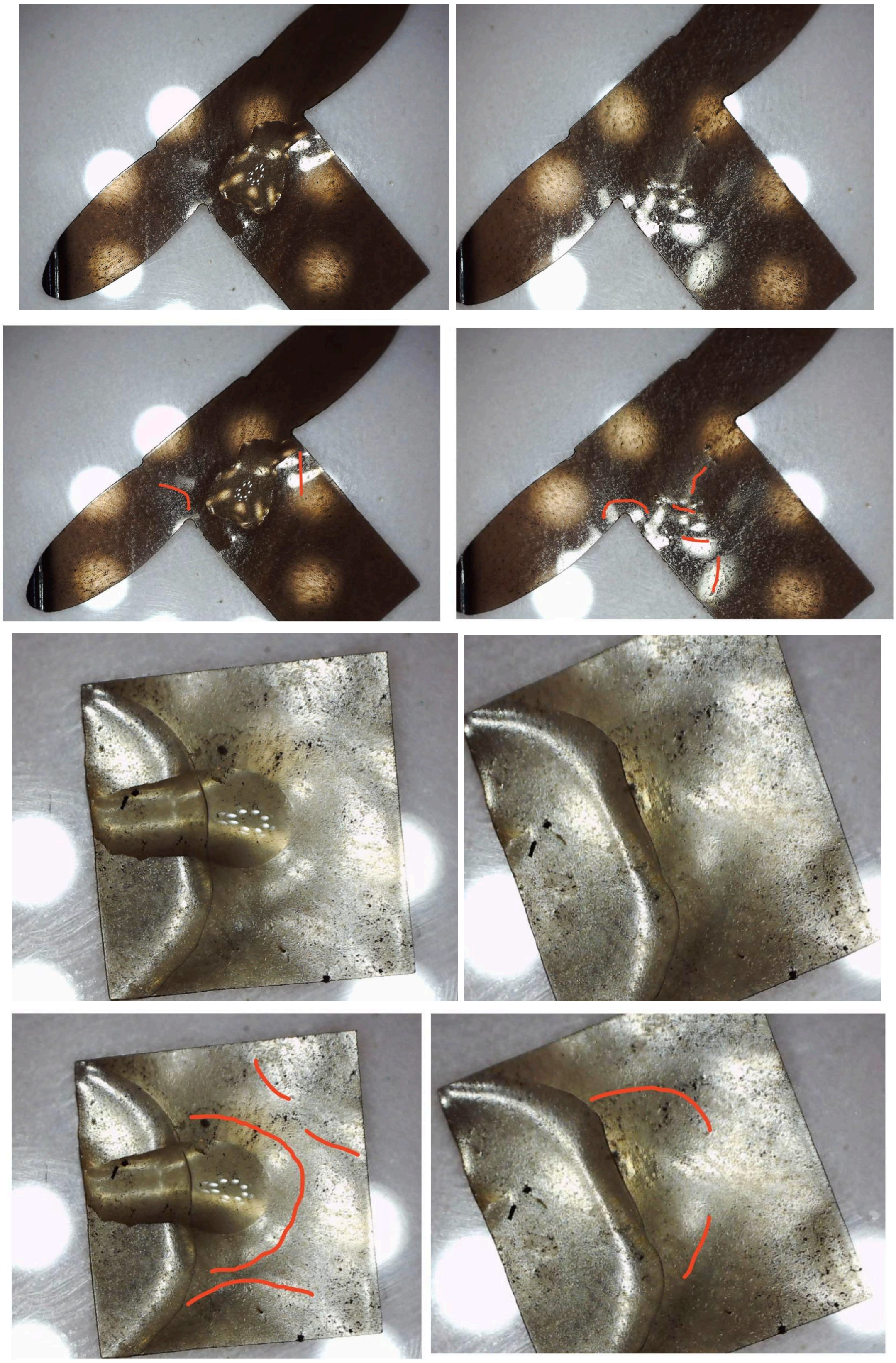


Fig. 23. CNC reaction to water on sample 4 with the figures of square and star. Red lines showcase where the movement most occurred. Left showcase material applied with water, Right showcase water removed.

The red lines showcase that when applied with the water for sample 4, the material absorbed the water but did not make any movement that would classify as a deformation. When applied with water for the figure of a insect wing, the material moved upwards at the edges but when removed, the material started to act instead like a waveform, moving up and down. The same follows with the shape of a square. When removing the water for the square, the material did not react much and moved tiny, making it classified as no deformation occurred.

5. Discussion

When cutting the four samples with the laser cutting machine speedy 400. All four samples got cutted easily without any obstacles or problems. The main problem with the cutting was that the size of the figures were too small, making it hard to reach the material. There is also a high chance for the cutted part to fall down the holes of the machines, causing extra material to be cutted and making a risk that a few figures were not included in this study due to lack of material and time.
The cutting process did not leave any noticeable burn marks except that the material could break easily when removed after the process, causing the figures to have small damage.

For the electrical and temperature testing, all four materials have similar structure and deformation time. Sample 1 had the quickest deformation time, especially with the insect wings and oval. Sample 2 and sample 3 had similar time of deformation, with a margin of time of seconds. Sample 4 had instead the longest time to deform and not visible deformation reaction. The design of deformation had to be modified due to a component, peltier module, that could not hold a longer period of time. If it would, the component would be damaged. With that, the design deformation had to be modified so that if the material moved, that would instead be the data collected.

For the moisture part, Sample 2 and Sample 3 had the most reaction. The figures, especially the oval, reacted most and moved away when the water was applied. The oval for sample 3 had a longer period of time to deform and reform compared to Sample 2 oval, it showed the most visible out of the two.

For what the best figure to be used in future projects, the oval and insect wings had the best deformation properties. It reacts faster, has more visible deformation and reformation but also that most reactions occur around circular edges compared to stars and squares that have straight edges. The star is not a suitable figure for future projects due to complicated figures and needs to have much larger size for it to work to fly. It tends to follow a path that if the total moles in a CNC is less, the sample with the respective figures. react more rapidly and have a easier time to deform

To summarize, the best sample can not be marked due to more accurate tests that need to be done. Sample 1-3 has better deformation time of properties but also reacts faster compared to sample 4.

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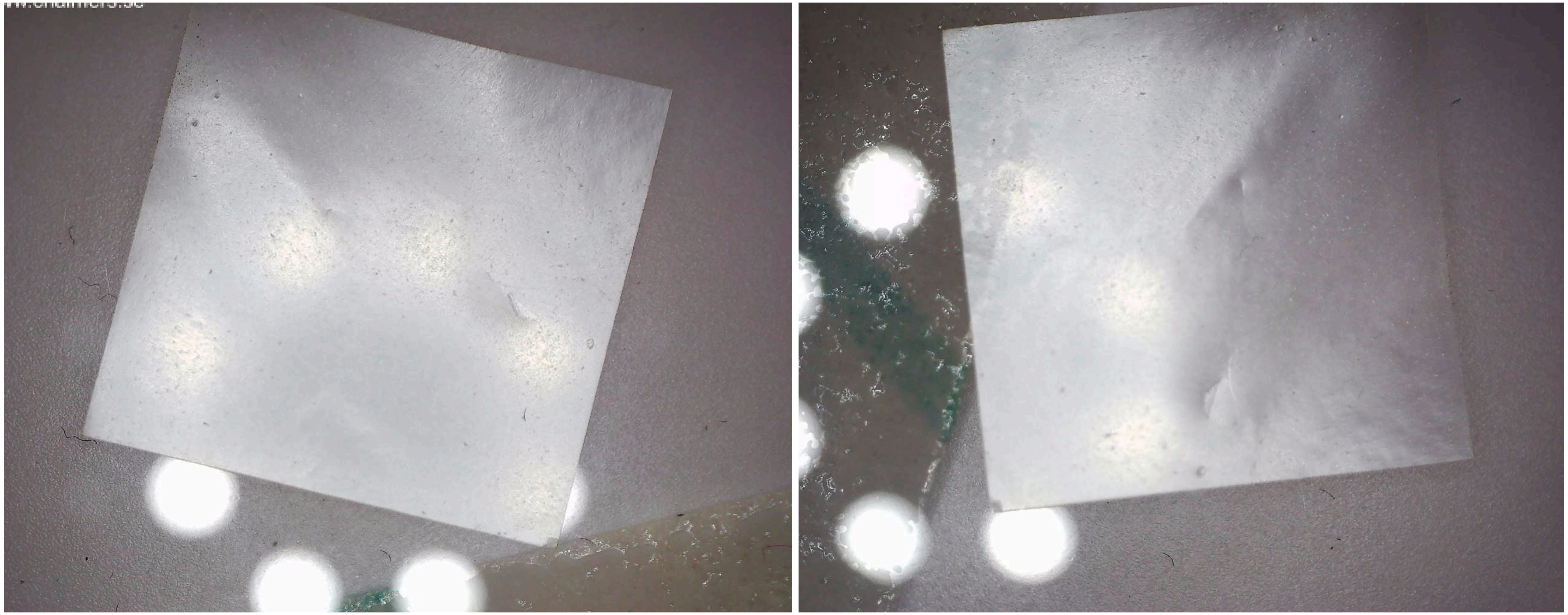
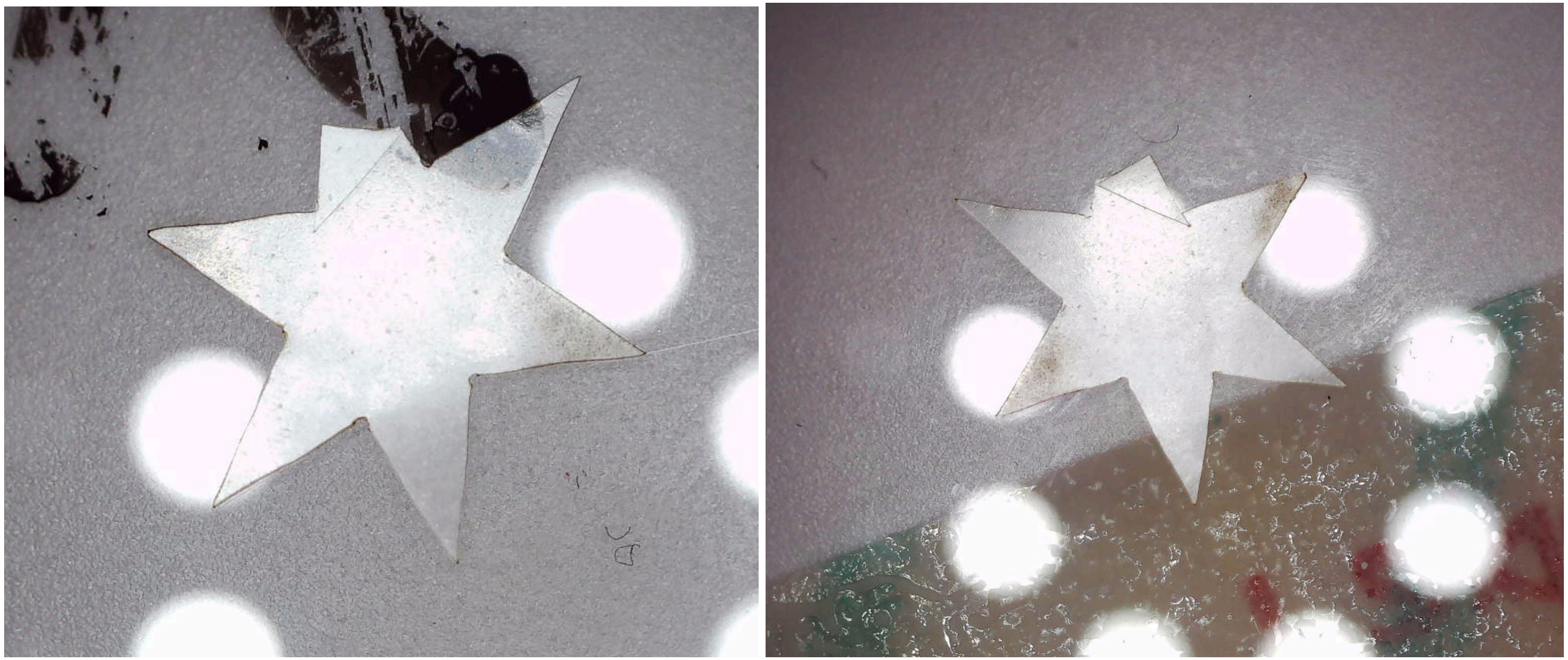
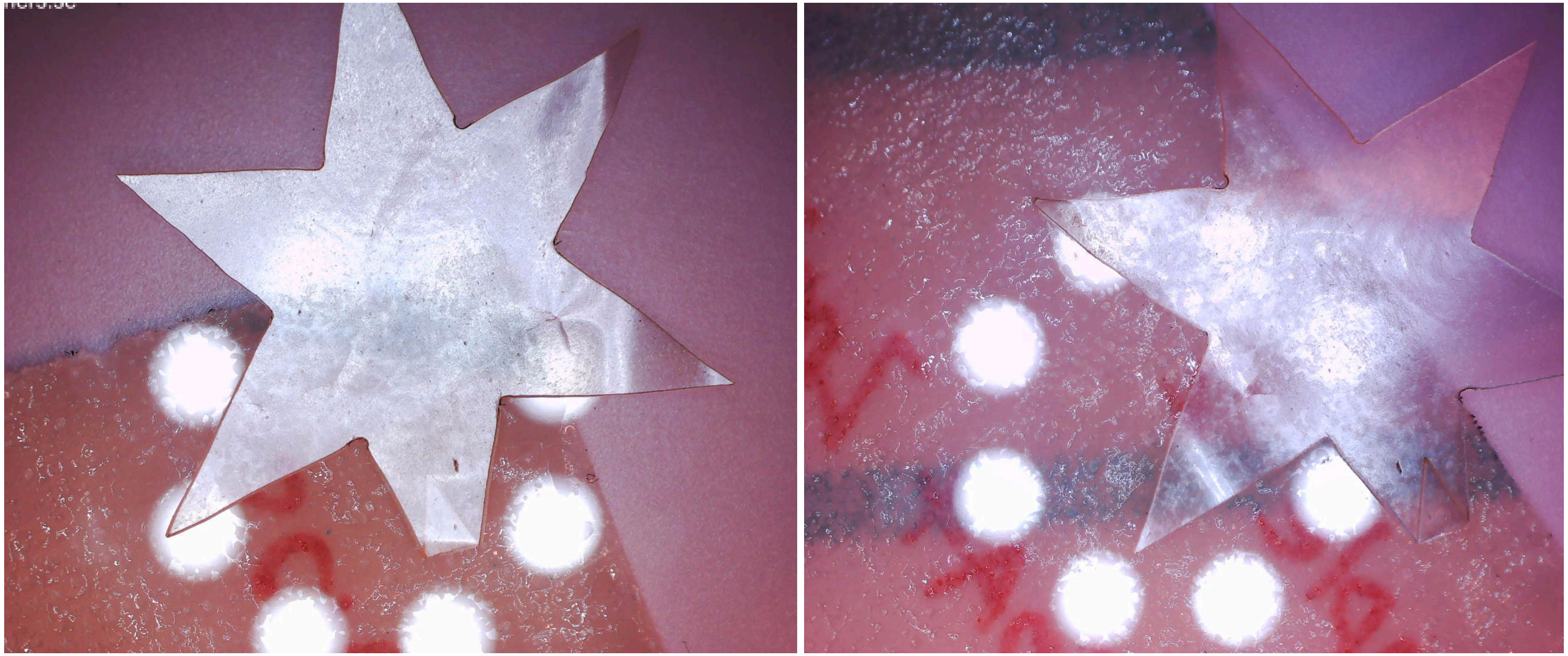
Appendix



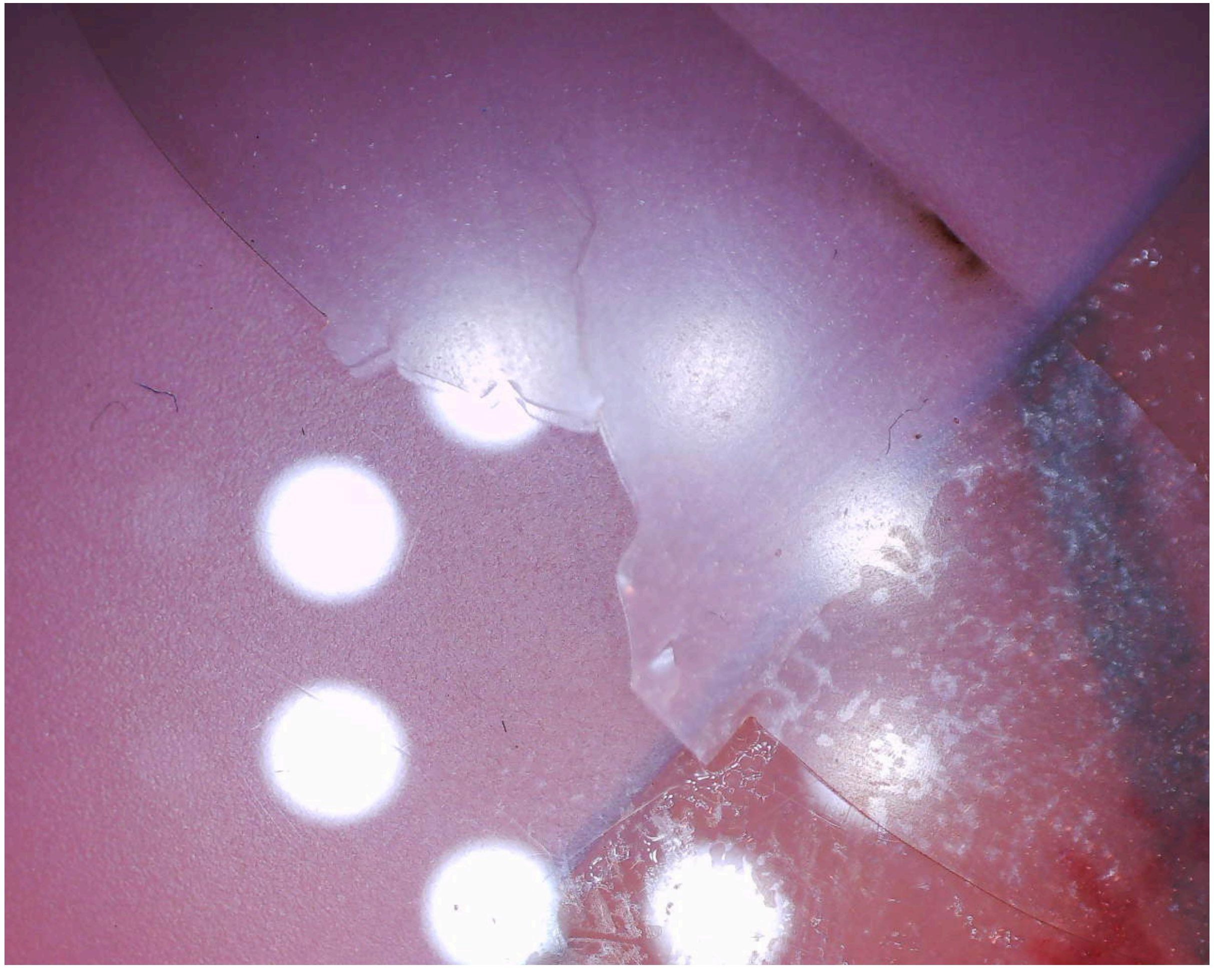
Sample 1 peltier module test for square with 0.4V and 0.2A(left) and 1V and 0.4A (right)



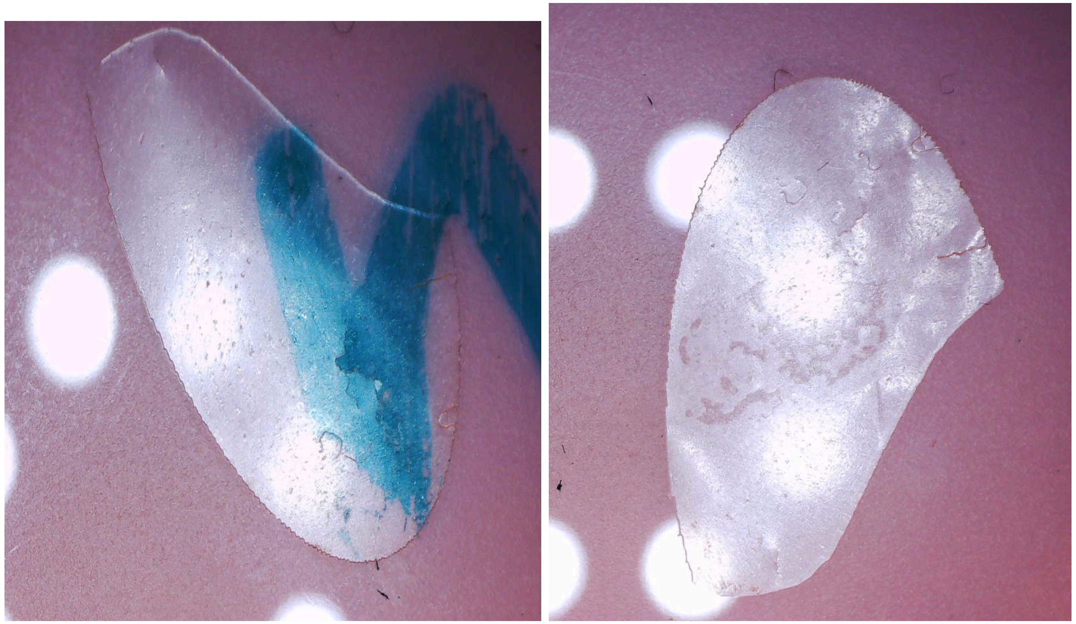
Sample 1 peltier module test for star with 0.4V and 0.2A(left) and 1V and 0.4A (right)



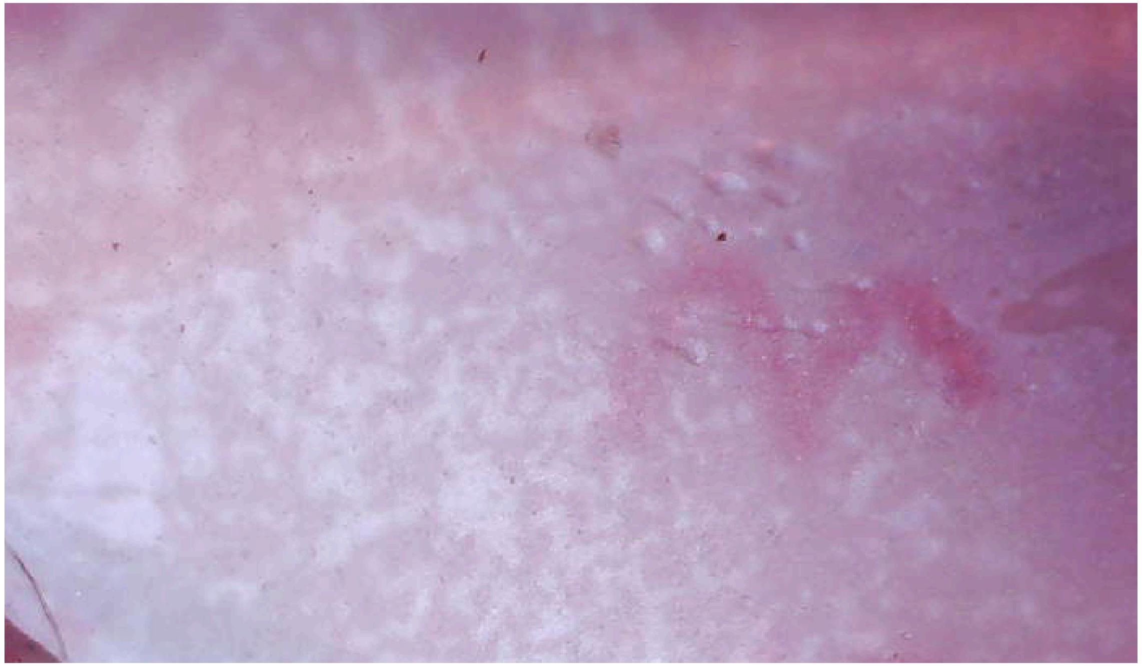
Sample 2 peltier module test for star with 0.4V and 0.2A(left) and 1V and 0.4A (right)



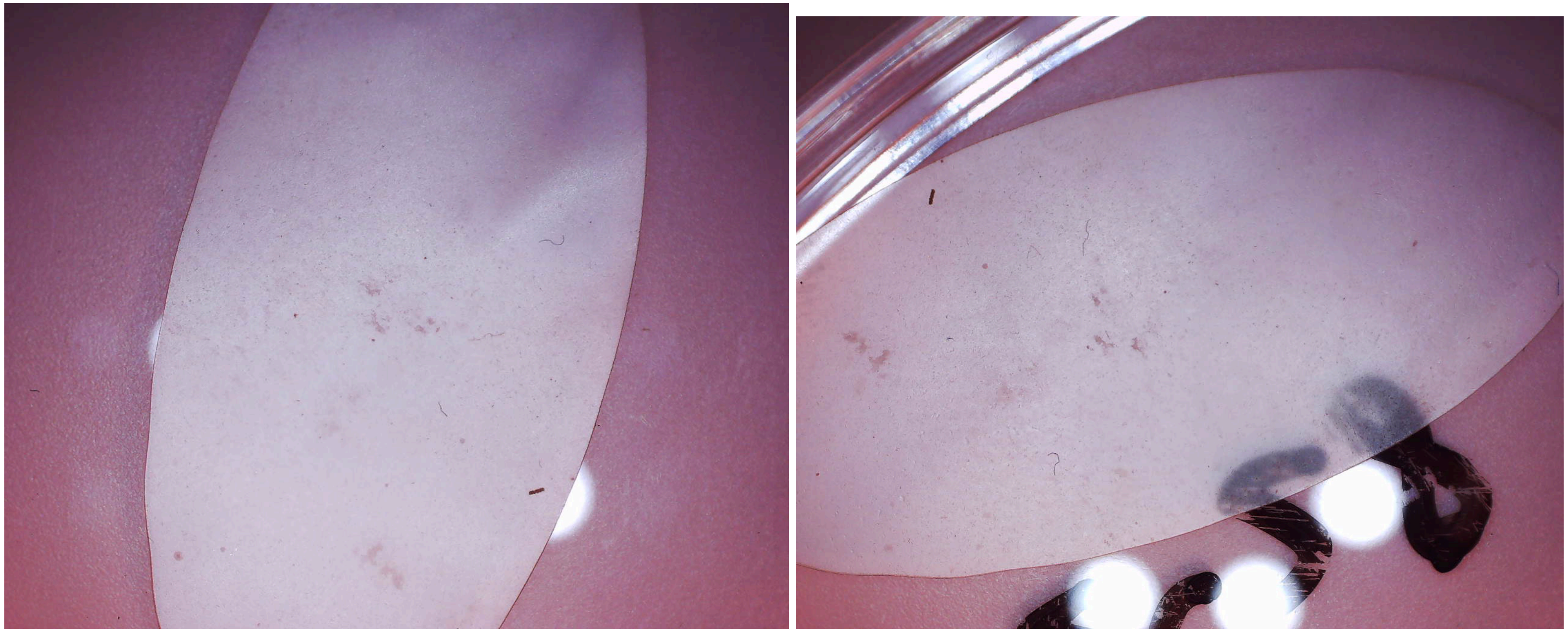
Sample 2 peltier module test for insect wings that has been broken with 0.4V and 0.2A(left) and 1V and 0.4A (right)



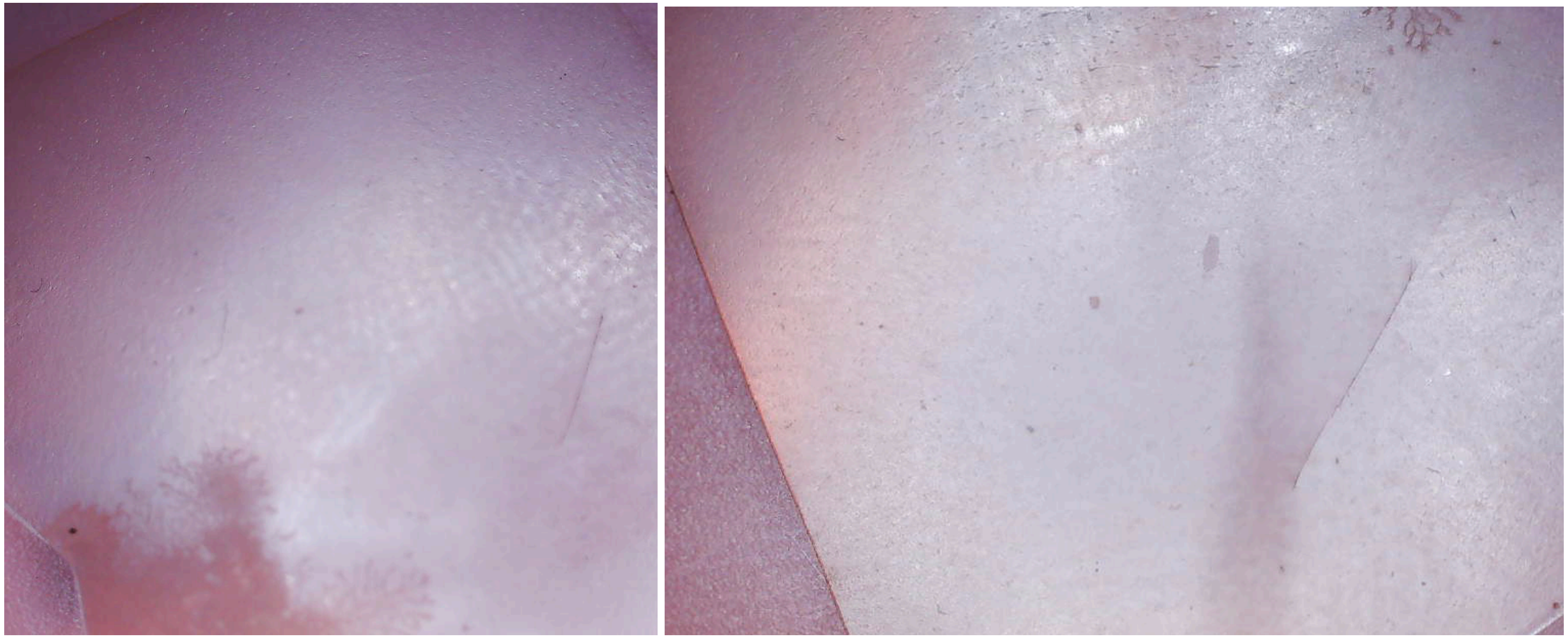
Sample 2 peltier module test for oval with 0.4V and 0.2A(left) and 1V and 0.4A (right)



Sample 3 peltier module test for square with 1V and 0.4A



Sample 4 peltier module test for oval with 0.4V and 0.2A(left) and 1V and 0.4A (right)



Sample 4 peltier module test for oval with 0.4V and 0.2A(left) and 1V and 0.4A (right)