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Development and evaluation of a chair design made out of recycled paper from Ethiopia

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WE SHALL NOT CEASE FROM OUR EXPLORING AND THE END OF ALL OUR EXPLORING WILL BE TO ARRIVE WHERE WE STARTED AND KNOW THE PLACE FOR THE FIRST TIME

- T.S. ELIOT

DEVELOPMENT AND EVALUATION OF A CHAIR DESIGN MADE OUT OF RECYCLED PAPER FROM ETHIOPIA

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PREFACE

This is my thesis work for the degree, Master's in technology, faculty for Science and Technology at the Norwegian University of Life Science (NMBU). This thesis marks the end of a six-year study within the program for mechanical engineering, process technology and product development. My specialization has been within product development and the thesis has been planned and written during the spring term of 2018.

The process of selecting a subject for my thesis was a hard and interesting journey. It was important for me that the subject would spark my curiosity as well as it filled my desire for learning and creativity. The idea came to life during a two-month long internship in Ethiopia during the summer of 2017, with a Norwegian startup that worked within paper recycling. The ball started rolling and the subject aligned with my interest in innovation, product development and entrepreneurship. The dream has always been to create something new and to work outside the Norwegian boarders, and through this thesis I can contribute to giving waste a new and interesting life.

It is with great gratitude that I want to thank my main supervisor Associate Professor Carlos Salas Bringas with the institute for Science and Technology at NMBU, for outstanding help and guidance throughout all the aspects of the master's thesis. Your knowledge and motivation were truly inspiring to me. A big thank you to my co-supervisor Associate Professor Jan Kåre Bøe with the institute for Science and Technology at NMBU, for invaluable help, feedback and genuine interest in my thesis. The thesis wouldn't be the same without your input. I also want to thank Senior Engineer Egil Stemsrud and Engineer Jon Asper with the institute for Science and Technology at NMBU, for wonderful help with the trials, without you the thesis wouldn't be complete.

Further I would like to extend a big thank you to Penda Manufacturing and CEO Marie Nielsen for betting on me and letting me explore this inspiring subject for my thesis after my internship with you during the summer of 2017. Thank you for bringing me along from the early concept development and through the ups and downs of running a startup, this has taught me a lot.

My father, Technical consultant Kjell-Roger and brother, CNC Operator Stian, who have offered outstanding help and knowledge with great technical discussions, CAD-design and production of the test rods for the trials. Thank you so much. I would also like to thank my mother and sister, Trine and Millie, for motivating me and keeping my spirits up throughout the master thesis. Finally, I would like to thank my friends, fellow students and family who have been an invaluable support throughout my studies and master thesis. A special thank you to my closest friends Guro, Elisabeth, Silje and Heidi for incredible memories, a lot of fun, invaluable motivation and support.

Thank you all for supporting and believing in me.

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May 15, 2018

Stine Øksnes Vornes

ABSTRACT

This master thesis is a part of Penda Manufacturing PLC project to look into alternative uses for recycled paper in addition to the production of pulp and one of these alternatives is the use of recycled paper in furniture production. Penda Manufacturing is a paper recycling startup based in Addis Ababa, Ethiopia. With a population of 102.5 million people, Ethiopia is the second most populated country in Africa and a country with many resources and opportunities. Waste paper is a highly attainable resource in Ethiopia, but to gain access to this resource, awareness about paper recycling needs to be raised.

So far, Penda has built up a sustainable recycling process for cardboard, but due to the requirements set by the paper mill they collaborate with Penda still lacks a recycling process for the remaining waste paper that is collected. The objective for Pendas project is to find an alternative use for the paper that is not being recycled into pulp at the moment, which include all sorts of recyclable paper with the exception of cardboard.

The idea for the thesis was established during an internship with Penda and was further developed through the production of paper-based panels at the Technical Institute in Denmark. The paper-based panels are produces from 70% recycled Ethiopian paper and 30% Danish office paper. With a dream of producing school furniture from recyclable paper for the UN. The main objective for this thesis is to investigate, develop and test a solution for the use of recycled paper as the main component in the production of furniture in Ethiopia. This will be done through testing the selected material, and by developing and designing a concept for a chair produced from paper-based material. The work will show if the selected method is functional and whether the material is durable or not, which will lead to a recommendation for further work on the project.

The process of developing a concept for the chair and testing the materials, is based on a set of process steps which establishes a frame for the work process. The process steps include methodology, a concept development and screening, a presentation of the selected concept, testing the materials and further development of the of the concept. At the end of the process, each of the aspects of the process steps are evaluated.

The main objective for the product, in short, is to provide a concept for a piece of furniture that is intended for school use in the age group of 12 – 35 years and is also mainly produced from recycled paper. Through the use of product development methodology, like SCAMPER, the idea and concept alternatives for the product are challenged by twisting and turning them, which results in new ideas and solutions that haven't been thought of before. The final concept is selected through the use of Pugh´s method, which compares the alternatives against each other and grade them according to a set of criteria established for the alternatives. The selected concept for this thesis is a chair inspired by rectangles and triangles, with a footrest to adapt the chair for the selected age group and a frame under the seat that stabilizes the seat.

The experimental methodology for the material testing is built up by an experimental plan which states the main objective and partial objectives for the trial. The main objective for the trials is to test the mechanical properties for the paper-based panels made using the waterless method with different binders through testing the tensile strength, the bending properties, the contact angle and the surface roughness. Further, is the experimental methodology built up by individual methodology for each of the trials and the equipment that is used.

Three trials were conducted with a minimum of three samples of each of the three material mixtures Biotack, Dextrin and Silicate.

The trials presented results within tension properties, the contact angle and wettability, and the surface roughness of the material. The results established a foundation for the further development and testing of the material, since the calculation based on the results from the tension properties trial showed that the material presented in the thesis is strong enough to be used alone in a chair. Further, is the concept developed through assessing the robustness, maintenance, recycling, production method and economics related to the chair and material and marks the end of the concept development.

The thesis work concludes with a recommendation to further test the material properties and to verify that the material will withstand the forces applied to the chair, as calculated in the thesis. It is also recommended that the design concept for the chair should be user tested, through the production of prototypes and to be further developed based on the results from the user test. The final chair concept is given these dimensions: Seat height in the front is 445 mm and the seat height in the back is 430 mm. The seat width and depth are 400 mm x 380 mm, while the height of the backrest from the seat surface is 455 mm. The angel of the seat and backrest is 2.26 ° and 5 °, while the total height and depth of the chair is 885 mm and 420 mm.

SAMMENDRAG

Denne masteroppgaven er en del av Penda Manufacturing PLC sitt prosjekt for å se på alternative anvendelser av resirkulert papir, i tillegg til produksjon av papirmasse Et av disse alternativene er å bruke resirkulert papir i møbelproduksjon. Penda Manufacturing er en gjenvinnings oppstart som fokuserer på resirkuleringen av papp og papir, og er basert i Addis Abeba, Etiopia. Med en befolkning på 102,5 millioner mennesker er Etiopia det nest mest befolkede landet i Afrika og et land med mange ressurser og muligheter. Avfallspapir er en svært tilgjengelig ressurs i Etiopia, men for å få tilgang til denne ressursen må bevissthet om resirkulering av papir spres.

Hittil har Penda etablert en bærekraftig resirkuleringsprosess for papp, men på grunn av kravene fra papirfabrikken de samarbeider med, mangler Penda fortsatt en resirkuleringsprosess for det gjenværende avfallspapir som samles inn. Målet for Pendas prosjektet er å finne en alternativ bruk for papiret som ikke gjenvinnes i dag og som inkluderer alle typer resirkulerbart papir med unntak av papp.

Ideen til avhandlingen ble presentert under en internship med Penda og ble videreutviklet gjennom produksjon av papirbaserte paneler på Teknisk Institutt i Danmark. De papirbaserte panelene produseres fra 70% resirkulert etiopisk papir og 30% dansk kontorpapir. Med en drøm om å produsere skolemøbler fra resirkulerbart papir til FN er hovedmålet med denne oppgaven å undersøke, utvikle og teste en løsning for bruk av resirkulert papir som hovedkomponent i produksjon av møbler i Etiopia. Dette vil bli gjort ved å teste det valgte materialet, og ved å utvikle og designe et konsept for en stol produsert av papirbasert materiale. Arbeidet vil vise om den valgte metoden er funksjonell og om materialet er holdbart eller ikke, noe som vil føre til en anbefaling for videre arbeid på prosjektet.

Prosessen med å utvikle et konsept for stolen og teste materialene, er basert på et sett prosesstrinn som etablerer en ramme for arbeidsprosessen. Prosesstrinnene inkluderer metodikk, konseptutvikling og -screening, en presentasjon av det valgte konseptet, testing av materialer og videreutvikling av konseptet. Ved slutten av prosessen evalueres hver av aspektene i prosesstrinnene.

Hovedformålet med produktet er kort sagt å skape et konsept for et møbel som er beregnet for bruk i skolehverdagen og for aldersgruppen 12 - 35 år. Produktet er også hovedsakelig produsert av resirkulert papir. Gjennom bruk av produktutviklingsmetodikk, som SCAMPER, blir ideen og konseptet alternativer for produktet utfordret ved å vri og snu dem, noe som resulterer i nye ideer og løsninger som ikke har vært tenkt på før. Det endelige konseptet er valgt ved bruk av Pughs metode, som sammenligner alternativene mot hverandre og gir alternativene karakterer i henhold til et sett av kriterier fastsatt for alternativene. Det valgte konseptet for denne oppgaven er en stol inspirert av rektangler og trekanter, med fot støtte for å tilpasse stolen for den valgte aldersgruppen og en ramme under setet som stabiliserer og styrker setet.

Den eksperimentelle metoden for materialtestingen er bygget opp av en forsøksplan som angir hovedmål og delmål for forsøket. Hovedmålet for forsøkene er å teste de mekaniske egenskapene til de papirbaserte panelene som er laget ved hjelp av en vannløs produksjons metode med hvor forskjellige bindemidler som påvirker sammensetningen i panelet. ved å teste strekkfastheten, bøy egenskapene, kontaktvinkelen og overflatens grovhet. Videre er den eksperimentelle metoden bygget opp ved hjelp av individuell metodikk for hvert av forsøkene og utstyret som brukes.

Tre forsøk ble utført med tre prøvestaver av hver av de tre materialblandingene Biotack, Dextrin og Silikat i hvert av forsøkene.

Forsøkene som presenteres, resulterer i spenningsegenskaper, kontaktvinkelen til materialet og overflatens grovhet. Resultatene etablerte grunnlag for videreutvikling og testing av materialet, siden beregningen basert på resultatene fra spenningsegenskaperprøven viste at materialet presentert i avhandlingen er sterkt nok til å bli brukt alene i en stol. Videre er konseptet utviklet gjennom å vurdere robusthet, vedlikehold, resirkulering, produksjonsmetode og økonomi relatert til stolen og materialet og markerer slutten av konseptutviklingen.

Avhandlingen avsluttes med en anbefaling å gjennomføre ytterligere testing av materialegenskapene og for å verifisere at materialet tåler kreftene som påføres stolen, som er beregnet i avhandlingen. Det anbefales også at designkonseptet for stolen skal testes, gjennom produksjon av prototyper og videreutvikles basert på resultatene fra brukertesten. Det endelige stol konseptet er gitt disse dimensjonene: Setehøyde foran er 445 mm og setehøyden baksiden er 430 mm. Setebredden og dybden er 400 mm x 380 mm, mens ryggstøttens høyde fra seteoverflaten er 455 mm. Stol platens og ryggstøttens vinkel er 2,26 ° og 5 °, mens stolens totale høyde og dybde er 885 mm og 420 mm.

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ABBREVIATIONS

CONCEPT	EXPLANATION
Cradle to Cradle	Design concept inspired by nature and focuses on eliminating wast.
Natural capitalism	*The world´s stocks of natural assets including soil, air, water and all living things.*
Blue economy	*Open-source movement.*
Performance economy	*Four goals: extension of the products life, waste prevention, goods with long life's and reconditing activities.*
Biomimicry	*The imitation of models, systems, and elements in nature with a purpose of solving human problems.*
Regenerative design	*Process oriented system.*
Popliteal height	*The height measured vertically from the floor to the underside of the thigh just behind the knee on a sitting person.*
Buttock-popliteal length	*The length measured horizontally from the backward surface of the buttock to the back of the lower leg on a sitting person.*
Non-procrustean	*User centered design that deals with people like they are and not what they might be.*
Waste hierarchy	*Tool used to priorities the efficient use of resources.*
UN	*United Nations.*
CAD	*Computer-aided design.*
FEM	*Finite Element Method.*
PLC	*Public Limited Company.*
BIFMA	*The Business and Institutional Furniture Manufacturer's Association.*

1 INTRODUCTION

The subject of the thesis is introduced through the presentation of the background for the thesis, which represents the why´s of the thesis. Based on the background, a screening of the existing solutions and the marked is completed to see what have been done so far, how they have done it and what needs the market has. This lays a foundation for the thesis as a whole and the final result will be built upon this information.

1.1 Background

When choosing a university or institution to study at today, there is a sea of options and combinations to consider. The reason for choosing the Norwegian University of Life Sciences (NMBU), was to enter a creative and innovative environment filled with unique initiatives and opportunities that focuses on the future and the environment.

Throughout the years at NMBU there have been a lot of interesting and exciting opportunities and one of them was an internship in Ethiopia during the summer of 2017. Through the internship at Penda Manufacturing PLC, the idea for this thesis came to life. The two-month internship in Ethiopia was followed by a visit to the Technical Institute in Taastrup, Denmark, in September 2017 with Penda. This was the first step towards making paper-based furniture and a small batch of paper-based panels were made. During the week-long visit, different glues and material mixtures were tested.

The goal for the paper-based furniture was to make a product from the recycled paper that wasn't produced into pulp, at Pendas manufacturing site. The dream is to make furniture that can be used in schools and education centers in Ethiopia and other developing countries, but also worldwide and perhaps even in a collaboration with the United Nations.

Worldwide, there is an increasing focus on developing a sustainable and greener society and saving raw materials. One thing that has positively affected this focus is the 17 Sustainable Development Goals presented by the United Nations in 2015 as a part of the new sustainable development agenda. The SDG aims to end poverty, protect the planet and ensure prosperity for all, and each goal has targets that it is set to reach before 2030. As a result of the SDG goal number 14, Ocean, plastic pollution is getting a lot of attention these days. It is predicted that in 2050 the ocean will contain more plastic than fish (UN, 2018).

It is a huge problem worldwide, not only at sea but in general. Almost every day there is a new article about plastic pollution, which has a positive effect, since people are actually taking action each day. One of the trends that has increased in popularity lately is plogging, which combinates jogging with picking up waste. The trend was started in 2016 in Sweden as an organized activity and has now started to catch on worldwide. Plogging is an effect of the growing concerns related to plastic pollution (Ritschel, 2018).

Another result of the increasing focus on the environment and shortage of raw materials, is industrial ecology (IE) that has grown quickly as a field. Industrial ecology involves the transformation of industrial development and production processes from an "open loop" to a "closed loop" system (Bøe, 2014a).

In an open loop, the product is treated as waste after it has served its purpose and in a closed loop, the product is treated as a resource that can be used as raw material in new products or productions after it has served its purpose. Industrial ecology also views industrial systems as ecosystems, where the main idea is built upon the principle of nature-based ecosystems. Nature-based ecosystems doesn't produce waste that can´t be used within the ecosystem, and industrial systems in IE should be modelled in the same way, to make them sustainable over time (Bøe, 2014a).

Recycling is a big part of industrial ecology and creating a circular economy. There are several benefits with recycling and producing products from recycled materials, it reduces the release of pollutants and it reduces the landfills that are growing rapidly worldwide. Recycling is also a more sustainable use of resources, which saves energy and can replace raw materials. When producing a product from recycled materials, the product is produces by using different kinds of waste as raw material (Bøe, 2014a).

Ethiopia is a country with a diverse nature, ranging from a 125 m below sea-level in the Danakil Depression in the Afar region at to the Ras Dejen at 4550 m above sea-level located in the Seimen Mountains and Amhara region. With Addis Ababa as the capital and a total population of 102.4 million people Ethiopia is the second most populated African country (The World Bank, 2018).

In 2011, Ethiopia established an initiative called Ethiopia's Climate-Resilient Green Economy, CRGE, which is a green economy strategy, where the goal is to achieve middle income status by 2025 while developing a green economy (Federal Democratic Republic of Ethiopia, 2011).

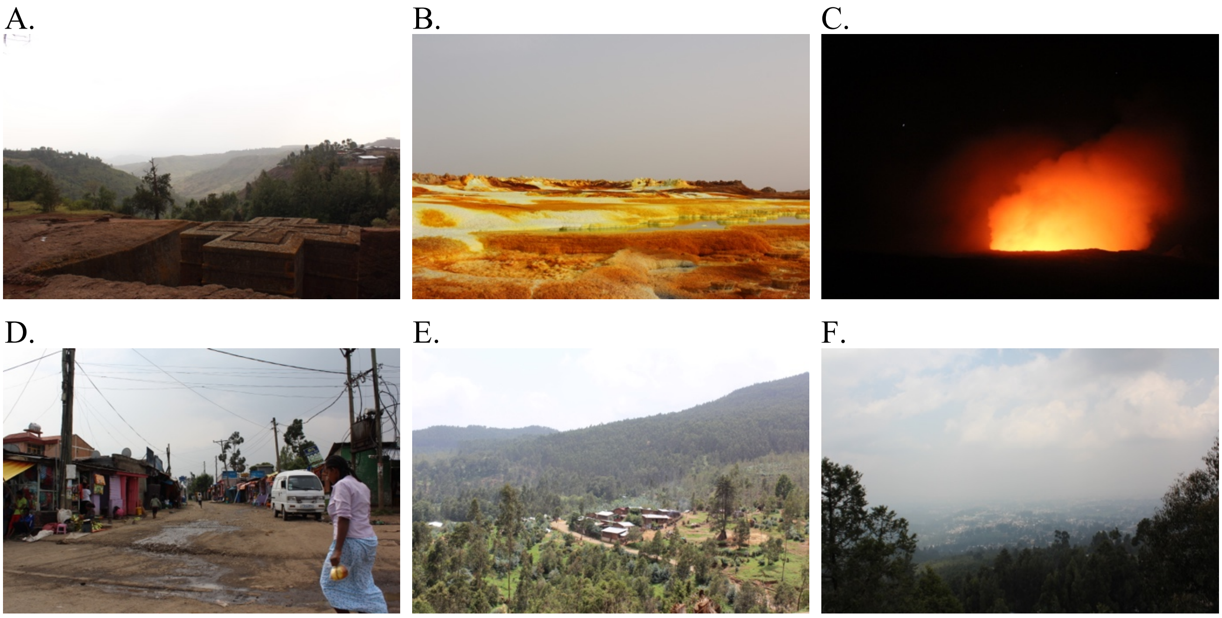


Figure 1.1: Pictures from all over Ethiopia. ***A)*** *The St. Georg Church in Lalibela.* ***B)*** *The Danakil Depression in the Afar region, north in Ethiopia.* ***C)*** *The active volcano Erta Ale in the Afar region.* ***D)*** *A random street in Addis Ababa.* ***E)*** *A small community at the foot of Entoto, a mountain in Addis Ababa.* ***F)*** *The view of Addis Ababa from Entoto. (Photo: Authors own)*

While being one of the fastest growing countries in the world, Ethiopia has a poor waste management system which is not capable handling the rapid growth and urbanization the country is experiencing. In Addis Ababa, there are several waste management companies that promises that they recycle the waste that is picked up from offices and factories but in reality, everything goes straight to the landfill.

Waste in Addis is also collected by microenterprise collectors, the collectors are usually unemployed youth who have started their own microenterprise to collect general waste, paper/carton or plastic from firms for free, for then to sell it to companies that collects waste or that is recycling either paper/carton or plastic.

Penda Manufacturing PLC also known as Penda Paper, was founded in Ethiopia by Marie Nielsen in 2015 and was founded with three goals in mind. First, they want to contribute to build a circular economy for waste paper and cardboard in Ethiopia. Second, they want to create 20 000 jobs and income opportunities in recycling by 2025 and third, they want to contribute to making Ethiopia a green middle-income country by 2025 (Nielsen, 2017).

In partnership with the Addis Ababa municipality they are working with 7000 microenterprise collectors that collects paper and cardboard for Penda. The paper Penda recycles is collected by their own trucks and brought to their manufacturing site in Akaki Kality, which is an industrial area in Addis. At the site the paper is sorted and bailed, before it is processed into pulp. Then the pulp is sold to the paper mill Penda is collaborating with and is processed into cardboard boxes by the paper mill.

To this date, Penda only producing carboard into pulp because that is what the paper mill needs. Due to this there is a lot of paper that is being stored at the manufacturing site and Penda is now looking into other ways to use this paper. One of the ideas, is paper furniture which is the focus of this thesis.

A. B. C.

Figure 1.2: From Pendas manufacturing site and the industrial area in Akaki Kality, Addis Ababa, Ethiopia. ***A)*** *The yard of Pendas manufacturing site in Akaki Kality.* ***B)*** *Inside Pendas manufacturing site.* ***C)*** *One of the streets in the industrial area in Akaki Kality. (Photo: Authors own)*

The goal for this thesis is to test and develop paper-based material for the production of furniture in Ethiopia, while also developing a design concept for a chair made from material which can be used in schools and education centers. The material will be tested to see if its durable enough to be used in furniture production and was made using a waterless production method developed at the Technological Institute in Taastrup, Denmark.

1.2 Existing solutions

Both the market for paper recycling and furniture production is quite large worldwide, but there are relatively few companies and designers that have combined the two. The ones that have made furniture from paper have used creative and innovative solutions that involves everything from seaweed to papier-mâché. Below is a selection from the literature study completed for this thesis.

One of the first designers to produce furniture from paper is Hans-Peter Stange, who is the founder of Stange Design and the designer behind the furniture that the Australian founded company KARTON sells. Stange started his design studio, Stange Design, in 1985 after graduating as an Industrial designer in Berlin (Stange-Design, Unknown).

The design studio has been involved in the development and production of cardboard furniture since they opened, and they are working in the areas of furniture, exhibits and displays. The idea is simple, light weighted, foldable furniture and products. The furniture is produced in-house so the production quality is kept constant and is easy to control. The cardboard is made to their own specifications and consist of 60-90% recycled paper while the rest is virgin paper, to ensure high stability (Stange-Design, Unknown).

The company KARTON is a part of the Australian Kartongroup that have sold Stange´s cardboard furniture since 2011 and is currently shipping in Australia, Canada and The United States. They have everything from beds and bookshelves to tables and chairs, as shown in figure 1.3. Their cardboard furniture is made from the same mix of virgin and recycled paper that all of Stange´s products are made from because the virgin paper pulp adds additional strength to the mixture. They also only use glue that is made from vegetable starch and all the cardboard furniture is 100 % recyclable. (KARTON, 2014)

A. B. C.

*Figure 1.3: A selection of Hans-Peter Stanges and KARTON´s foldable cardboard furniture. **A)** KARTON´s Chairman´s table and Berlin storage system. **B)** KARTON´s Paperpedic bed and Berlin bookcase. **C)** KARTON´s Juno 2 dresser and Berlin bookcase. Photo: Courtesy of the KARTON Group (KARTON, 2014).*

Then there is Moooi Paper Furniture, which is a collection made by Studio Job for the brand and design house Moooi. Studio Job was founded in the Netherlands by the designers Nynke Tynagel and Job Smeets in 2000. Their paper furniture collection contains everything from lamps and wardrobes to desks and tables and is mainly one-off or limited edition works, as shown in figure 1.4. Some pieces in the collection are made completely out of paper, in the form of office paper, cardboard and honeycomb. Other pieces have wood added into the paper combination (Moooi, 2018).

For the paper furniture, they use an industrialized papier-mâché process, where layers of paper and glue is added to a structure of cardboard honeycomb, which dries into a solid construction. The assembly of the furniture is made as a building set, where each piece can be put together without the use of screws, bolts or glue. Each component slides into the other which enables the parts to bare its own weight and share its strength with each other. Their first paper piece, a chandelier, was made together with Moooi in 2005 (Moooi, 2018).

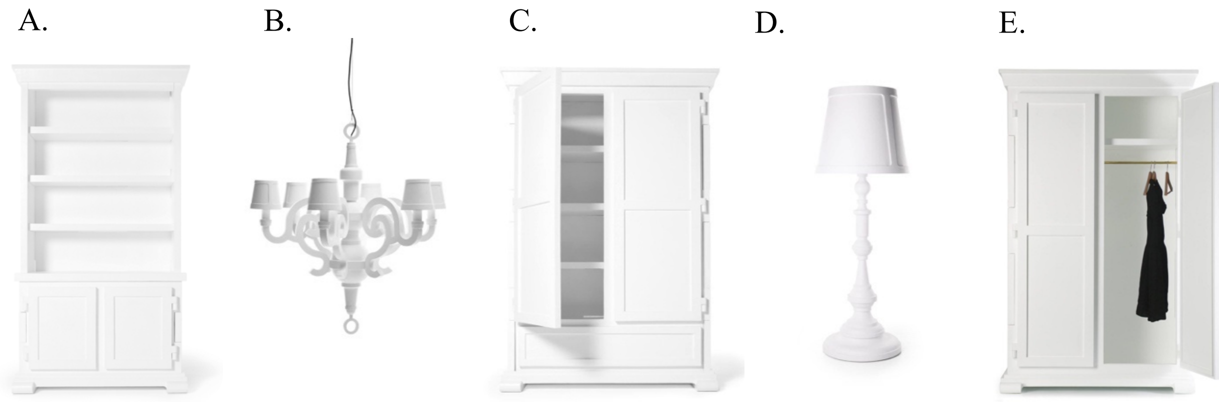


*Figure 1.4: A selection of the Moooi Paper furniture created by Studio Job. The cabinets are made completely out of paper, while the lamps have wood added into the paper mix. **A)** Paper Cabinet. **B)** Paper Chandelier L. **C)** Paper Cupboard. **D)** Paper Floor Lamp. **E)** Paper Wardrobe. Photo: Courtesy of Lonneke van der Palen and Moooi (Palen, 2018).*

ECOR is developed by NOBEL Environmental Technologies in cooperation with the US Department of Agriculture and was founded as a company in 2006 in the United States. They produce advanced environmental composite panels formed from waste fibers, water, pressure and heat. The fibers used in the panels are derived from old corrugated cardboard, old news prints, office waste, forest waste, agricultural fiber and bovine process fiber (ECOR, 2018).

The process and pulp used to manufacture the panels makes them 100 % recyclable and gives them four times the strength of a Medium Density Fiberboard. ECOR has five basic panels in their product range where four out of five are made from 100% recycled office paper or old corrugated cardboard and they use these boards in everything from constructing directional signs and dining tables to enhance the acoustics in a room. They also use different constructions like wave shapes or honeycomb to increase the strength of the panels, which gives them a larger field of application (ECOR, 2018). Figure 1.5 presents a selection of the products ECOR produce.

A. B. C.

Figure 1.5: A selection of ECOR´s products from recycled paper and cardboard. ***A)*** *ECOR panel made from 100% recycled old corrugated cardboard.* ***B)*** *Designs made from ECOR panels.* ***C)*** *Honeycomb structure made from ECOR panels. Photo: Courtesy of ECOR and NOBEL Environmental Technologies (ECOR, 2018).*

Terroir is a material develop from seaweed and paper and it is a part of a research project that focuses on the use of local materials by the Danish designers Nikolaj Steenfatt and Jonas Edvard. The material is described as tough and durable with a warm and tactile surface, and with the lightness of paper (Steenfatt, 2014).

To produce the material, they collect seaweed from the coast of Denmark which is dried and ground into powder before it is cooked into glue. Then the material is mixed with paper granulate made out of recycled paper. The reason that seaweed works as a glue is because it contains Alginate, which is the natural polymer of brown algae that is viscous and has an adhesive effect. The goal for the project is to use Terroir for products and furniture and it have so far been used to produce chairs and lamps, as shown in figure 1.6 (Steenfatt, 2014).

A. B. C.

Figure 1.6: The material under construction and the finale products created by Steenfatt and Edvard. ***A)*** *The material before it is molded into a given shape.* ***B)*** *The Terroir chair with wooden legs.* ***C)****Lamps made out of the Terroir material. Photo: Courtesy of Emil Thomsen Schmidt (Schmidt, 2014).*

IKEA, the Swedish furniture warehouse, announced in 2016 that they are looking into the possibility of making furniture out of paper and that their designer has experimented with everything from paper sofas and tables to bookshelves made out of paper. So far, they have found nine different paper-based materials that could be used in the production of furniture and the most interesting one was paper pulp, because it can be molded into various shapes and with the use of additives the material could be water resistant and produced in any color. The designers at IKEA are also looking at the use of paper clay, paper glue, paper cotton and washable paper (Dasey, 2016).

1.3 Market needs and potentials

With an increasing focus on turning waste into resources and reducing the use of raw materials, products of recycled materials are becoming more and more relevant. The use of waste as a resource also contributes to reducing the amount of waste delivered to the landfills each day. This field brings along a lot of innovation and contributes to progress in the areas of producing products with a longer lifetime, and products that can be reused, redesigned and recycled.

The market for paper furniture have potential in all parts of the world. As one can see in chapter 1.2, most of the paper-based furniture on the marked today is mainly made and produced in Europe and the US, while it is distributed on these continents as well as in Australia. This creates big opportunities and open markets in Africa, Asia and South America. The primary market for this product will be the furniture market in Ethiopia, and more specific in Addis Ababa. The furniture market includes both furniture for daily use and furniture need for institutions, like schools and educations centers. Ethiopia is growing rapidly, as mention in chapter 1.1, and is a country with a lot of potential. The startup and innovation environments are booming in Addis, where people from all over the world are settling to start their new businesses.

The product will most likely be more popular with the younger generation living in Addis, while it will use some time to reach the market for the older generation. It will also be able to reach the startup and innovation market, which is often more concerned with new and exciting solutions of all kinds. Even though the chair, that will be designed in this thesis, is primarily intended for school use and studying, it can also transcend into everyday use in an office or home. To reach the potential that is out there, more information and products need to reach the market of the everyday user. When hearing about paper-based furniture people often think that it is an interesting and exciting idea, but don't really believe that the product will hold. This also goes for introducing the product in Ethiopia. The more people know, the more realistic it is that they would want to purchase the product.

1.4 Terms of Reference

Through the collaboration with Penda Manufacturing the main focus for the thesis will be to test different paper-based materials that is developed for furniture production in Ethiopia, while designing and further developing a chair made out a paper-based material. An important aspect of the thesis work will be to test the material properties of the paper-based panels, to ensure that the chair will withstand the loads that are applied during use. The chair will be designed for school use and the paper-based panels used in this thesis are produced using a waterless method. Paper-based materials can be produced through several different processes, where the most regular one is paper pulp.

1.5 Issues and technological bottlenecks

The possible problems and focus points related to the thesis give an indication for the direction of the thesis and lay the foundation for what the project plan should contain and how the work schedule should be built up. While the technological bottlenecks create awareness around possible obstacles that can occur while working with the thesis.

1.5.1 Problems and focus points

The thesis will focus on investigating, developing and designing a chair made from paper-based panels for production in Ethiopia. Problems and focus points for the thesis:

- Which solutions and methods have already been used and tested by other producers and designers? How have they developed their furniture from paper-based materials?
- Will the paper-based material be durable enough for use in furniture alone?
- How can the chair be designed to fit the demands of the users and to fulfill the task it is produced for?
- How can a chair made from paper-based materials be designed to be durable and functional for everyday use?

1.5.2 Technological bottlenecks

When working with different materials, methods and equipment, obstacles can arise in every area. Some of the technological bottlenecks that can arise with this thesis is divided into two groups: Material and methods, and Equipment.

Materials and methods

- Shortage of material for the material testing
- Defects in the material
- Use of the wrong method in relation to the concept selection and trial setup
- Use of the wrong method to produce the trial samples

Equipment

- Lack of precession in the equipment while producing the trial samples and testing them
- Defects in the measurement system within the equipment used to test the trial samples

2 PROJECT PLAN

When working on a project, it is important to have an overview that covers all the areas of the project. It is also important to set clear boundaries for what's going into the project and not. A project plan provides the needed overview and structure towards a main goal. The main goal is built up by several partial goals, which forms a work schedule that is limited by the timeframe for the project. The timeframe is a good reference point, when setting limitations for the work. This chapter shows how the work process for the thesis is going to be structured.

2.1 Objectives

The objectives for the thesis are divided into a primary objective and part objectives. The part objectives work as building blocks on the way to reaching the primary objective and forms the work schedule for the thesis.

2.1.1 Primary objective

The primary goal for the thesis is:

"To investigate, develop and test a solution for the use of recycled paper as the main component in the production of furniture in Ethiopia. This will be done through testing the selected material, and by developing and designing a concept for a chair produced from paper-based material. The work will show if the selected method is functional and whether the material is durable or not, which will lead to a recommendation for the further work on the project."

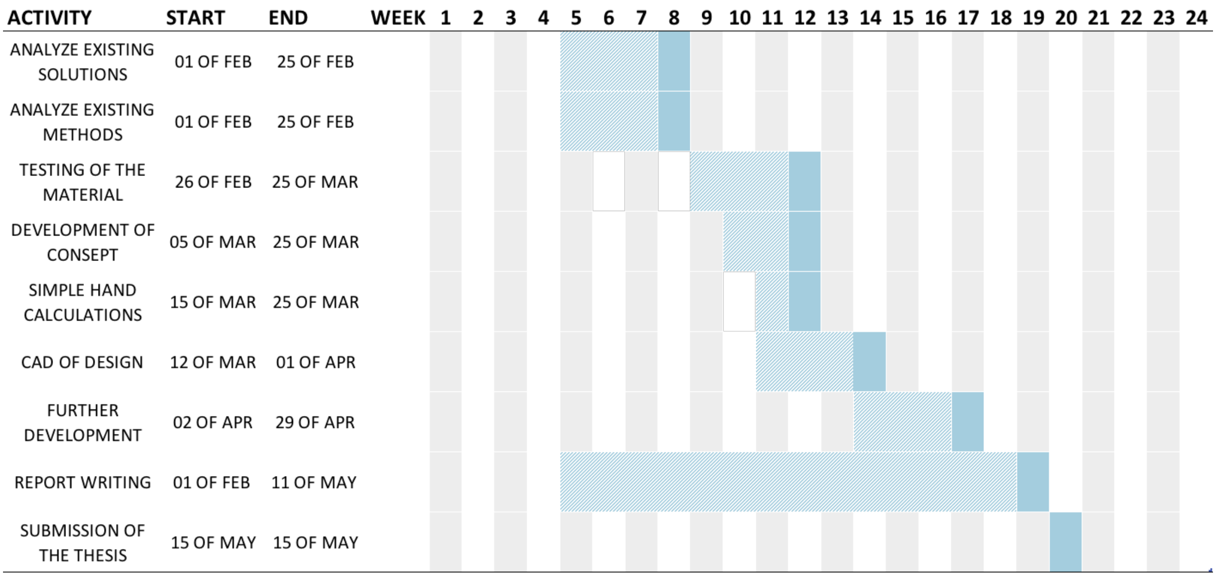
2.1.2 Partial objectives

The main objective for the thesis is divided into the following part objectives:

- To analyze the existing solutions and methods.
- To perform simple hand calculations of the stresses that work on a chair.
- To test the material properties of the paper-based material.
- To develop a preliminary concept.
- To develop a CAD of the conceptual design.
- To further develop the product.
- To write a report.
- To submit the thesis.

2.2 Work schedule with milestones

Table 2.1: Work schedule for the thesis. The shaded areas represent the length of the work period and the solid blue blocks represent the milestone for each objective.



2.3 Limitations

When working on projects, it is important to set limitations to the work to have a clear view of what the project should and should not contain. In this project, the limitations are set in relation to the timeframe for the project and in accordance with the quality and workload that is expected.

- Only one production method will be tested, the waterless method for producing panels.
- Only simplified hand calculation will be performed and the assembly method for the chair will not be calculated.
- The calculation of the chair, should be recalculated to assure that the calculations is correct, and they should also be checked through a FEM analysis.
- The chair will not be produced during the timeframe of the thesis.
- The number of samples tested is limited to three different mixtures and to three of each sample, because of limited access to the different material mixtures.
- The only trial that will be executed is to find the hydrophilicity, surface roughness and tensile properties.
- Lamination and coating of the furniture will not be discussed in depth.
- The assembly method for the chair, will not investigated or discussed in depth.

3 THEORY AND TECHNOLOGY

To be able to write a thesis, a theoretical foundation is needed. The relevant theory for this thesis focuses on recycling, which includes the process of recycling. It also includes, how the material in the paper-based panels, used in the thesis, is built up and how the panels are produced. Closely related to recycling is a circular economy and is also a part of the theoretical foundation. Further, is also ergonomics and anthropometrics an important part of the theory for the thesis, which contributes to a wider and deeper understanding of what is important when designing and developing a chair.

3.1 The material

The material that will be used in this thesis is paper-based panels produced at the Technical Institute in Denmark, using the waterless method presented below in chapter 3.3. The material consists of 70 % recycled paper from Ethiopia and 30 % Danish office paper. The Ethiopian paper is a mixture of receipts, notebooks, paper trimmings, newspapers and similar types of paper. The mixture of Ethiopian and Danish paper establishes a more realistic mixture of the paper collected in Ethiopia, which is the paper that will be used in the end.

When producing the panels, 15 % glue, which is related to the paper mass, is mixed in to the paper. While producing the panels seven different glues were tested in the paper mixtures to see how they differed from each other. The glues that were tested in the different panels are Cornstarch (homemade), Potato starch (homemade), Silicate glue from Bollerup Jensen, Dextrin (homemade), Protein glue from Pro-Glue, Soyad from Herkules and starch w/ PVB 1531 from Pro-Glue. The starch w/PVB 1531 glue from Pro-Glue is also called Biotack and is referred as Biotack throughout the thesis.

Through the panel production, the density of each of the panels where found which is shown in table 3.1.

Table 3.1: Density of the different paper-based panels.

GLUE	UNIT	CORN	POTATO	SILICATE	DEXTRIN	PROTEIN	SOYAD	BIOTACK
Density	Kg/m3	650 - 870	700	870	870	870	870	870

3.2 Recycling

Recycling is the process of collecting and turning waste, that would otherwise be thrown away at the landfill, into new materials and products. Recycling is a well-known concept and a key component in today’s waste reduction. It is also a part of the waste hierarchy. Recycling is important worldwide and in 2017, Germany was the country with the highest recycling rate and recycled 56.1% of its waste (Gillies et al., 2017). There are many materials that can be recycled, like glass, metal, plastics, textiles, tires, electronics, paper and cardboard. Composting of food and garden waste is also considered recycling.

The process of recycling can be simplified and divided into three steps. First, the waste is collected and processed. The waste can be collected in several ways, straight from the house, office or company and at selected pick up points. Then the collected waste is sorted and processed into materials that can be used for production. In the second step, the recycled materials are manufactured into different products, like plastic bottles, newspapers or car bumpers. In the last step, the products are distributed to the consumer through retail sellers (EPA, 2017).

As mentioned in chapter 1.1, there are several benefits with recycling. Recycling reduces the amount of waste sent to the landfill and conserves natural resources. It also works positively on the economy, since the country is using local resources and, in some cases, reducing import of the products produced from recycling within the country. Recycling also create a lot of jobs, in both collection of the waste and recycling of the waste. It also creates jobs within the production of products from recycled materials.

3.2.1 Paper recycling

The process of recycling paper starts with collecting the paper. The paper intended for recycling has to be collected separately from other waste, since contaminated paper isn't accepted for recycling. The paper is often collected by local waste management companies form private houses, offices and other institutions with trucks only intended for paper collecting. The paper is then transported to a paper mill or a company that works within paper recycling.

When the paper reaches the facility where it will be recycled, it is sorted in to different grades of paper, since not all types of paper can be sorted. In some cases, the paper is sorted at a sorting station before it is transported to the facility where it is going to be recycled.

After the paper is sorted and graded, the paper is placed into a pulper which is also called a vat. The pulper chops the paper into small pieces and mixes it with water. This process breaks down and separates the paper fibers. When the paper has been transformed into pulp, large contaminants, like plastic, paper clips, staples and tape, are removed through a screening process. The fibers are cleaned, and the final pulp is screened and processed a number of times to reach the needed quality for producing paper.

The next step in the process is deinking the pulp, which removes the ink from printing and involves two processes. The first step is washing the pulp through rinsing it with water, this removes small ink particles. To remove larger particles of ink, air bubbles are blown in to the pulp, which separates the ink from the mixture. The ink then floats to the surface, where it is removed (EPRC, 2017).

If needed, the next step is to bleach the pulp. This is often done with hydrogen peroxide and makes the pulp whiter, which is needed when producing office paper among other things. At last, the pulp is pressed into large paper sheets, by spraying it onto to a large sheet called a web, which is then pressed using rollers to get the remaining water out. Then the web is run through heated rollers to make the paper completely dry before it is processed into large rolls and ready to be manufactured into new products (BIR, unknown).

3.2.2 Paper recycling in Ethiopia

Paper recycling is not widespread in Ethiopia. Before Penda Manufacturing was established in 2015, there were no companies devoted to recycling paper.

The paper Penda recycles is collected by their trucks at local skip-points or directly from large offices and then transported to their sorting station. At the sorting station the cardboard is sorted out from the rest of the paper and then used to produce pulp, while the regular paper is sorted into three different categories and stored until it can be used. When the pulp is produced it is sold to the paper mill Penda is collaborating with and there the pulp is manufactured into paper rolls and cardboard boxes. This chain satisfies the requirements for a circular economy, which is one of Penda´s main goals.

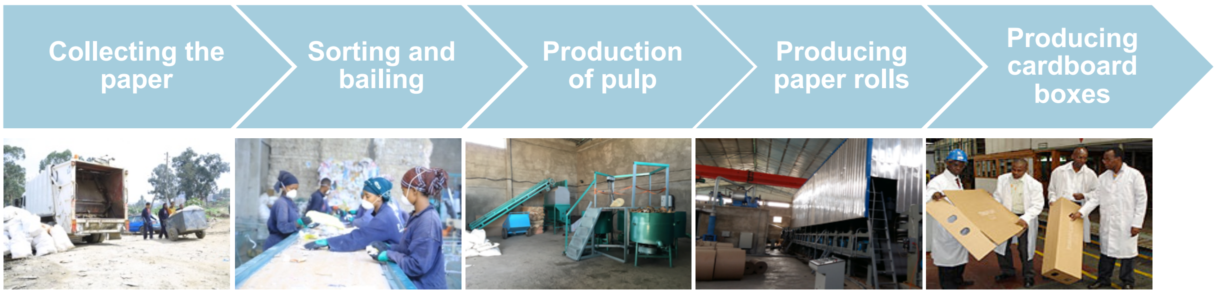


Figure 3.1: Penda´s paper recycling value chain for producing cardboard boxes in collaboration with a local paper mill (Penda Manufacturing, 2017).

The regular paper, which can be anything from white office paper to newspapers and cigarette paper, is further sorted into different categories and then bailed so it can be stored. At the moment the different types of regular paper are just taking up space, because the paper mill Penda is collaborating with only uses recycled cardboard to produce pulp.

The regular paper stored at Penda´s site, is the paper that will be used and focused on throughout this thesis.

3.3 The production of paper-based panels

The theory presented in this chapter is based on the production technology used to produce the paper-based panels for this thesis.

Production of paper-based panels using a waterless production method

There are several ways to produce paper-based materials, and the most common way is the production of paper pulp, which is a part of the recycling process of paper, as explained in section chapter 3.2. The paper-based material that will be tested and used in this thesis, is produced in a waterless production process developed at the Technological Institute in Taastrup, Denmark. The panels are produced from 70% Ethiopian paper and 30 % Danish office paper, to get a realistic mixture that equals the paper mixture recycled in Ethiopia as explained in chapter 3.1.

The production process consists of six steps.

Step one is to shred the waste paper by using an industrial paper shredder, where the paper is shredded into smaller pieces by rotating knives into narrow stripes of paper. The paper is shredded to meet the material size requirement for step two.

A. B. C.

Figure 3.2: The process that the paper goes through in step one of the production process of the paper-based material. ***A)*** *The paper shredder used at the Technical Institute.* ***B)*** *The waste paper from Ethiopia before it is shredded.* ***C)*** *The waste paper from Ethiopia after it is shredded by the paper shredder. (Photos: Authors own)*

In step two, the shredded paper is processed through a hammer mill, where the paper is shredded into smaller pieces by repeated blows of small hammers. The paper is processed through the hammer mill three times to achieve the desired size of the paper particles.

A. B. C.

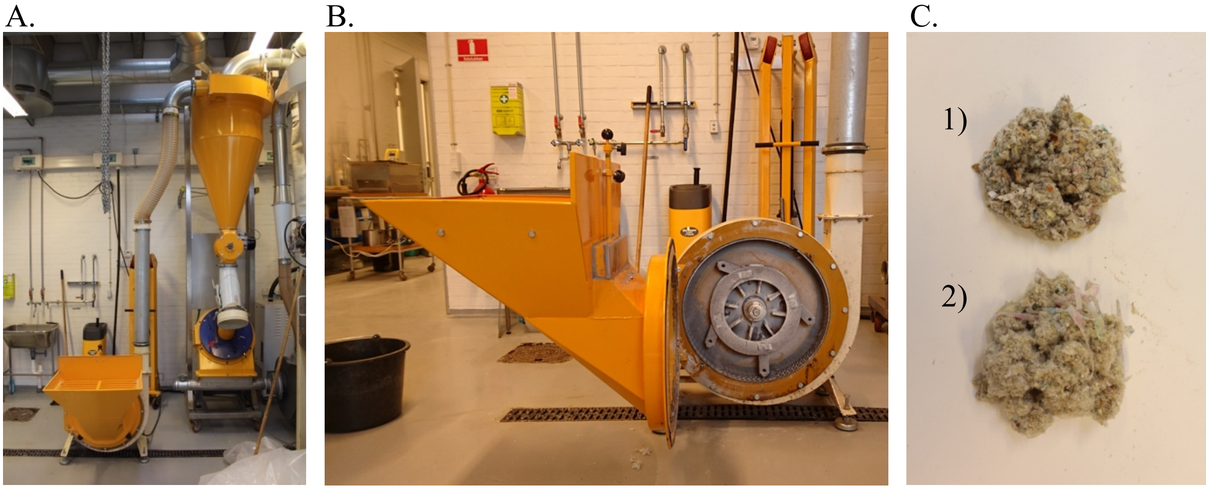


Figure 3.3: The process that the paper goes through in step two of the production process of the paper-based material. ***A)*** *The hammer mill used to shred the paper into smaller pieces. The shredded paper from step one goes into the hammer mill on the left side.* ***B)*** *The inside of the hammer mill.* ***C)*** *The paper after it have gone through the hammer mill. 1) The paper when it has gone through the hammer mill twice. 2) The paper when it has gone through the hammer mill three times. (Photo: Authors own)*

In step three of the processes, the paper particles are measured up into the correct amount needed to make one panel. Then paper is added into a large industrial tumble-dryer, where the selected amount of glue is sprayed evenly into to the mix while the tumble-dryer is running.

When the paper and glue is properly mixed, the mix is added to the dryer part of the machine and left to dry while the air is flowing through. The humidity level of the paper is measured every half hour until the paper mix reaches a humidity level around 10 %. Then the mixture is ready to proceed to the next step of the process.

A. B. C. D.

Figure 3.4: The machine used in step three of the production process. ***A)*** *The "tumble-drier" seen from the side.* ***B)*** *The "tumble-drier" seen from the front. 1) The dryer, which is the end station of the paper in this stage.* ***C)*** *The part of the "tumble-drier" where the glue is added.* ***D)*** *The glue gun used to spray the glue into the "tumble-drier". (Photo: Authors own)*

Step four is where the paper mixture is added into the desired shape of the panel, in this case a 200x200 mm mold. The paper is gently packed into the case to two thirds of the cases height, then the lid is added. While pressing down on the lid the case is carefully pulled over the lid and the paper structure is ready to be pressed into a panel.

A. B. C. D.

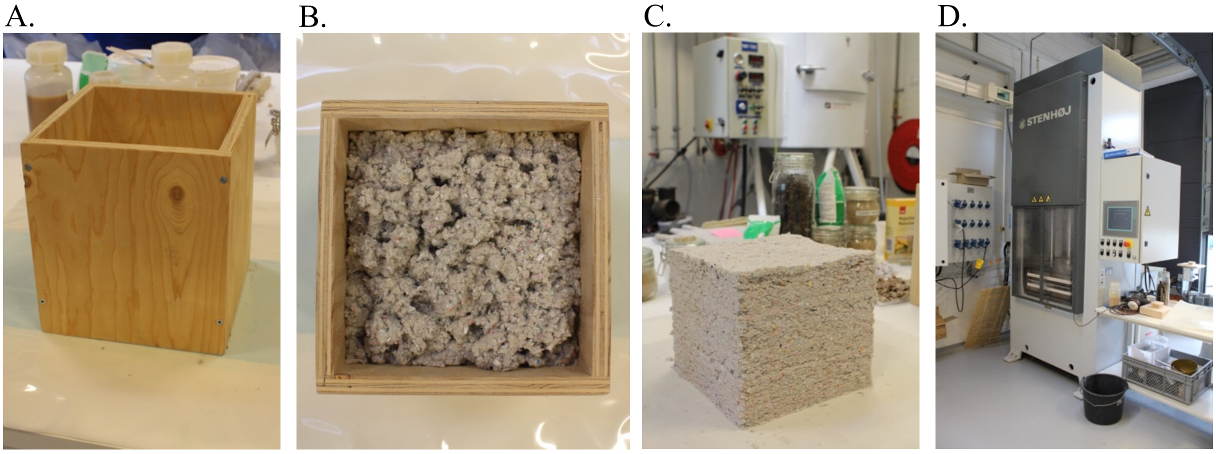


Figure 3.5: The process that the paper goes through in step four and five. ***A)*** *The mold used in step four.* ***B)*** *The mold filled with the paper mix.* ***C)*** *The molded paper-mix.* ***D)*** *The heated forming press used in step five of the process. (Photo: Authors own)*

At step five, the paper structure is pressed into a 12 mm thick panel by using a heated forming press from Stenhøj hydraulics.

When the paper mass is pressed into a panel the glue added during step four reacts with the heat and is the binder that hardens the panel. Each panel is pressed for about 10 minutes, with various load until it reaches 12 mm.

At the finale step, each panel is cooled down in room temperature while having pressure in the form of weights added on top of them for about 30 minutes. The weight added on top is approximately 10 kg.

A. B.

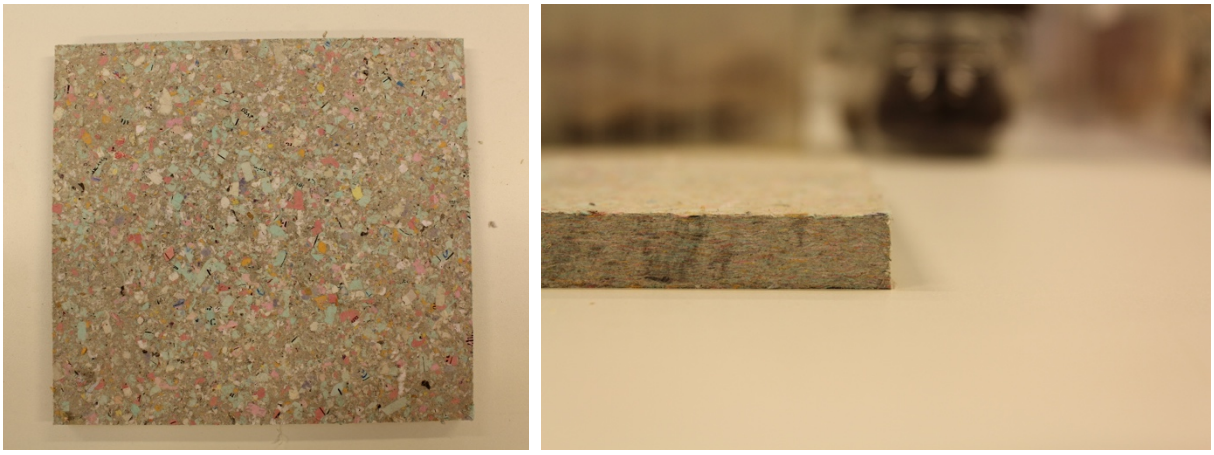


*Figure 3.6: The finished product after cooling. **A)** The panel seen from above. **B)** The panel seen from the side. (Photo: Authors own)*

3.4 Circular Economy

Circular economy (CE) has its conceptual roots in Industrial Ecology, the Cradle to Cradle concept, Natural Capitalism, Blue Economy, Performance Economy, Biomimicry and Regenerative Design. The concept was first defined by the British environmental economists David Pearce and Kerry Turner in 1989, who pointed out that the economic systems do not have a built-in tendency to recycle like the natural systems do. But that if the economic systems are constructed to be a closed and circular system, that disposes waste at a rate that corresponds with the environment´s capability to absorb it, the circular system will function like a natural system with the exception of the reduction of the natural resources that do not renew themselves (Pearce & Turner, 1989).

A circular economy is defined and works as a regenerative system that aims to preserve and exploit the full potential of materials, products and resources through each step of its lifecycle. This is done by designing waste out of the system through reusing, repairing, remanufacturing and recycling materials, products and resources, so that each item reaches its full potential (Ellen Macarthur Fundation, 2017).

Penda Manufacturing are contributing to a circular economy by building a recycling system for paper and cardboard in Ethiopia. From the early days of the company, the goal has been to build a sustainable business that contributes to Ethiopia’s goal of building a green economy and reaching middle-income status by 2025, as mentioned in chapter 1.1. Penda have so far built a functional system for cardboard and are now working on building a functional system for the other paper they are collecting.

3.5 Ergonomics and anthropometry

Ergonomics and anthropometry are closely related and highly relevant when designing furniture in general, and especially when designing for a work space. It is important to have some insight and a basic understanding of the two subjects to design the best version of a chair made out of paper-based panels and at the same time is suited for school use.

3.5.1 Ergonomics

Ergonomics is the science of work, which studies the humans who preform it and the different ways it is executed. It also studies the different tools and equipment the workers use, the places they work and the psychosocial aspects of the working situation of the worker (Pheasant, 1996). Based on the study of the work process, ergonomics aims to fit the job to the worker and the product to the user by designing the needed tool for the task at hand.

Ergonomics is influenced by many disciplines, like anthropometry, biomechanics, mechanical engineering, industrial engineering, industrial design, information design, kinesiology, physiology and a wide range of psychology disciplines. Where anthropometry and biomechanics are very influential. Anthropometry is the study of human dimensions, while biomechanics is the study of the mechanical aspects of biological system. (IEA, 2018)

Based on the combinations of disciplines that ergonomics is influenced by, the field can be divided into three main research fields. The first is physical ergonomics which uses characteristics from anthropometry, biomechanics, physiology and anatomy in relation to physical activity. Physical ergonomics is essential in designing the workplace and equipment to the user. Cognitive ergonomics is the second research field and studies mental processes, like memory, motor response, perception and reasoning in work related situations to enhance the well-being of a person and system performance. Third is organizational ergonomics which studies the optimization of sociotechnical culture and the policies, processes, and organizational structure within the culture (IEA, 2018).

Ergonomics in relation to design is built upon the principle of user-centered design. User-centered design is when the design of an object, a system or an environment that is intended for human use, is based upon the physical and mental characteristics of its human users. User-centered design is empirical, iterative, participative, non-procrustean, system-oriented, pragmatic, accounts for human diversity and the user´s task (Pheasant, 1996).

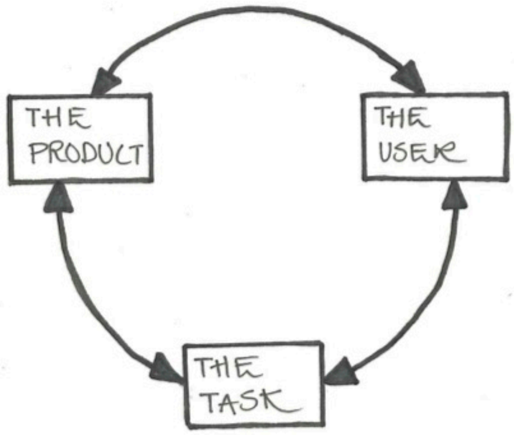


Figure 3.7: The circle of user-centered design, which focuses on the product, the user and the task. (Figure inspired by (Pheasant, 1996))

Two techniques that are often used in relation to ergonomics and user-centered design, are a task analysis and a user analysis. A task analysis where the definition of what the user is actually going to do with the product in mind. A user trial is where a representative sample population test a prototype of the product, that is intended for them, under in a controlled environment. The objective is to produce a product that achieves an almost perfect match with the user relative to the task at hand. The most important criteria in ergonomic design are functional efficiency, comfort, quality of working life, health and safety (Pheasant, 1996).

3.5.2 Anthropometry

Anthropometry is the science that concerns the measurements of the human body and is used to determine the difference between individuals based on different parameters, like size, race, shape, strength and working capacity. (Panero & Zelnik, 1979) Anthropometries is a very important branch of ergonomics, as mentioned in chapter 3.6.1, and within ergonomics, anthropometry matches the physical form and dimensions of a product or workspace with the user. It also matches the capacity of the workers to the work task that is being performed (Pheasant, 1996).

The need for anthropometric data began to develop and increase in the 1940s, the demand occurred in serval industrial fields and especially within the aircraft industry. Even though an increasing demand didn't occur until the 1940s, pioneering work was done within the field of anthropometry already in 1870 when Quetlet, the Belgian mathematician, published his book Anthropometrie. This book is credited for creating the term "Anthropometry" and for founding and formalizing the science. But the fascination of the human body size can be dated back to Vitruvius and the 1st century B.C. Rome (Panero & Zelnik, 1979).

Anthropometric data is often expressed as percentiles, where the population is divided into 100 percentages categories and presented in a bell-shaped curve, where each curve only refers to one body dimension at a time. Percentiles in anthropometry can be defined as: "The percentage of the population that falls below the value of an variable" (Wang & Chen, 2012).

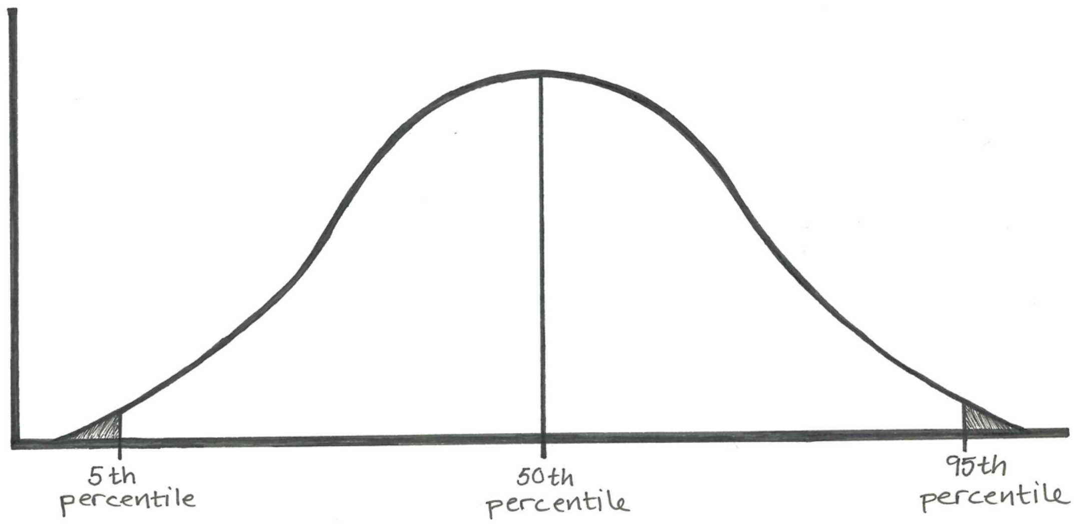


Figure 3.8: A bell-shaped curve which shows the 5th percentile, the 50th percentile and the 95th percentile marked on the curve (Photo: Authors own).

A 5th percentile height indicate that 95 percent of the selected population will be taller than this, while a 95th percentile indicates that only 5 percent of the selected population will be taller than this and that 95 percent of the selected population will be of the same height or shorter. It is important to remember that there is no such thing as a 95th percentile, 50th percentile or 5th percentile man or woman. A person can have a 95th percentile height, while having a 50th percentile side arm reach and a 65th percentile knee height (Panero & Zelnik, 1979).

3.5.3 Ergonomics and anthropometry in chair design.

When designing furniture, or in this case a chair, there is no such thing as an average man or woman. It is therefore important to design for the population as a whole and it is preferable to design for the 5th or the 95th percentile because that will serve the greatest portion of the population. There are two types of human body dimensions that impact interior design, structural and functional dimensions. Where structural dimensions include measurements of the head, torso and limbs in normal positions, while functional dimensions include measurements of the human body in working positions or during a movement related to a specific task (Panero & Zelnik, 1979).

The act of sitting is far too often viewed as a static activity, when it actually is a dynamic one and is therefore also one of the hardest elements to design when it comes to interior design. Sitting involves a body that is continuously changing to respond to the various tasks that are performed in that position. It also involves the process of getting into and out of the seat, and the process of sitting as a whole should be seen as a process of continuous motion. (Panero & Zelnik, 1979)

When designing furniture that is used for sitting, there is a lot to take into consideration both regarding ergonomics and anthropometry, but most important is that the seat is comfortable for the time period it is being used, that it supports the body and that it is designed to the task or activity it is going to be used for. There are several factors that impact the comfort of sitting, and those factors can be divided into characteristics for the seat, the user and the task. For the seat, dimensions, angels, profile and optionally cushioning are important, and for the user, the body dimensions, aches and pains, circulation and state of mind are important. When designing in regard for the task, visual, physical and mental demands, and the duration of the task are key characteristics (Pheasant, 1996).

The basic dimensions required for designing a chair or a seating option should include seat height, seat depth, seat width, backrest height and armrest height and spacing.

Seat height

The distance from the top of the seat surface and down to the floor. If the seat height is too high, the thighs get compressed which can cause discomfort and reduce blood circulation. If it is too low, the legs may be extended and positioned forward, which leads to depravation of stability. But a person will still be more comfortable in a chair with too low seat height, than in a chair with too high seat height. To find the right seat height according to anthropometry, the popliteal height should be the measurement that is used. Here one would preferably use the 5th percentile data, so that the seat height also will fit the smallest body dimensions. It's important to add a conservative measurement to the measurements collected from anthropometry to compensate for the lack of clothing and shoes on the examinees (Panero & Zelnik, 1979).

Seat depth

The distance from the front of the seat to the back of the seat. A seat depth that is too long will press the front of the seat edge into the area behind the knees and can cut off the blood circulation to the legs and feet. If the depth is too short, it can give the user the feeling of falling out of the front of the chair and will not give the needed support for the lower thighs. To find the right seat depth according to anthropometry, the buttock-popliteal length should be the measurement that is used (Panero & Zelnik, 1979).

Backrest

The primary function is to support the lumbar region, which extends from the waist to the middle of the back. This is one of the most important parts of the chair to ensure a proper fit for the user, but it is also one of the hardest parts to design and dimension because of the curvature of the spine. It is important to avoid providing a design that is too close to the curvature, since it can prevent the shifting of body positions. The height of the backrest in full, depends on the intended area of use for the chair (Panero & Zelnik, 1979).

Cushioning can also be included in the design of a chair. The main purpose is to distribute the pressure from the weight of the body over a larger surface. If the cushioning is too soft, it will provide a great deal of discomfort to the human body (Panero & Zelnik, 1979).

Table 3.2: Critical work chair measurement in centimeters (Panero & Zelnik, 1979).

SOURCE	a. SEAT WIDTH	b. SEAT DEPTH	c. SEAT HEIGHT	d. C.L. OF BACKREST HEIGHT FROM SEAT SURFACE	e. BACKREST HEIGHT	f. ANGLE OF TILT OF SEAT SURFACE	g. ANGLE OF BACKREST
Croney	43.2	33.6 - 38.1	35.6 - 48.2	12.7 – 19.0	10.2 – 20.3	0° – 5° or 3° – 5°	95° – 115°
Diffrient	40.6	38.1 - 40.6	34.5 - 52.3	22.9 – 25.4	15.2 – 22.9	0° – 5°	95°

Table 3.2 continues: Critical work chair measurement in centimeters (Panero & Zelnik, 1979).

SOURCE	a. SEAT WIDTH	b. SEAT DEPTH	c. SEAT HEIGHT	d. C.L. OF BACKREST HEIGHT FROM SEAT SURFACE	e. BACKREST HEIGHT	f. ANGLE OF TILT OF SEAT SURFACE	g. ANGLE OF BACKREST
Dreyfuss	38.1	30.5 - 38.1	38.1 - 45.7	17.8 – 27.9	12.9 – 20.3	0° – 5°	95° – 105°
Grandjean	40.0	40.0	37.8 - 52.8	_	20.0 – 30.0	3° – 5°	Adjustable
Panero-Zelnik	43.2 - 48.3	39.4 - 40.6	35.6 - 50.8	19.2 – 25.4	15.2 – 22.9	0° – 5°	95° – 105°
Woodson-Conover	38.1	30.5 - 38.1	38.1 - 45.7	17.8 – 25.4	15.24 – 20.32	3° – 5°	20°

Table 3.2 shows a collection of critical work chair measurements conducted by different scientist and put together in a table by Panero and Zelnik, in their book Human Dimensions & Interior Space. The measurements from table 3.2 is related to figure 3.9, which shows where the different measurements are taken.

A. B. C.

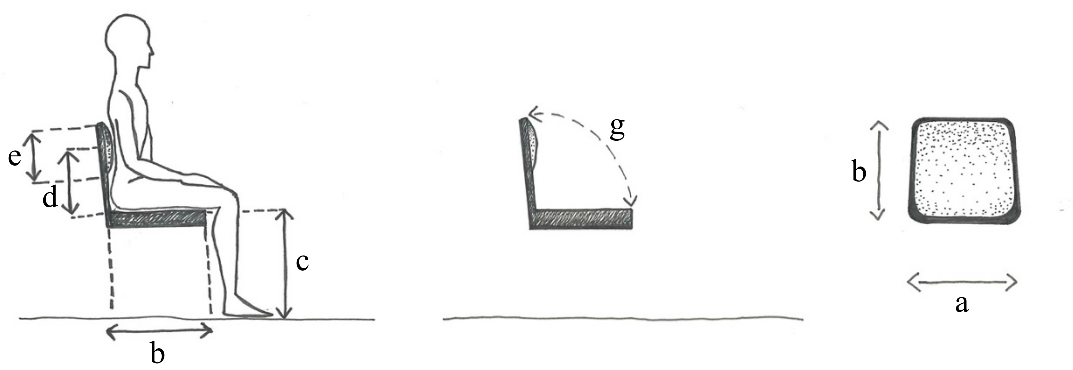


Figure 3.9: All the measurements from table 3.2 converted to drawings, except measurement f. A) The drawing shows a person seated in a chair and measurements b) the seat depth, c) the seat height, d) the backrest height from the seat surface and e) the backrest height. ***B)*** *The drawing shows measurement g) which is the angle of the backrest.* ***C)*** *The drawing shows measurement a) the seat width and measurement b) the seat depth.*

4 METHODOLOGY

Methodology is used to collect data, samples and information to solve a problem in a systematic way. The terminology and methodology contribute to giving a wider and deeper understanding of the thesis. While the software and sources that are used give an insight into how the information is collected and processed. An overview of how the thesis is quality assured is also given, to assure that the information and work is of quality. The work process of the thesis is visualized through a presentation of the process steps.

4.1 Terminology

4.1.1 Symbols

Table 4.1: The symbols used in the thesis.

SYMBOLS	EXPLANATION	SI-UNIT
θ_c	Contact angle	°
R_a	Roughness average	-
R_z	Mean roughness depth	-
E	Elasticity modulus	MPa
$\mathbf{F}$	Force	N
ΔF	Delta force (difference in force)	N
$\mathbf{F_{max}}$	Maximum force	N
l_1	Gauge length	mm
Δl	Delta length (difference in length)	mm
$\mathbf{A}$	Area	m^2
f_t or R_m	Tensile strength	MPA
CI	Confident interval	-
SD	Standard deviation	-
N	Number of data points	-
n	Safety factor	-
σ	Stress	N/mm^2
m	Mass	kg
g	Gravity	m/s^2
l	length	m
$\mathbf{b}$	width	m
τ	Shear stress	N/mm^2

4.1.2 Calculation formulas

Table 4.2: The formulas used in the thesis.

SIGNIFICANCE	FORMULA	INDEX
Force from load	$F = m \times g$	(1)
Stress	$\sigma = \frac{F}{A}$	(2)
Shear stress	$\tau = \frac{V}{A}$	(3)
Bending moment	$\sigma_b = \frac{M_b}{W_b}$	(4)
Youngs Modulus / E-modulus	$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l}$	(5)
The difference in force	$\Delta F = F_2 - F_1$	(6)
Area of a rectangle	$\mathrm{A} = l \times b$	(7)
The difference in length	$\Delta l = l_2 - l_1$	(8)
Tensile Strength	$f_t = \frac{F_{max}}{A}$	(9)
Confidence Interval of 95%*	$CI = 1{,}96 \times \frac{SD}{\sqrt{N}}$	(10)
Standard Deviation*	$SD = \sqrt{\frac{\sum\lvert x - \mu^2\rvert}{N}}$	(11)
Allowable stress	$\sigma_{till} = \frac{R_m}{n}$	(12)

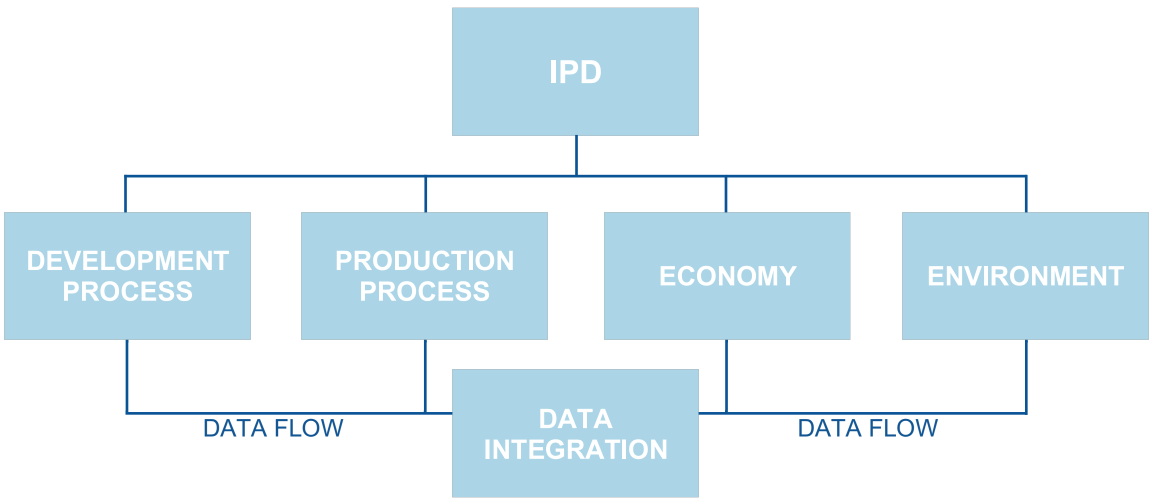
*The formulas for calculating the confidence interval and standard deviation is used in attachment 4, Data collected from the surface roughness trial.

4.2 Product development methodology

The key to developing a good concept and product is the use of different methods.
Product development methodology contributes to new and innovative solutions for the concept at hand and helps the creator to see the product in a different way, which can lead to a completely different solution than the idea that was first presented.

4.2.1 Integrated product development (IPD)

The Integrated Product Development methodology, IPD, aims to achieve higher efficiency, lower execution time and higher learning effect in product development projects. IPD has its roots in the US and is now used in big and small projects all over the world. The methodology combines a higher number of disciplines compared to traditional product development work and can be referred to as a "to-do list" of what elements are important to include when organizing a project in product development (Bøe, 2014a). The four key areas of integrated product development at NMBU are the development process, the production process, the economy and the environment and they are presented in figure 4.1.



Figur 4.1 : Overview of the IPD methology and the four branches it is diveded into.

The data flow, represents the flow of information from the four key areas and into the section where the data is integrated.

4.2.2 PUGH

The purpose of Pugh's method is to choose the best solution for a product and its users through mathematical selection. In order to distinguish the different options from each other, a set of criteria is set up. The criteria are chosen with regard to what is important for the product and the user of the product. Ease of use is often an important criterion when it comes to product development. (Bøe, 2014b)

Each option will then be given a grade in relation to the different criteria. The grades operate on a scale of simple values and in this thesis a scale of one to five will be used, where 5 is very good and 1 is not good. The grades for each option are summarized in the end when all the criteria have been rated. Furthermore, the selection process can be carried out with or without weighting the criteria. When weighting the criteria, each grade is multiplied by the weighting of the corresponding criterion before the grades of each option are summed up. After each option is summarized, one is left with a list where the concept with the highest score is what often one chooses to investigate further in the product development process.

Table 4.3: Example of a matrix using Pugh´s selection method.

CRITERIA	OPTION 1	OPTION 2	OPTION 3
Ease of use	4	3	5
Maintenance	1	4	2
Inspiration	3	2	3
SUM	8	9	**10**

Table 4.4: Example of a weighted matrix using Pugh´s selection method.

CRITERIA	WEIGHTING	OPTION 1	OPTION 2	OPTION 3
Ease of use	40 %	4	3	5
Functionality	40 %	1	4	2
Complexity	20 %	3	2	3
SUM	100 %	2.6	3.2	**3.4**

Table 4.4 shows an example of a matrix with three options using Pugh´s selection method, while table 4.5 shows a weighted matrix with three options using Pugh´s selection method. For each example the ranking is performed by using a scale that runs from 1-5, where 1 is the lowest score and 5 is the highest. Option 3 is the concept with the highest score in both examples after each alternative has been graded against the product and user criteria and would be the option that is selected for further work in this example.

4.2.3 SCAMPER

The purpose of SCAMPER is to twist and turn on issues, concepts and solutions to achieve a better outcome. The method is an assembly of eight points that help one to see a concept from different angles. By using SCAMPER with an open mind, it will challenge, improve and change the original concept while contributing to finding new and creative solutions that wasn't thought of in the original concept selection (Bøe, 2014b).

SCAMPER consists of these eight points:

- **Substitute.** To have a new part of a product or process function as the part that is replaced.
- **Combine.** To bring different functions of a product or process together to increase the area of use.
- **Adapt.** To adjust the product or process to suit different uses.

- **Magnify.** To increase the size, weight or shape of the product or process in whole or a part of the product/process.
- **Minify.** To decrease the size, weight or shape of the product or process in whole or in part.
- **Eliminate.** To remove a quality, part or function of the product or process.
- **Elaborate.** To look into components and functions, to see if the can be changed or used in other areas.
- **Rearrange.** To change the order of the components in the product or process.
- **Reverse.** To turn around the order of the components in the product or process. Start at the end and work backwards.

4.3 Use of sources

In the search for relevant literature a series of web searches in different databases has been completed. These databases have been used in the search for relevant literature: Google Scholar, Oria and Web of Science. Through the library at NMBU there has been free access to relevant books and other literature necessary to complete the thesis.

To document the sources EndNote X8, have been used.

4.4 Software

To write a comprehensive thesis the use of different software is necessary. During the production of this thesis these programs have been used:

- **Microsoft Office 365 (2016)**
  Microsoft Word for Mac has been used to write the thesis.
  Microsoft Excel for Mac has been used to produce tables and figures.

- **SolidWorks**
  Computer Aided Design (CAD) program used for two and three-dimensional design. SolidWorks has been used to design the test samples for the experiments.

- **EndNote X8**
  EndNote has been used to collect and cite references used in the thesis.

- **SCA 20**
  SCA 20 has been used to find and analyze the results related to the measurements of the contact angle.

- **NEXYGEN Plus**
  Nexygen plus is used to process the data collected by the Lloyd machine during the tension properties trial.

- **Microsoft OneDrive**
  Microsoft OneDrive is used for secure storage of the thesis.

- **Pages**
  Pages is used to create figures for the thesis.

4.5 Quality assurance

To quality assure each part of the thesis work is important, when one aims to deliver a product that is reliable and of quality.

4.5.1 Quality assurance of the project work

The thesis is quality assured through the use of qualified cousolers at NMBU and through Penda Manufacturing. Reliable methods for screening the different processes in the thesis have also been used alongside relevant literature from acknowledge sources. The reference technique is quality assured through the use of EndNote X8 and the English version of the NMBU Harvard style.

4.5.2 Quality assurance of the material testing

The test samples are produced by an experienced CNC operator. The Norwegian standards NS 8105 and NS-EN 780, will be consulted for the size and shape of the test rods used for the tensile properties trial and for collecting the results, but the size and shape of the test pieces is modified to fit the amount of material at hand. The test rods will be tested in approved laboratory equipment. The surface roughness measurement trial, Ra and Rz, is completed according to ISO 4287:1997.

Methodology is an important part of material testing, which ensure that the testing is carried out in accordance to the standards or guidelines set for the different tests. In this thesis three different trials will be completed, where the tension properties, surface roughness and contact angle will be tested. The methodology related to the material testing is presented in chapter 9, testing of material properties.

4.5.3 Quality assurance of the material

The paper-based plates have been produced by approved laboratory and laboratory personnel at the Technological Institute in Taastrup, Denmark. The paper used in the panels is recycled paper imported from Ethiopia and Danish office paper, while the glue is delivered from well-known manufactures.

4.6 Process steps

The visualization of the process steps shows how the work process of the thesis will take place through the various phases of the remaining work. The process steps also provide a general overview of the work process and will be used in the evaluation and discussion of the thesis in its entirety. It may also be necessary to evaluate the processes and repeat some of the steps during the work period, based on the results that is obtained along the way.

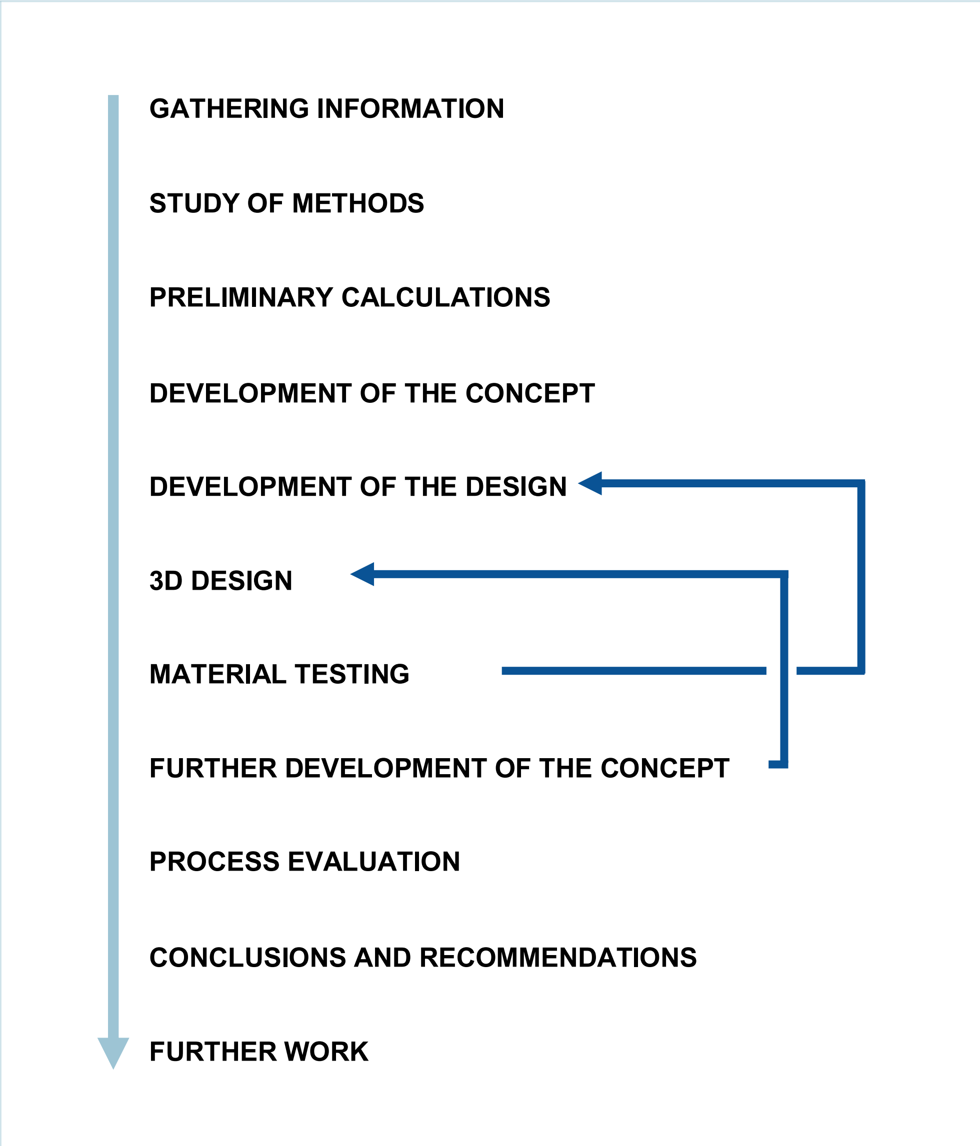


Figure 4.2: A visualization of the different stages of the thesis work process. Arrows and cycles are indicated as improvement processes.

The arrows, which creates cycles, indicates an improvement process. The material testing will affect the design of the product, if the material in the product isn't strong enough for example, then it would be necessary to cycle back to the process of developing the concept or altering it through 3D design.

5 PRODUCT SPECIFICATION

When designing a product, it is important to have a clear goal for the creative development process, so that the right and most important characteristics are brought into the design process. This is done by selecting a primary goal for the product, with partial objectives and characteristics that supplements it. Requirements and metric specifications will help to shape the product and bring forward the most relevant requirements.

5.1 Product objective and requirements

The primary objective for the product

“Furniture produced from paper-based material intended for school use should be functional, durable, stable and ergonomic. It should also be produced mainly from recycled paper and all parts of the finished product should be recyclable at the end of the product´s life, which fulfills the requirements of a circular economy.”

Partial objectives for the product

- The product should have a simple and functional design.
- The product should be durable and stable.
- The product should be designed according to ergonomics and anthropometry.
- The product should be easy to produce, assemble and use.
- Every part of the product should be recyclable.

Requirements for the product

The requirements for this product are based on the requirements established by the company, the user and the function the product supplies. These requirements are:

- All parts of the product should be recyclable.
- Fulfill the requirement of a circular economy.
- The product should be designed for the task it will be used for.
- The product should be designed for the age group it is intended for, 12-35 years.

5.2 Ranking of product characteristics

To generate a good concept, it is important to rank the main characteristics of the product in relation to each other to find the key features that can be brought further into the concept design. This is done through the use of Pugh’s method. In chapter 3.5.1 it is established that when designing a comfortable chair or couch there are three important sets of characteristics to consider, the seat, the user and the task it is designed for.

Based on the three sets of characteristics, the requirements for the product and other features that are relevant to the product, these main characteristics have been established as the most important for the chair:

- **Durable and stable design**
  The chair will be designed for school use and this requires a product that will withstand the use it is meant for. The chair will definitely be used to sit on, but it may also be used to stand on or have two people sitting on it. A student may spill something on it or the school may need to stack the chairs when storing them, which is all important elements to have in mind while designing the chair, so it will be stable and endure the use it will be put through.

- **Ergonomically designed**
  The chair is designed for the user and the task that the user will be executing. Anthropometric data will also influence the ergonomic design.

- **Anthropometry related design**
  The chair is designed in relation to the dimensions of the human body, and the dimensions should be based on the age group the product is intended for, which is 12-35 years for this product.

- **Ease of maintenance**
  The chair in itself should be easy to maintain through cleaning and repairs. Smooth surfaces and replaceable parts.

- **Recyclable**
  The chair will mainly consist of recycled paper, and the materials that will be added to the product, like metals from screws, laminates used to protect the recycled paper panels, or add-ins to the paper-mix, should all be recyclable at the end of the product´s life.

- **Production cost**
  Represents the cost of producing the chair. A low production cost is favorable when producing a product to ensure a higher profit or to be able to provide a low-cost product, but a low production cost is not preferred if it affects the quality of the product that is being produced.

The ranking is carried out with a scale running from 1 – 5, where 5 equals a very important characteristic and 1 equals a characteristic which is not important.

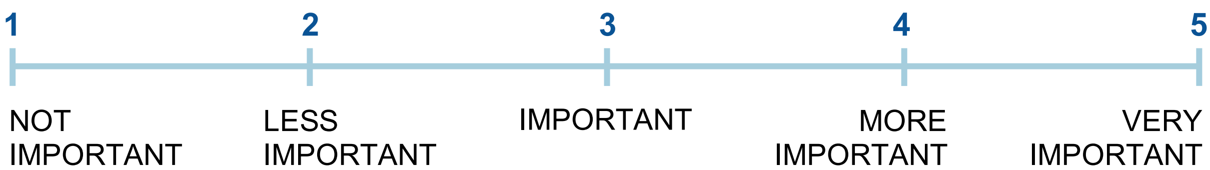


Figure 5.1: The scale that is used to rank the product characteristics after their importance.

Each of the characteristics will be ranked in table 5.1, according to the scale represented in figure 5.1 and the ranking will follow the methodology for Pugh’s method.

Table 5.1: The weighting of the different product characteristics.

PRODUCT CHARACTERISTICS	WEIGHTING
Durable and stable design	5
Ergonomically designed	4
Ease of maintenance	4
Anthropometry focused design	5
Recyclable	5
Production cost	3

5.3 Metric border specifications

The metric border specifications for a chair has been based on the maximum and minimum values stated and recommended by the different designers and the measurements established by them in table 3.2 presented in chapter 3.5.3. The measurements can be used as guidelines when designing the chair for the thesis along with other important characteristics.

Table 5.2: The metric boarder specifications for a chair.

SPECIFICATION	UNIT	MINIMUM	MAXIMUM
Seat width	mm	381	483
Seat depth	mm	305	406
Seat height	mm	345	528
Backrest height from seat surface	mm	127	279
Backrest height	mm	102	300
Angel of tilt of seat	°	0°	5°
Angle of backrest	°	95°	105°

5.4 Basic specifications for the chair

The basic specifications for the chair that will be designed in the thesis, is carefully selected with the user, the task and the comfort of the seat in mind. The age group for the users is set to be 12 – 35 years and the chair will be used in tasks related to school, which includes classroom education and studying among other activities.

The metric border specification presented in chapter 5.3, table 5.2, is based on anthropometric measurements of the adult population. Since the user age is set to be between 12 and 35, it is important to include anthropometric measurements of a 12-year-old so that the metric border specifications for the chair accounts for the whole age group and not only the adult population.

Table 5.3: The 50th percentile dimensions of a 12 year (Tilley & Associates, c2002).

SPECIFICATIONS	UNIT	DIMENSIONS
Knee buttock	mm	500.38
Buttock-popliteal length	mm	408.94

Table 5.3 continues: The 50th percentile dimensions of a 12 year (Tilley & Associates, c2002).

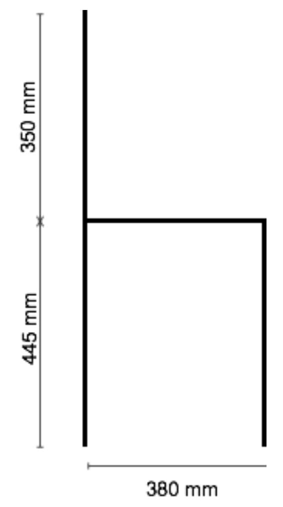
SPECIFICATIONS	UNIT	DIMENSIONS
Knee height	mm	472.44
Popliteal height	mm	376.94

The buttock-popliteal length and popliteal height in table 5.3 has been established based on the stated measurements of a 12-year-old in the book, The measure of man and woman (Tilley & Associates, c2002). This is done through subtracting the measurement of the calf from the knee-buttock measurements to establish an approximate measurement of the buttock-popliteal length and a ¾ measurement of the thigh is subtracted from the knee height to establish an approximate measurement of the popliteal height.

The final basic specification established with the entire age group in mind and by consulting the anthropometric measurements is presented in table 5.2 and table 5.3.

Table 5.4: The basic specifications for the product and a simple sketch of a chair with the dimensions.

SPECIFICATION	UNIT	DIMENSIONS
Seat width	mm	400
Seat depth	mm	380
Seat height	mm	445
Total backrest height from seat surface	mm	350
Backrest height	mm	200
Angle of backrest	°	95
Angle of seat	°	0



The specifications for the chair may need to be altered depending on the results from the material testing and the design of the chair. Based on the specifications, the youngest user will grow into the chair and by applying the right design elements going forward the chair will still be comfortable for the youngest user.

6 CONCEPT GENERATION

To design a good concept, it is important to generate various concepts to see the product from several points of view. This is done through the use of different methods from product development, like a function analysis and SCAMPER. This is combined with a creative process where illustrations are created of new and interesting alternatives that can take a product to a new level or create a whole new solution.

6.1 Function analysis of a paper-based chair

The function analysis of a paper-based chair, which is presented below in figure 6.1, shows the primary, secondary and tertiary functions off a chair produced from recyclable materials. The primary functions show that paper furniture contributes to a circular economy and that the furniture will be made out of recycled paper using the production method for pulp or the waterless production method explained in chapter 3.3. The secondary function is making a chair and the tertiary functions are the elements that go into the chair and the production.

In this case the elements that go into the tertiary functions of the chair are divided into the seat, task and user. For the seat it is important that it is comfortable, that it has the right dimensions and design. Within those areas are the use of ergonomics, anthropometry, cushioning, the profile and angels of the seat.

The task that the chair will execute will be to supply a seating alternative at a school or in an educational center where it will be used in lectures and study halls. Another important part of the chair´s task is that it is comfortable enough so that students can use it for the duration of eight hours.

The intended user of the chair is students between the ages of 12 and 35 years. The age range is based on anthropometric measurements. It is also important to consider the health of the user, like aches and pains, and circulation, so that the chair doesn't create any damage to the body or cut off the blood circulation.

Even though the chair is divided into three elements, the elements complement each other and work together towards a complete chair that fulfills the requirements that is set for the product. For the production part of the chair, the method and production form for the materials in the chair are already chosen and are based on the dry production method explained in chapter 3.3.

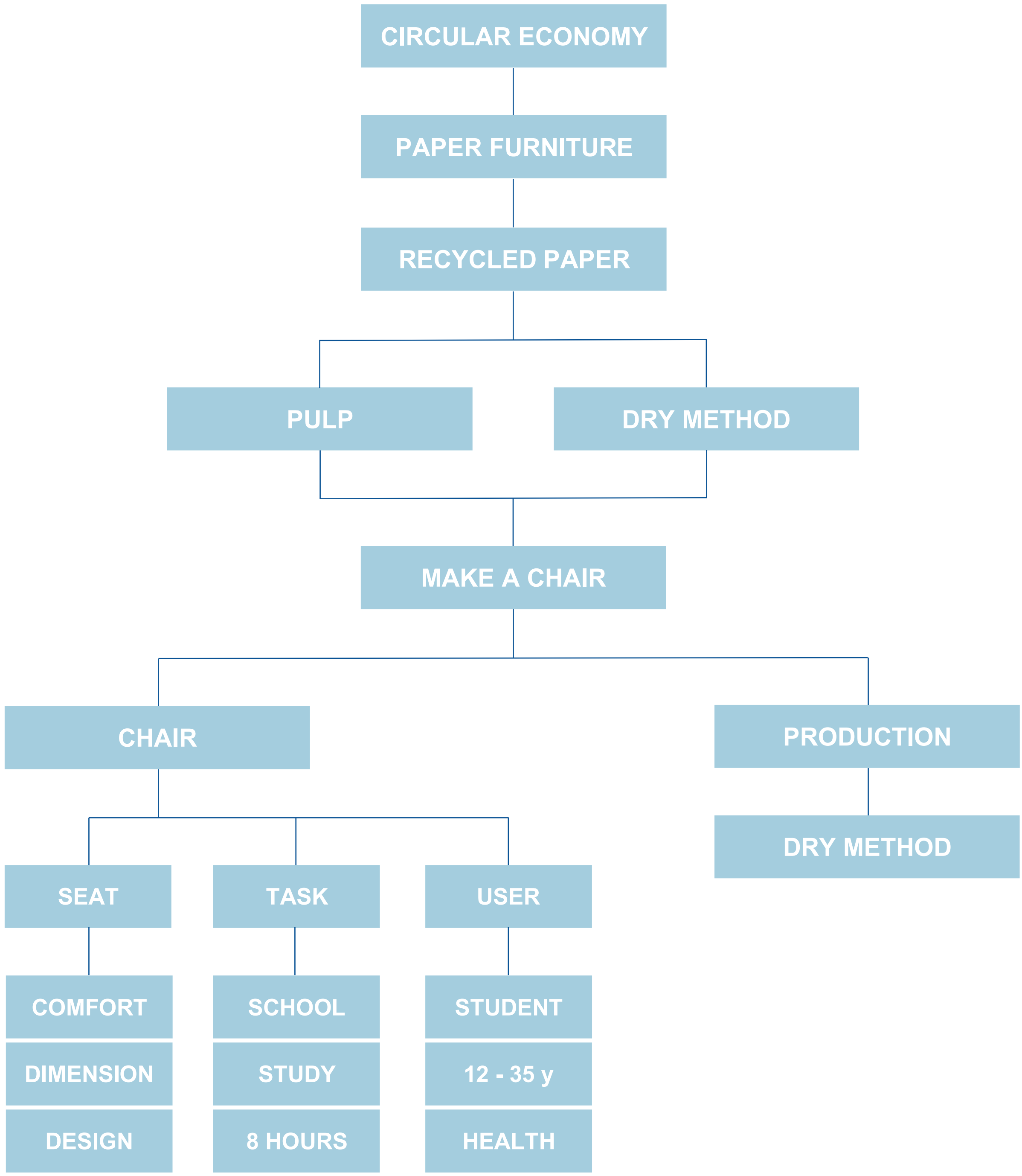


Figure 6.1: Shows the function analysis of paper-based furniture.

The overview established by the function analysis helps create a clearer view of the important areas of the different functions and will be useful throughout this chapter.

6.2 Feature alternatives

To get a clearer overview of the different feature alternatives, they are listed in a table which evaluates the pros and cons with each option. Through a SCAMPER analysis of the chair, the different elements that can be retained and changed are viewed and the advantages and disadvantages with each of them are reviewed.

Table 6.1: SCAMPER analysis for a paper-based school chair.

SCAMPER	IMPROVEMENTS	BENEFITS
SUBSTITUTE	The use of recycled paper as the material.	Reduces the use of raw materials. Saves resources.
COMBINE	The use of other recycled materials in combination with the paper mix.	May increase the strength of the material.
ADAPT	The material can be used in all types of furniture and in construction.	Reaches a bigger market.
MAGNIFY	The thickness of the seat.	Makes the seat stronger and more durable.
MINIFY	The cushioning on the seat and back.	Makes the chair more comfortable.
ELIMINATE	Elements that can't be recycled.	The product can qualify to be a cradle to cradle product and will contribute to building a circular economy.
ELABORATE	Reduce the number of parts.	Shortens the assembly time.
REARRANGE	Changeable parts.	Can be adapted to the task it will be used for.
REVERSE	Make it into a swinging chair, by eliminating the legs and hanging it from the ceiling.	Can be adapted to a larger age group.

Based on the SCAMPER analysis preformed in table 6.1, these improvements will be brought further into the product development process:

- Thickness of the seat.
- Elements that can´t be recycled.

The improvement regarding the use of recycled paper as the material is already in use, since the use of recycled paper panels is a part of the goal for the product. The alternative regarding the use of other recycled materials in combination with the paper mixture is a great alternative to strengthen the material mixture if that is needed but will not be assessed in this thesis since it requires a new material mixture.

Based on the characteristics established in chapter 5.2, the function analysis in chapter 6.1 and the SCAMPER analysis completed above, an analysis will be completed of the features needed to make the chair stable and durable, which will focus on how the seat can be strengthened. An analysis will also be completed on how the chair can be designed so that it will fit the length of a 12-year-old as well as the length of a 35-year-old.

The feature alternatives for strengthening and stabilization of the seat is presented in table 6.2 are designed for a general chair and can easily be adapted for the final design of chair. The suggestions are based on the SCAMPER analysis in table 6.1 and function analysis in figure 6.1.

Table 6.2: Feature alternatives for the stabilization of the seat, by using a frame that goes under the seat.

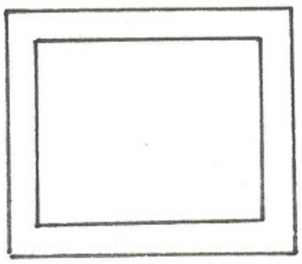
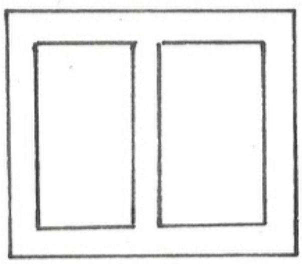
METHOD	BENEFITS	DISADVANTAGES
RECTANGLE  *Figure 6.2: Simple rectangle*	Easy to assemble and produce. Can easily be adapted to the shape of the seat. Low production cost. Easy to maintain.	May not be strong enough.
SINGLE STRAIGHT SUPPORT BEAM  *Figure 6.3: Rectangle with one straight support beam*	Increases the stability and durability of the seat. Easy to maintain.	Takes more time to produce.

Table 6.2 continues: Feature alternatives for the stabilization of the seat.

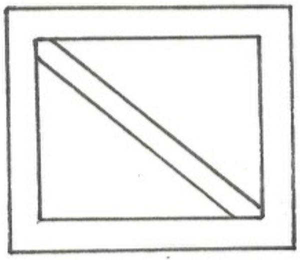
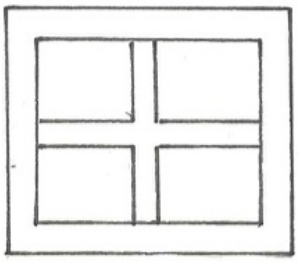
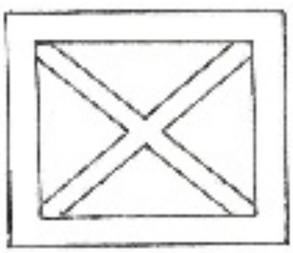
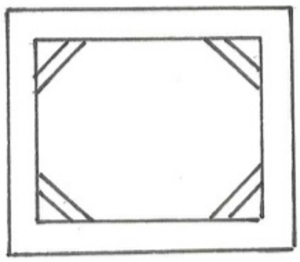
METHOD	BENEFITS	DISADVANTAGES
SINGLE CROSSED SUPPORT BEAM  *Figure 6.4: Rectangle with one crossed support beam*	Easy to maintain.	Takes more time to produce.
TWO STRAIGHT SUPPORT BEAMS  *Figure 6.5: Rectangle with two straight support beams*	Strong. Can easily be adapted to the shape of the seat.	Takes more time to produce and assemble. Increases the production cost. Harder to keep clean.
TWO CROSSED SUPPORT BEAMS  *Figure 6.6: Rectangle with two crossed support beams*	Strong. High stability and durability. Can easily be adapted to the shape of the seat.	Takes more time to produce and assemble. Increases the production cost. Harder to keep clean.

Table 6.2 continues: Feature alternatives for the stabilization of the seat.

METHOD	BENEFITS	DISADVANTAGES
FOUR SINGLE SUPPORT BEAMS  *Figure 6.7: Rectangle with four support beams*	Can easily be adapted to the shape of the seat.	Increases the production cost. Takes more time to produce and assemble. Harder to keep clean and maintain.

Through a workshop on how a chair can be adapted for a growing person, the easiest element to implement into the design of a chair was a footrest. A footrest will shorten the needed popliteal height for the user, which will satisfy the specified age group. A footrest will also work as a support beam which will stabilize the chair and at the same time it will not be in the way for the taller user. The feature alternatives for the footrests presented in table 6.3, is designed for a general chair and can easily be adapted for the final design of the chair.

Table 6.3: Feature alternatives for the adaption of a growing body.

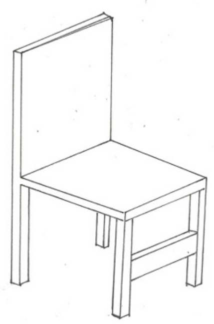
METHOD	BENEFITS	DISADVANTAGES
SINGLE FOOTREST  *Figure 6.8: Single footrest*	Easy to assemble. Easy to produce and to maintain. Can easily be adjusted to the needed height.	May cause instability.

Table 6.3 continues: Feature alternatives for the adaption of a growing body.

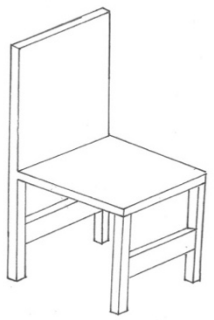
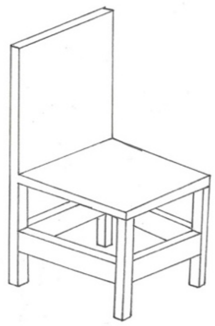
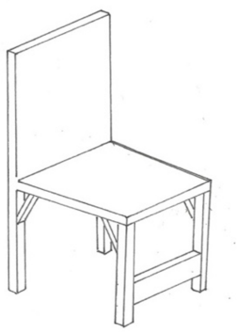
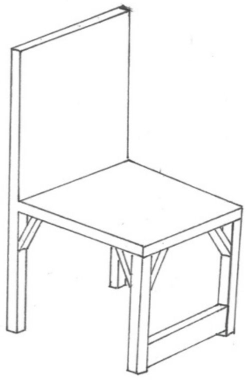
METHOD	BENEFITS	DISADVANTAGES
DOUBLE FOOTREST  *Figure 6.9: Footrest with support beam in the back*	Easy to assemble. Easy to produce and to maintain. Increases the stability of the chair legs.	Increases the production cost.
4-SIDED FOOTREST  *Figure 6.10: Footrest with support beams all the way around*	Increases the stability of the chair. Easy to assemble.	Takes more time to produce. Increases the production cost.
FOOTREST WITH SINGLE SET SUPPORT BEAMS  *Figure 6.11: Footrest with a single set of small support beams under the seat.*	Combines the footrest with stabilizations of the legs and seat.	Increases the production cost. Harder to assemble.

Table 6.3 continues: Feature alternatives for the adaption of a growing body.

METHOD	BENEFITS	DISADVANTAGES
FOOTREST WITH DOUBLE SET SUPPORT BEAMS  *Figure 6.12: Footrest with a double set of small support beams under the seat.*	Increases the stability of the chair. Combines the footrest with a double set of support beams for the seat.	Takes more time to assemble. Increases the production and maintenance cost. Harder to maintain.

6.3 Simple hand calculations

The preliminary hand calculations of the chair will be based on the measurements stated in chapter 5.4, Basic specifications for the chair. The calculations are simplified and will not account for the angle of the seat.

When calculating the forces that works on a chair, several different situations needs to be accounted for. In this case, the scenarios that will be accounted for is presented in table 6.4 along with the maximum weight the chair needs to withstand is also presented in the table.

Table 6.4: Scenarios the chair can be put through and the mass related to each scenario.

SCENARIO	PERSONS	MASS
One person sitting on the chair.	1	125.0 kg
One person, with a child on the lap.	1.5	187.5 kg
Two people sitting on the chair.	2	250.0 kg
Two people sitting on the chair, with someone on their lap.	2.5	312.5 kg

In total should the chair withstand a total maximum weight of 312.5 kg, according to table 6.4. According to BIFMA, should the backrest withstand 68 kg (BIFMA, 2011).

Based on these assumptions, will the chair be calculated with 68 kg working on the backrest and 245 kg on the seat surface.

Forces working from the person on the backrest

$$F = m \times g \tag{1}$$

$$F_{backrest} = 68\ kg\ \times 9.81\ m/s^2$$

$$F_{backrest} = 667.1\ N$$

Forces working from the person on the seat

$$F = m \times g \tag{1}$$

$$F_{seat} = 245\ kg\ \times 9.81\ m/s^2$$

$$F_{seat} = 2430.5\ N$$

Reaction forces x-axis

$$F_{backrest} - F_{xE} = 0$$

$$667.1\ N - F_{xE} = 0$$

$$F_{Ex} = 667.1\ N$$

Reaction forces y-axis

$$(F_{yD} \times 380mm) + (\ F_{seat} \times 190\ mm) - (F_{backrest} \times 795\ mm) = 0$$

$$F_{yD} = \frac{-(2403.5\ N \times 190\ mm) + (667.1\ N \times 795\ mm)}{380\ mm}$$

$$F_{yD} = 193.9\ N$$

$$F_{yD} - F_{seat} + F_{yE} = 0$$

$$F_{yE} = \ -193.9\ N + 2430\ N$$

$$F_{yE} = 2209.6\ N$$

Since there are four legs, and the front and back legs are calculated separately all the reaction forces need to be divided by two.

$$F_{Ex} = \frac{667.1\ N}{2}$$

$$\boldsymbol{F_{Ex} = 333.6\ N}$$

$$F_{yD} = \frac{193.9\ N}{2}$$

$$\boldsymbol{F_{yD} = 96.95\ N}$$

$$F_{yE} = \frac{2209.6\ N}{2}$$

$$\boldsymbol{F_{yE} = 1104.8\ N}$$

Moment in B

$$M_{BC} - (1108.8\ N \times 0.19\ m) + (96.95\ N \times 0.38\ m) = 0$$

$$M_{BC} = 247.5\ Nm$$

$$M_{BA} - (333.6\ N \times 0.35\ m) = 0$$

$$M_{BA} = 116.8\ Nm$$

$$M_B = M_{BC} + M_{BA}$$

$$M_B = 247.5\ Nm + 116.8\ Nm$$

$$M_B = 364.3\ Nm$$

Stress in the legs

$$\sigma_{Front} = \frac{F_{yD}}{A} \tag{2}$$

$$\sigma_{Front} = \frac{96.95\ N}{(30 \times 30)mm^2}$$

$$\boldsymbol{\sigma_{Front} = 0.108\ N/mm^2}$$

$$\sigma_{Back} = \frac{F_{yE}}{A} \tag{2}$$

$$\sigma_{Back} = \frac{1104.8\ N}{(30 \times 30)mm^2}$$

$$\boldsymbol{\sigma_{Back} = 1.23\ N/mm^2}$$

Shear stress in the backrest

$$\tau = \frac{V}{A} \tag{3}$$

$$\tau = \frac{667.1\ N}{(30\ \times\ 400)mm^2}$$

$$\boldsymbol{\tau = 0.0556\ N/mm^2}$$

Bending moment

$$\sigma_b = \frac{M_b}{W_b} \tag{4}$$

$$\sigma_b = \frac{364273\ Nmm}{\frac{bh^2}{6}}$$

$$\sigma_b = \frac{364274\ Nmm}{\frac{(30mm \times 350mm)^2}{6}}$$

$$\boldsymbol{\sigma_b = 0.595\ N/mm^2}$$

The stress in the legs equals, $\sigma_{Front} = 0.108\ N/mm^2$ and $\sigma_{Back} = 0.108\ N/mm^2$, while the shear stress in the backrest $\tau = 0.0556\ N/mm^2$ and the bending moment equals $\sigma_b = 0.595\ N/mm^2$.

The calculations will be further assessed after the material testing.

6.4 Shape and aesthetics options

Design is a way of creating things, anything from a building to a bicycle or to technology. The field of design is built up by an endless number of techniques, methods, philosophies, principles and so much more. One element in design is form and shape. The form and shape of an object can be described as geometric or organic. Geometric shapes and forms are mathematical and pure forms like squares, triangles, rectangles and circles or forms created by volumes like pyramids, cubes and cylinders. Organic shapes and forms are flowing, unpredictable and inspired by natural elements like the sky, plants, sea and everything nature contains (Neby & Myklebust, 2016).

Another element in design is aesthetics, which is a field of study within philosophy and concerns nature, creation and appreciation of beauty. The aesthetics of an object is affected by its color, shape, texture, patterns and much more. Aesthetics are in all human senses and people tend to value things that are beautiful as much as they are usable (Ulrich, 2018).

The shape and aesthetics options presented below in table 6.4 have all been inspired by geometric shapes like triangles, squares, circles and rectangles as a starting point and evolved further. The creative processes started with one of each shape and continued with the combination of several shapes. The alternatives are clearly affected by the term “form follows function.”

Table 6.4: Shape and aesthetics options for the design of the chair in whole.

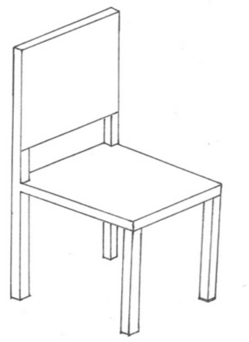
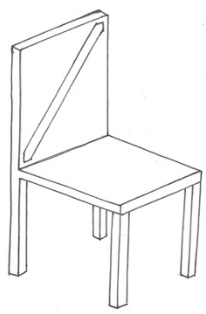
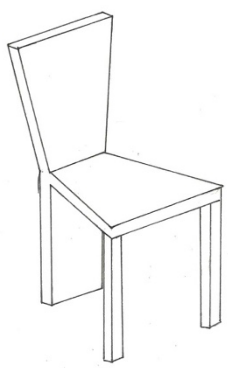
METHOD	BENEFITS	DISADVANTAGES
SQUARES  *Figure 6.13: Chair inspired by squares.*	Easy to maintain and clean. Easy to produce and assemble. Simple and functional design. Low production cost.	Plain.
SQUARES AND TRIANGLES  *Figure 6.14: Chair inspired by squares and triangles.*	Easy to maintain. Easy to assemble. Inspiring. Simple and functional design.	The pattern on the backrest may be challenging to clean. The backrest may not be strong enough.
TRIANGLES  *Figure 6.15: Chair inspired by triangles.*	Easy to maintain and clean. Inspiring. Easy to assemble.	Demanding to produce. May be unstable due to the design of the legs.

Table 6.4 continues: Shape and aesthetics options for the design of the chair in whole.

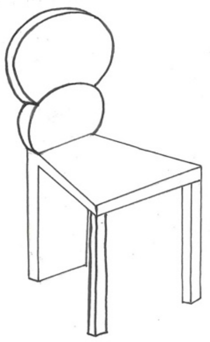
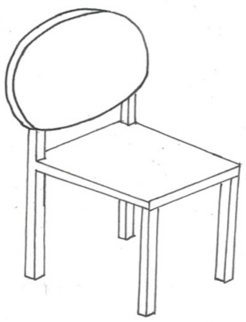
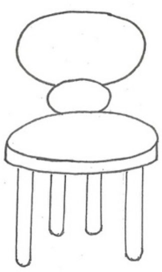
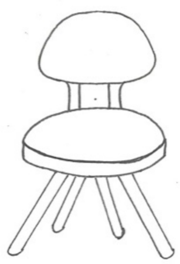
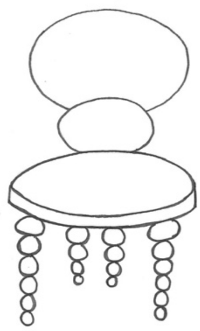
METHOD	BENEFITS	DISADVANTAGES
TRIANGLES AND CIRCLES  *Figure 6.16: Chair inspired by triangles and circles.*	Easy to clean. Inspiring.	May be unstable due to the design of the legs. Demanding to produce. Challenging to maintain because of the shape of the backrest. Requires several different shapes to produce it. May be unstable due to the design of the legs.
SQUARES AND CIRCLES  *Figure 6.17: Chair inspired by squares and circles.*	Easy to produce and assemble. Simple and functional design. Easy to maintain and clean.	Requires several different shapes to produce it.
CIRCULAR SHAPES 1  *Figure 6.18: Chair inspired by circular shapes.*	Inspiring.	Demanding to produce. Challenging to maintain and clean because of the shape of the backrest.

Table 6.4 continues: Shape and aesthetics options for the design of the chair in whole.

METHOD	BENEFITS	DISADVANTAGES
CIRCULAR SHAPE 2  *Figure 6.19: Chair inspired by circular shapes.*	Simple and functional design.	Demanding to produce. Hard to stack. Challenging to assemble and maintain.
CIRCULAR SHAPE 3  *Figure 6.20: Chair inspired by circular shapes.*	Inspiring.	Demanding to produce. The legs are hard to keep clean. High production cost. Hard to stack.

7 CONCEPT SELECTION

A concept selection is based on a thorough concept generation where alternatives have been established, evaluated and illustrated based on methods, theory and product specifications among other things. The selected concept will be the base for the design of the chair, which in the end may be recommended for production.

7.1 Development of selection matrix

The selection matrix for the feature alternatives, stabilization of the seat and adaption of a chair to a growing body, presented in chapter 6.2, is developed based on the criteria established through the ranking of the product characteristics in chapter 5.2 and through the function analysis of the product in chapter 6.1. The selection matrix for the shape and aesthetic options presented in chapter 6.4 is developed based on the same criteria set for the selection matrix for the feature alternatives. The characteristics that are important for the development of the chair and its components, are carefully chosen and weighted after their importance.

The screening will be weighted with scale running from 1 – 5, where 5 is the highest score and 1 is the lowest score.

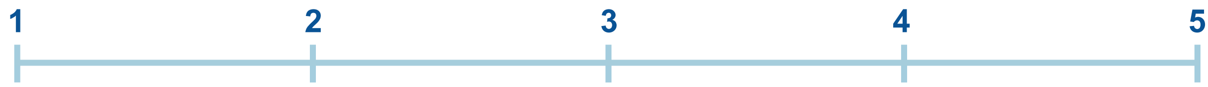


Figure 7.1: The scale used during the screening of the different alternatives.

7.2 Concept screening

In the selection matrix for the strengthening and stabilization of the seat the following criteria have been used and the selection matrix is presented below in table 7.1:

Functionality: Weighting 40%. Here the ease of use and the assumed strength of the alternatives for strengthening and the stabilization of the seat are assessed. A high score represents a highly functional product that is easy to use, produce and adapt to the different aesthetic options for the chair, while a low score represents a product with a lower level of functionality which is less user-friendly and harder to produce.

Complexity: Weighting 35%. Here the complexity of the strengthening and stabilization of the seat are weighted, the more parts the construction consists of, the higher is the complexity and assembly time. A high score represents a low level of complexity, while a low score represents a high level of complexity.

Maintenance: Weighting 25%. The maintenance of the solution should be easy to preform and if needed the damaged parts should be easy to replace. A high score represents an alternative that is easy to maintain and clean, while a low score represents an alternative that is more time consuming and harder to maintain.

Table 7.1: Selection matrix for the stabilization of the seat.

CRITERIA	WEIGHTING	FIGURE 6.2	FIGURE 6.3	FIGURE 6.4	FIGURE 6.5	FIGURE 6.6	FIGURE 6.7
Functionality	40 %	3	2	2	3	4	4
Complexity	35 %	5	4	4	3	3	3
Maintenance	25 %	5	4	4	4	4	3
SUM	100 %	**4.20**	3.20	3.20	3.25	3.65	3.40

The alternative that came out with the best score in table 7.1 is figure 6.2, which is a simple rectangle with no extra support beams. If a stronger solution is needed, the alternative represented by figure 6.6 will be used.

In the selection matrix for the adaption of the chair to a growing body, the following criteria have been used and the selection matrix is presented below in table 7.2:

Functionality: Weighting 30%. Here the ease of use of the alternatives for adapting the chair to a growing body is assessed. A high score represents a highly functional product with a solution that is user-friendly, easy to produce and can easily be used by the age range. A low score represents a product with a lower functionality, which is harder to produce, less user-friendly and can´t be used as easily by the age range.

Complexity: Weighting 30%. Here the complexity of the footrest is weighted, the more parts the construction consists of, the higher is the complexity and assembly time for the solution. A high score represents a low level of complexity, while a low score represents a high level of complexity.

Maintenance: Weighting 20%. The maintenance of the solution should be easy to preform and if needed the damaged parts should be easy to replace. A high score represents an alternative that is easy to maintain and clean, while a low score represents an alternative that is more time consuming and harder to maintain.

Adaption: Weighting 20%. The adaption of the solution is weighted based on how suitable the alternative is for the age range, if the solution is stable and how easily the solution can be adapted to different aesthetic options. A high score represents an alternative that can easily be adapted to the selected age range and to the final design of the chair, while a low score represents an alternative that is less adaptable.

Table 7.2: Selection matrix for the footrest.

CRITERIA	WEIGHTING	FIGURE 6.8	FIGURE 6.9	FIGURE 6.10	FIGURE 6.11	FIGURE 6.12
Functionality	30 %	5	5	5	5	5
Complexity	30 %	4	3	2	2	1
Maintenance	20 %	4	4	2	3	2
Adaption	20 %	3	3	3	3	2
SUM	100 %	**4.1**	3.8	3.1	3.3	2.6

The alternative that achieved the best score is the alternative represented by figure 6.8, a simple footrest with no support beams. If a stronger solution is needed, the alternative represented by figure 6.9 or 6.11 will be used.

In the selection matrix for the shape and aesthetic options for the chair the following criteria have been used:

Functionality: Weighting 30%. The ease of use of the different aesthetic alternatives for the chair is weighted here. The chair should be easy to use, easy to move/carry and should be stackable in one way or the other. A high score represents a highly functional product, while a low score represents a product with a lower functionality.

Complexity: Weighting 30%. Here the complexity of the chair in itself and the production is weighted, the more parts the construction consists of, the higher is the complexity and assembly time. A high score represents a low level of complexity, while a low score represents a high level of complexity.

Maintenance: Weighting 20%. The maintenance of the chair should be easy to perform. Maintenance includes repairs and cleaning of the chair. A high score represents a product that is easy to maintain and clean, while a low score represents a product that is more time consuming and harder to maintain.

Inspiration: Weighting 20%. The shape and aesthetic of a piece of furniture can bring life and inspiration into a room and the users of the room, which is very important when it comes to a classroom or study space. A high score represents a high level of inspiration to the room and the students, while a low score represents a low level of inspiration to the user and environment.

Table 7.3: Selection matrix for the shape and aesthetic options.

CRITERIA	WEIGHTING	FIG. 6.13	FIG. 6.14	FIG. 6.15	FIG. 6.16	FIG. 6.17	FIG. 6.18	FIG. 6.19	FIG. 6.20
Functionality	30 %	5	5	4	4	4	3	3	3
Complexity	30 %	4	4	3	3	4	3	2	1
Maintenance	20 %	4	4	4	3	4	3	3	3
Inspiration	20 %	1	2	2	4	2	5	4	5
SUM	100 %	3.7	**3.9**	3.3	3.5	3.6	3.4	2.9	2.8

The alternative that came out with the best score is represented by figure 6.14, which is inspired by squares and rectangles.

7.3 Preferred solution and aesthetics alternatives

After conducting the concept screen with the use of different methods the following elements have been selected for the chair:

- The design of the chair is inspired by squares and triangles, which creates a simple and user-friendly chair with a low complexity and easy maintenance. The design is represented by figure 6.14 in chapter 6.2.
- The seat of the chair will be strengthened and stabilized by a simple rectangular frame underneath the seat. The selected alternative is represented by figure 6.2 in chapter 6.2.
- A footrest will be added to the chair, so it will fit the selected age range and decreases the popliteal height for the shorter part of the population within the age range.

The selected elements will be put together and provide a base and concept of the chair design, together with the measurements stated for the chair in chapter 5.4, table 5.4.

8 CONCEPT DESIGN

Through the use of product development methodology, a concept for the chair was selected. The use of this methodology includes establishing product specifications and based on these specifications, concepts are generated with the help of a function analysis, the use of SCAMPER and aesthetics in combination with shape. When the concepts are generated, a screening of the concepts is completed with the help of Pugh's method and finale concept is selected based on the result from the screening. Through the use of 3D visualization in SolidWorks the selected concept is designed and presented.

8.1 From the selected concept to the final concept

When the selected concept was visualized in SolidWorks, the concept wasn't aesthetically pleasing, and the dimensions of the backrest were too small. The decision was made to alter the concept design to make the chair more aesthetically pleasing and to raise the height of the backrest, so it would be more comfortable for the taller end of the age group and still be comfortable for the shorter end of the age group. The different stages of the design process for the chair is presented below in figure 8.1.

A. B. C.

Figure 8.1: The design process of the chair, from the first draft to the finale draft.

To make the chair more aesthetically pleasing, the edge at the front of the seat was rounded of as well as the front edge on top of the backrest. Figure 8.1 B) and 8.1 C) are quite similar, but the difference is in how the parts of the chair will be machined. The design in figure 8.1 B) wasn't suited for processing the different parts of the chair out of panels and the design in figure 8.1 C) has been altered to fit the processing of the parts so they can be machined out of a panel.

8.2 The final concept

The finale design of the chair is presented below in figure 8.2 and 8.3, while the details of the chair is presented in figure 8.4 and figure 8.5. The construction drawing of the chair is presented in chapter 15, under attachment 2: ISO construction drawings of the chair.

The chair

Figure 8.2: The finale design of the chair, angled from the front.

A. B. C.

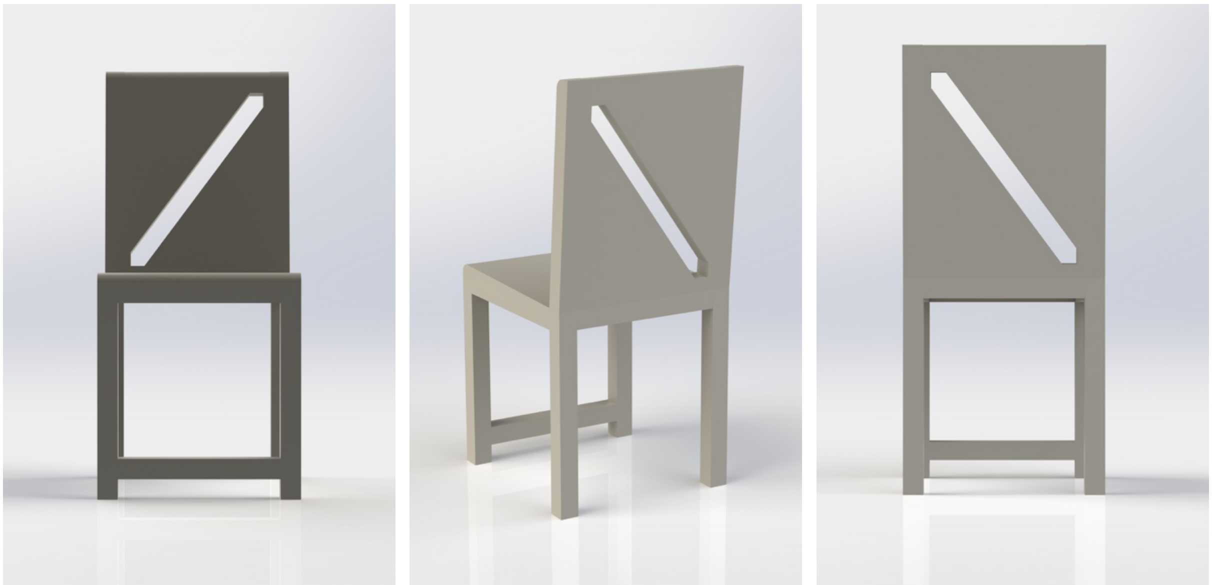


*Figure 8.3: The final design of the chair from various angles. **A)** The chair seen from the front. **B)** The chair seen angled from the back. **C)** The chair seen directly from the back.*

Details of the chair

The chair is assembled through two side frames, a plate for the backrest with a simple cut out as a detail and an angled plate the seat. The front of the seat is also reinforced while the rest of the reinforcement for the seat is incorporated in the frames and the thickness of the seat.

A footrest is also included in the design to shorten the popliteal length needed for the younger users.

Figure 8.4: One of the side frames needed to assemble the chair.

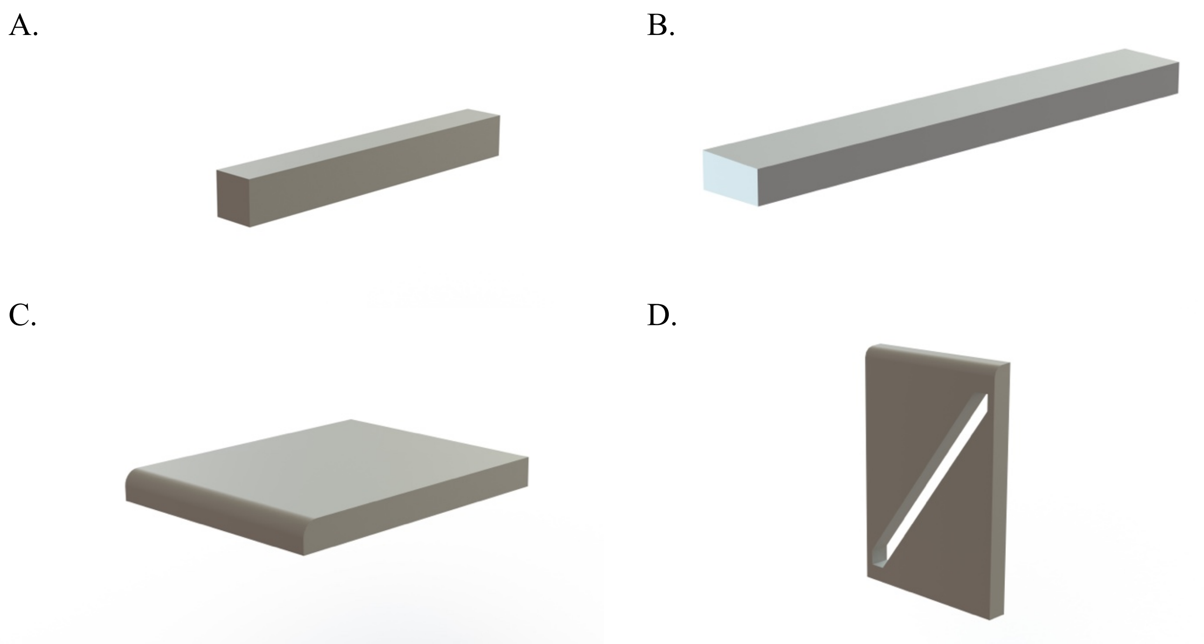


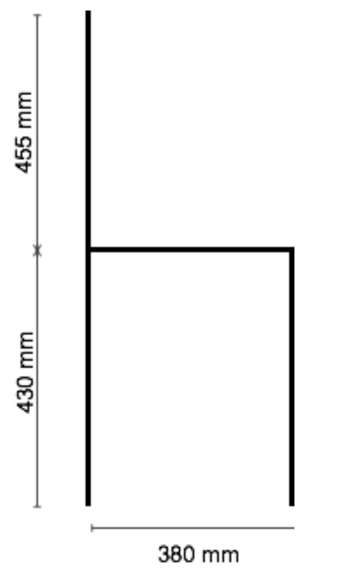
*Figure 8.5: The main parts that is needed to assemble the chair. **A)** The footrest. **B)** The reinforcement beam which is placed under the seat, in the front. **C)** The seat. **D)** The backrest.*

Finale product specifications

The general specifications for the chair is presented below in table 8.1, while the detailed specifications for the chair and all the parts are presented in chapter 15, under attachment 2: ISO construction drawings of the chair.

Table 8.1: The basic specifications for the final chair design.

SPECIFICATION	UNIT	DIMENSIONS
Seat width	mm	400
Seat depth	mm	380
Seat height (front)	mm	445
Seat height (back)	mm	430
Backrest height from seat surface	mm	455
Angle of backrest	°	95
Angle of the seat	°	2.26
Dimension of the chair legs	mm	40 x 40
Dimension of the footrest	mm	40 x 40
Total height of the chair	mm	885



9 TESTING OF MATERIAL PROPERTIES

The purpose of the experimental trials is to test the mechanical properties of the paper-based materials to see if they are durable enough to be used in furniture alone, which binder is the strongest and if the production method is a valid choice for producing the material. An experimental plan is put together and contains the goals for the experiments. To support the experimental plan, a methodology for each of the planned trials is provided and gives an insight into how each trial will be performed. The results are then recorded and discussed.

9.1 Experimental plan

Primary objective for the trial

"To test the mechanical properties for the paper-based panels made using the waterless method, with different binders, through testing the tensile strength, the bending properties, the contact angle and the surface roughness. This is done to see if the material meets the requirements that have been set for the product, which the material will be used in."

Partial objectives for the trial

- Experimental plan
- Methodology for the experiments
- Execution of the experiments
- Evaluation of the results

The partial objectives for the trials are based on the main objective.

Each trial will be completed by testing three different paper-based panels where the binders used in the different panels are Dextrin glue, Silicate glue and Biotack glue. The reason for only testing three of the seven glues used to create the different panels, is because the panels could not be shaped into the desired shape for the test rods needed to conduct the trails for tensile strength and bending properties. The panels made from potato starch glue and corn starch glue dissolved when being shaped into the test rods and the panels made from Soy glue and Bio Tack Protein glue were too small and would require the development of unique testing gear for the tensile strength trial.

The panels are made at the Technological Institute in Taastrup, Denmark, using the method described in chapter 3.3.

9.2 Methodology

The strength of a material depends on the ability to sustain a load without unnecessary deformation or failure. These properties are found within the material itself and can only be determined by different experiments. For the experimental trials conducted in this thesis, methodology for finding the tension properties, measuring the contact angle and wettability, and measuring the surface roughness, of a material is needed.

9.2.1 Measurements of tension properties

When testing the tension properties of a material, a test piece is fastened in a machine that slowly pulls the piece apart until it breaks by applying a load that is gradually increasing. The machine is constantly measuring the load that is applied and the extension of the material until it breaks. The results from the experiment are presented in a load-extension curve. Through the results from performing a test for finding the tension properties, several important mechanical properties can be found. For this test the focus will be on finding the tensile strength, f_t , and the elastic modulus for tension, E (Norsk Standard, 1980; Norsk Standard, 2005).

$$f_t = \frac{F_{max}}{A} \tag{9}$$

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l} \tag{5}$$

To perform the trial, a test piece has to be shaped out of the material or materials that is going to be tested. The shape and dimensions for the test piece that will be used in this trial, is shown in figure 9.1 and are shaped using a CNC router. For this trial, three test pieces form each of the material mixtures, Biotack, Dextrin and Silicate, will be tested. The test pieces have been shaped by consulting NS 8105 and NS-EN 789, but because of limited material supply the test pieces had to be dimensioned to fit the material available.

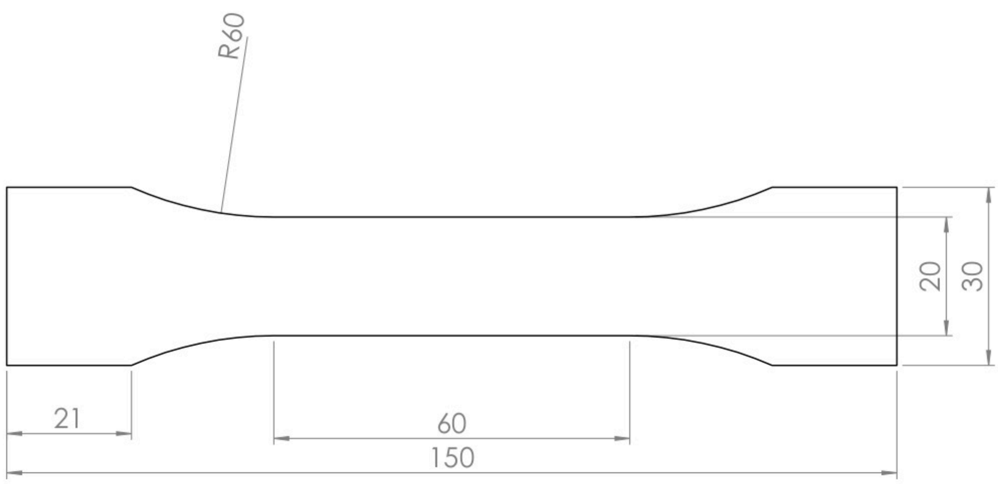


Figure 9.1: A drawing of the test pieces with the related dimensions.

The trial will be performed by using a Lloyd LR5K plus machine and the test pieces will be fastened in the machine by using clamps. It is important that the clamps don’t apply a bending moment to the test piece or let the material slip when it´s under load. The gauge length (l_1) and dimensions of the cross-section within the gauge length should be measured before the test piece is fasten in the machine (Norsk Standard, 2005).

The result will be reported to the computer that is connected to the Lloyd machine and will be presented in a load-extension curve, which will be used to calculate elasticity modulus.

9.2.2 Measurements of the contact angle and wetting properties

The measurement of a contact angle, which is the degree of wetting when a solid and liquid interact, is the primary data used when conducting a study of the wettability of a solid materials surface. The contact angle is the angle formed by a liquid at the three-phase boundary where the liquid, gas, and solid intersect. A small contact angle, < 90°, represents a high level of wettability and the surface of the material is said to be hydrophilic. A large contact angle, > 90°, represents a low level of wettability and the surface of the material is said to be hydrophobic (DataPhysics Instruments GmbH, Germany).

When measuring the contact angle, different methods like the Direct Measurement by Telescope-Goniometer, the Captive Bubble Method, the Tilting Plate Method, the Wilhelmy Balance Method, the Capillary Rise at a Vertical Plate, the Individual Fiber, the Capillary Tube, the Capillary Penetration Method for Powders and Granules, and the Capillary Bridge Method can be used (Yuan & Lee, 2013).

In this trial the Direct Measurement by Telescope-Goniometer is the method of choice. Through this method the contact angle is measured through direct measurement of the tangent angle at the three-phase contact point on a sessile drop profile is measured (Yuan & Lee, 2013). The method is also called the sessile drop method and is often referred to as the standard method to measure contact angels. When measuring the contact angle, the sessile drop is illuminated from one side with a diffuse light source and the contour of the drop is observed from the other side.

The trial will be conducted by using the OCA 15 EC, which is a video-based optical contact angle measuring instrument by DatapPysics and is used in a combination with the SCA 20 software. The SCA 20 can determine the contact angle based on five different calculation algorithms for a circle, eclipse, Laplace-Young, polynomial and tangent leaning. A manual mode can also be used to measure the contact angle (DataPhysics Instruments GmbH, Germany).

Through the software the drop phase and ambient phase parameters for Laplace-Young fitting are added. Then the dosing preparations are completed through prepping and mounting the syringe, adjusting the needle position and adjusting the focus of the optics until the image of the needle tip is sharp (DataPhysics Instruments GmbH, Germany). Further the dosing rate and volume is adjusted, in this case the dosing volume is 5 µl and the dosing rate set to fast which equals 2 µl/s, before the dose is dispensed. Then the sampling stage with the sample is carefully moved upwards without touching the needle tip and until the drop settles on the samples surface. The dispensing of the drop, settling of the drop and interaction between the drop and surface is filmed. From this film the contact angle is calculated through the algorithms in the software.

9.2.3 Measurements of the surface roughness

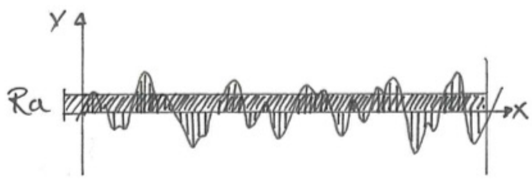
The surface roughness indicates the state of the surface. Surface irregularities of a material can be created intentionally through machining or the can be created by a wide range of factors.

The irregularities vary in shape and size, and the differences in irregularities effect the quality, performance and functions of the surface and the end product. Surface roughness measurements can be done through using one of two methods. The first alternative is a linear roughness measurement, this method measures a single line on the sample surface. The other alternative is the areal roughness measurement, this method measures an area of the surface and also sees the surface as it really is (Olympus Corporation, 2018).

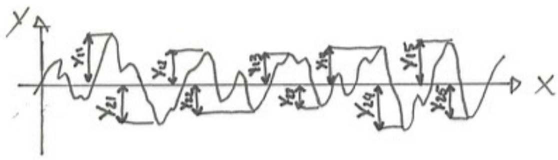
In this trial the linear roughness measurement method will be used and the results of Ra and Rz will be collected. There will be performed six measurements of each parameter, on each of the three material samples. In total, 18 measurements. The measurements are taken in accordance to ISO 4287:1997 and the surface roughness measuring tester SJ-210 from Mitutoyo will be used (Mitutoyo, United States).

Ra represents the mean roughness value and is the arithmetical mean of the absolute values of the profile derivations from the mean line of the roughness profile. While Rz represents the mean roughness depth, which is the mean value of the five highest and lowest peak values from the five sampling lengths within the evaluation length of the measurement (Olympus Corporation, 2018).

A.



B.



C.

$$R_z = \frac{(Y_{11} + Y_{12} + Y_{13} + Y_{14} + Y_{15}) + (Y_{21} + Y_{22} + Y_{23} + Y_{24} + Y_{25})}{5}$$

Figure 9.2: How Ra and Rz are measured. A) Ra is measured through using the mean of each of the values from the surface screening. B) Rz is measured through adding the five highest and lowest peak values and dividing them by dividing by five. C) The formula used to calculate Rz manually.

The confidence interval for Ra and Rz will be calculated for each of the materials with a 95% confidence interval, and an ANOVA analysis will be run for the same measurements. The ANOVA analysis shows if there are any statistically differences between the surfaces. $\rho < 0{,}05$ indicates that the averages are different, while when $\rho > 0{,}05$ indicates that the averages are not different. The calculations and the ANOVA analysis can be found in attachment 4 and 5.

9.3 Equipment

9.3.1 Measurements of tension properties

To measure the tensile strength of the material, different equipment is needed. To complete this trial, the following equipment was used:

- CNC router.
- Material samples from the three mixtures.
- Lloyd LR5K plus machine.
- Clamps.
- Calliper.
- Screw clamp.
- Nexygen Plus Software.

A. B. C.

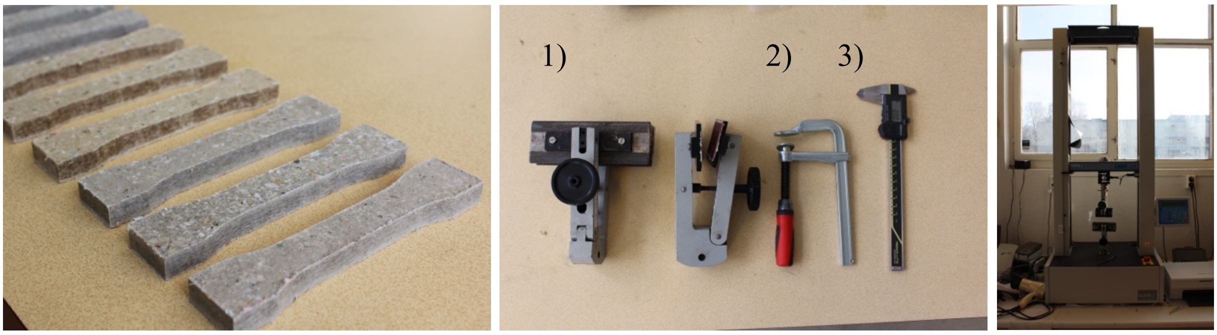


Figure 9.3: Some of the equipment needed to complete the trial. ***A)*** *Material samples from the three mixtures.* ***B)*** *Some of the equipment used during the trial**.** 1) Clamp for the Lloyd machine. 2) Screw clamp. 3) Calliper.* ***C)*** *The Lloyd LR5K plus machine.*

9.3.2 Measurements of the contact angle and wetting properties

Different equipment is needed to measure the contact angle and wetting properties of the material. To complete this trial, the following equipment was used:

- OCA 15EC - Video-based optical contact angle measuring instrument.
- Syringe filled with water.
- SCA 20 Software.
- Material samples from the three mixtures.

9.3.3 Measurements of the surface roughness

Different equipment is needed to measure the surface roughness of the material. The following equipment was used:

- Surface roughness measuring tester SJ-210 by Mitutoyo.
- Plate to place the tester on.
- Material samples from the three mixtures.
- Computer, to document the results.

9.4 Tension properties trial

To conduct the trial, test pieces of the different materials mixtures needed to be machined according to figure 9.1, chapter 9.2. The test pieces were machined through using a CNC router to ensure that all the parts would get the same shape and the same margin of error. The machining showed that two of the material mixtures wasn´t shapeable, due to that the material was too fragile.

This resulted in that only three material mixtures were tested, with three samples of each mixture, due to the fragile material and the two test samples that were too small.

When the material was to be tested, it almost slipped out of the clamps. To get the material to stay in the clamps, five screw clamps where mounted on the original clamps as shown below in figure 9.3.

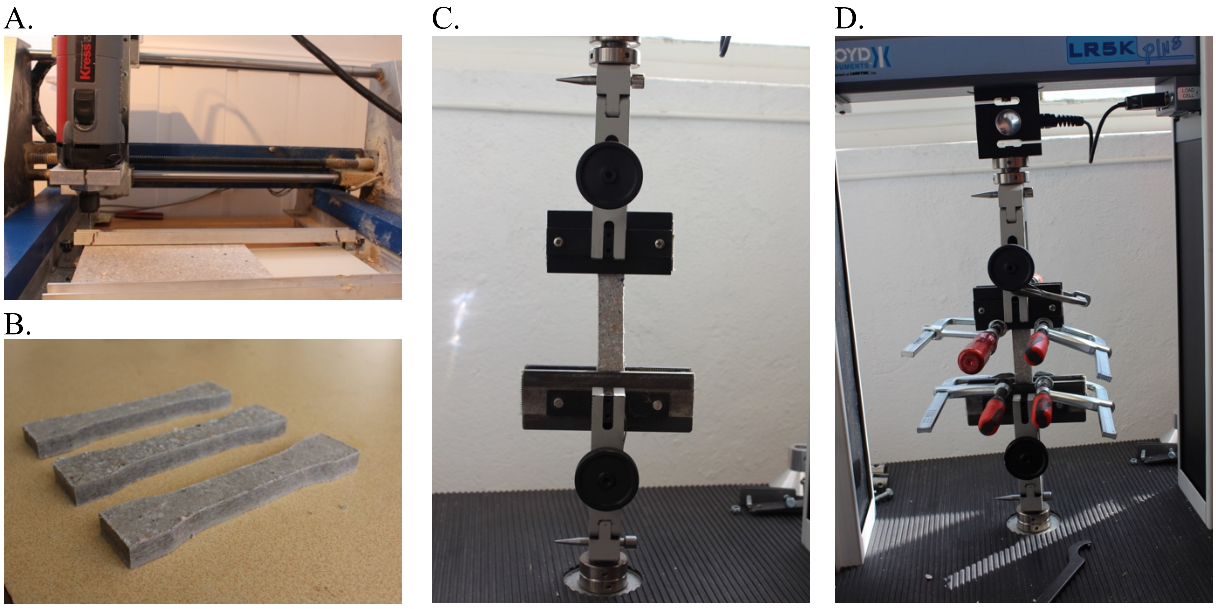


Figure 9.4: The process from machining the test pieces to testing them in the Lloyd machine. ***A)*** *The process of machining the test pieces in a CNC-router.* ***B)*** *The test pieces.* ***C)*** *A test pieces clamped in the Lloyd machine.* ***D)*** *A test piece clamped in the Lloyd machine with five screw clamps, to prevent the pieces from slipping.*

When the test pieces were properly clamped, the testing in itself went great. When the trial was completed, the results that were obtained during the trial was saved on the computer connected to the Lloyd machine. But when collecting the results later that week, something had went wrong in the process of saving the results and all the results were lost. Luckily, eight out of nine load-extension curves had been photographed and could be used to calculate the E-modulus for the materials. The load-extension curve that was lost, represented sample 1 of the Silicate material mixture.

Calculations of the Elasticity modulus for tension (Youngs modulus)

The process of calculating the Elasticity modulus is shown through the formulas below. ΔF and Δl is calculated through the use of the load-extension diagrams collected during the conduction of the trials and are presented in attachment 7. To get the same base for each of the ΔF and Δl calculation, $F_2 = 0.4 \times F_{max}$ and $F_1 = 0.1 \times F_{max}$.

The calculation of the E-modulus for each of the samples is shown in full, in attachment 8. The gauge length, l_1, is measured to 80 mm for all the samples and A equals the cross-section within the gauge length prior to the testing.

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l} \tag{5}$$

$$\Delta F = F_2 - F_1 \tag{6}$$

$$\mathrm{A} = l \times b \tag{7}$$

$$\Delta l = l_2 - l_1 \tag{8}$$

Calculation of the tensile strength

The tensile strength is calculated through the use of F_{max}, which is the maximum load the test piece could withstand prior to breaking. While A, equals the cross-section within the gauge length prior to the testing in this calculation as well.

$$f_t = \frac{F_{max}}{A} \tag{9}$$

The results and simplified calculations for each of the samples in the trial is presented below. The results are summarized in table 9.1, table 9.2 and table 9.3.

Biotack

Sample 1
Calculation of the E-modulus:

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l} = \frac{803.67\ N \times 80.00\ mm}{245.59\ mm^2 \times 0.397mm} = 609.75\ MPa$$

Calculation of the tensile strength:

$$f_t = \frac{F_{max}}{A} = \frac{2678.9\ N}{245.59\ mm^2} = 10.90\ MPa$$

Sample 2
Calculation of the E-modulus:

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l} = \frac{829.92\ N \times 80.00\ mm}{243.60\ \ mm^2 \times 0.417mm} = 653.60\ MPa$$

Calculation of the tensile strength:

$$f_t = \frac{F_{max}}{A} = \frac{2766.4\ N}{243.60\ mm^2} = 11.36\ MPa$$

Sample 3
Calculation of the E-modulus:

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l} = \frac{974.28\ N \times 80.00\ mm}{242.59\ mm^2 \times 0.588\ mm} = 546.41\ MPa$$

Calculation of the tensile strength:

$$f_t = \frac{F_{max}}{A} = \frac{3247.6\ N}{242.59\ mm^2} = 13.39\ MPa$$

Dextrin

Sample 1
Calculation of the E-modulus:

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l} = \frac{472.50\ N \times 80.00\ mm}{240.00\ mm^2 \times 0.342\ mm} = 460.50\ MPa$$

Calculation of the tensile strength:

$$f_t = \frac{F_{max}}{A} = \frac{1575.0\ N}{240.00\ mm^2} = 6.56\ MPa$$

Sample 2
Calculation of the E-modulus:

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l} = \frac{425.52\ N \times 80.00\ mm}{240.20\ mm^2 \times 0.539\ mm} = 262.90\ MPa$$

Calculation of the tensile strength:

$$f_t = \frac{F_{max}}{A} = \frac{1418.0\ N}{240.20\ mm^2} = 5.90\ MPa$$

Sample 3
Calculation of the E-modulus:

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l} = \frac{513.84\ N \times 80.00\ mm}{240.00\ mm^2 \times 0.334\ mm} = 512.80\ Mpa$$

Calculation of the tensile strength:

$$f_t = \frac{F_{max}}{A} = \frac{1712.8\ N}{240.00\ mm^2} = 7.14\ MPa$$

Silicate

Sample 1
Calculation of the tensile strength:

$$f_t = \frac{F_{max}}{A} = \frac{930.34\ N}{237.18\ mm^2} = 3.92\ MPa$$

Sample 2
Calculation of the E-modulus:

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l} = \frac{314.04\ N \times 80.00\ mm}{237.18\ mm^2 \times 0.375\ mm} = 282.47\ MPa$$

Calculation of the tensile strength:

$$f_t = \frac{F_{max}}{A} = \frac{1046.8\ N}{237.18\ mm^2} = 4.41\ MPa$$

Sample 3
Calculation of the E-modulus:

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l} = \frac{307.11\ N \times 80.00\ mm}{237.18\ mm^2 \times 0.274\ mm} = 373.61\ MPa$$

Calculation of the tensile strength:

$$f_t = \frac{F_{max}}{A} = \frac{1023.7\ N}{237.18\ mm^2} = 4.32\ MPa$$

The summarized results for each of the materials

Table 9.1: The summarized results for Biotack

BIOTACK	MAXIMUM LOAD	YOUNGS MODULUS	TENSILE STRENGTH
Sample 1	2678.9 N	609.8 MPa	10.9 MPa
Sample 2	2766.4 N	653.6 MPa	11.4 MPa
Sample 3	3247.6 N	546.4 MPa	13.4 MPa

Table 9.2: The summarized results for Dextrin.

DEXTRIN	MAXIMUM LOAD	YOUNGS MODULUS	TENSILE STRENGTH
Sample 1	1575 N	460.5 MPa	6.56 MPa
Sample 2	1418 N	262.9 MPa	5.90 MPa
Sample 3	1712.8 N	512.5 MPa	7.14 MPa

Table 9.3: The summarized results for

SILICATE	MAXIMUM LOAD	YOUNGS MODULUS	TENSILE STRENGTH
Sample 1	930.34 N	-	3.92 MPa
Sample 2	1046.8 N	282.47 MPa	4.41 MPa
Sample 3	1023.7 N	373.61 MPa	4.32 MPa

9.5 Contact angle and wetting properties trial

The results from the contact angle and wetting properties trial will be divided into two parts, the measurements of the contact angle and the swelling of the material.

Measurements of the contact angle

The results from the contact angle measurements are presented below in figure 9.4, figure 9.5 and figure 9.6. The three next figures show the individual contact angle results from each of the test samples versus the absorption time for each of the material mixtures.

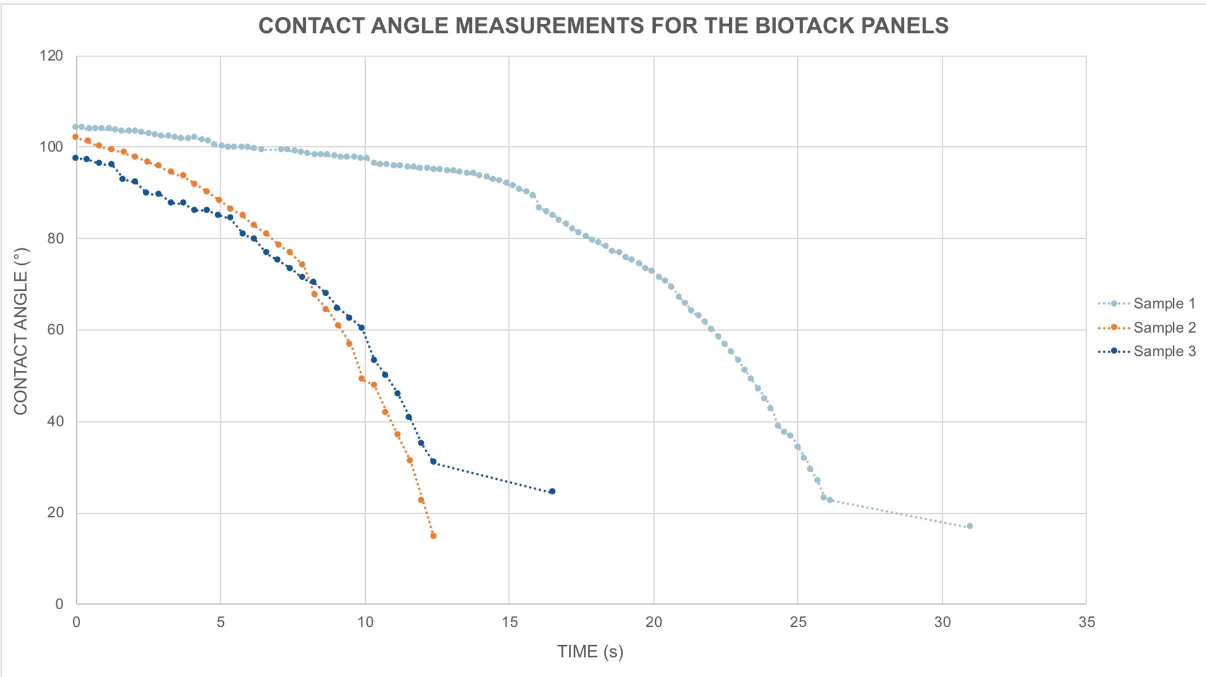


Figure 9.5: The contact angle measurements versus time for the three trials completed with the Biotack mixture.

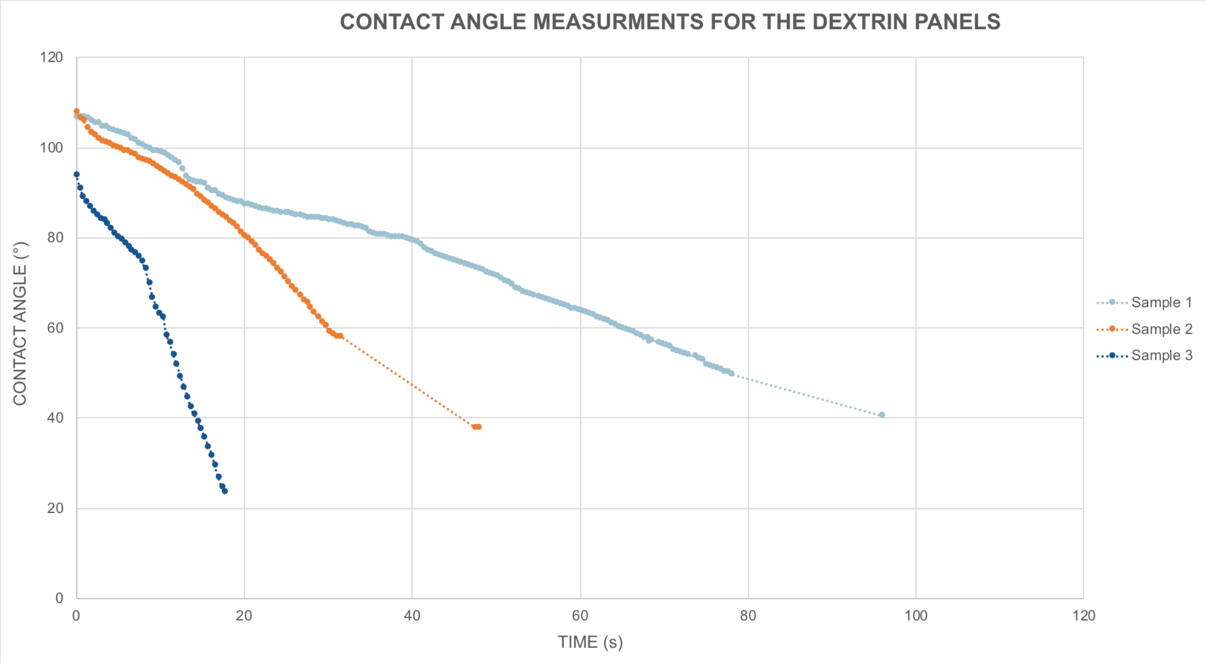


Figure 9.6: The contact angle measurements versus time for the three trials completed with the Dextrin mixture.

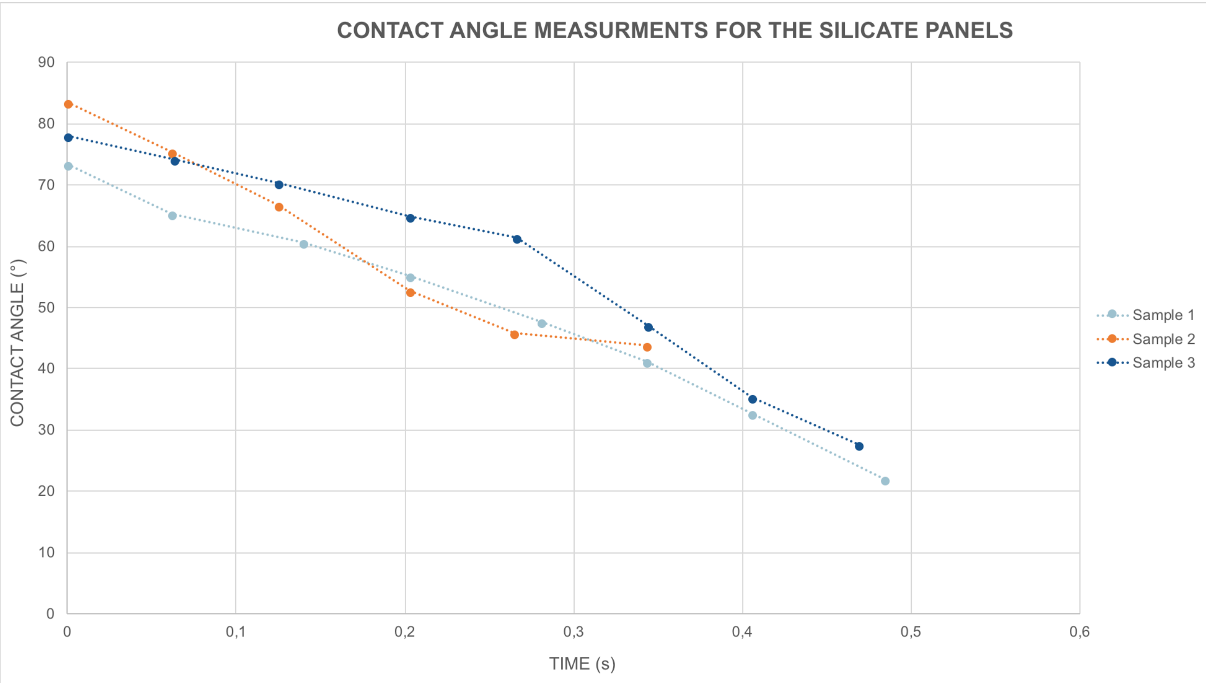


Figure 9.7: The contact angle measurements versus time for the three trials completed with the Silicate mixture.

Material swelling

The results from the material swelling are presented below in figure 9.7, figure 9.8 and figure 9.9. The swelling is caused by the water absorption in relation to the contact angle trial and varies greatly between the material mixtures.

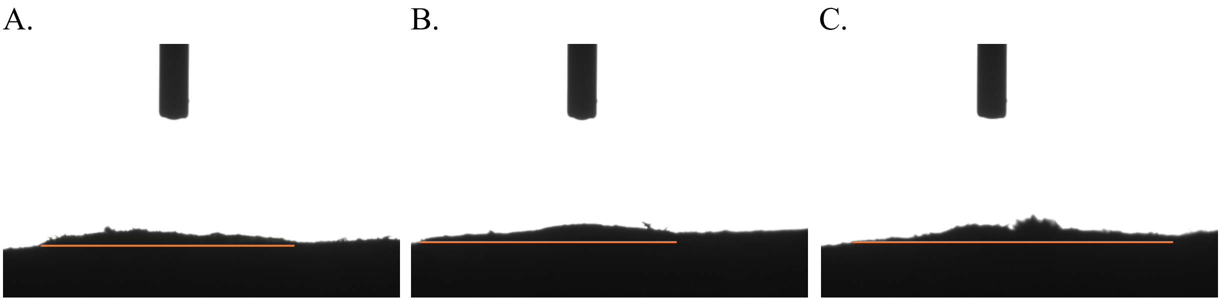


Figure 9.8: The material swelling due to the water drop placed on the surface of the panel with Biotack in the material mix. The swelling is marked by an orange line in each picture. ***A)*** *The swelling from trial one.* ***B)*** *The swelling from trial two.* ***C)*** *The swelling from trial three.*

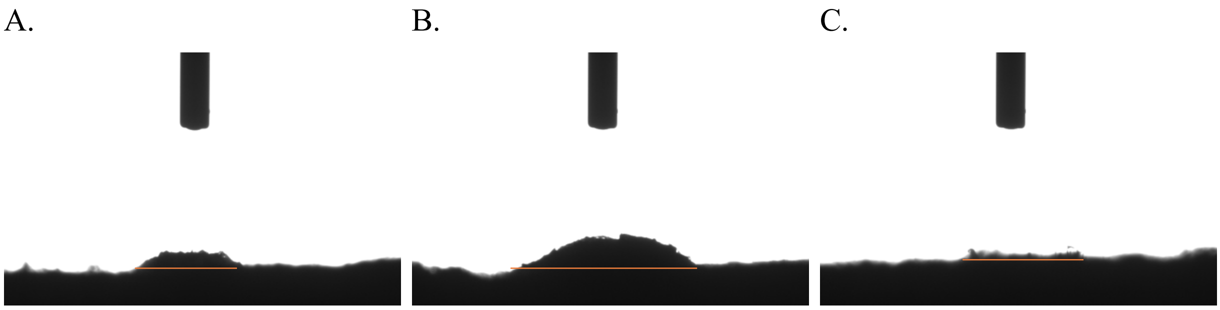


Figure 9.9: The material swelling due to the water drop placed on the surface of the panel with Dextrin in the material mix. The swelling is marked by an orange line in each picture. ***A)*** *The swelling from trial one.* ***B)*** *The swelling from trial two.* ***C)*** *The swelling from trial three.*

Figure 9.10: The material swelling due to the water drop placed on the surface of the panel with Silicate in the material mix. The swelling is marked by an orange line in each picture. ***A)*** *The swelling from trial one.* ***B)*** *The swelling from trial two.* ***C)*** *The swelling from trial three.*

9.6 Surface roughness trial

The results from the surface roughness trial are presented below in figure 9.10 and figure 9.11. The figures show the average of 18 samples for each of the material mixture. The first figure shows the result of the Ra measurements with a 95% confidence interval, while the second figure shows the results of the Rz measurements with a 95% confidence interval.

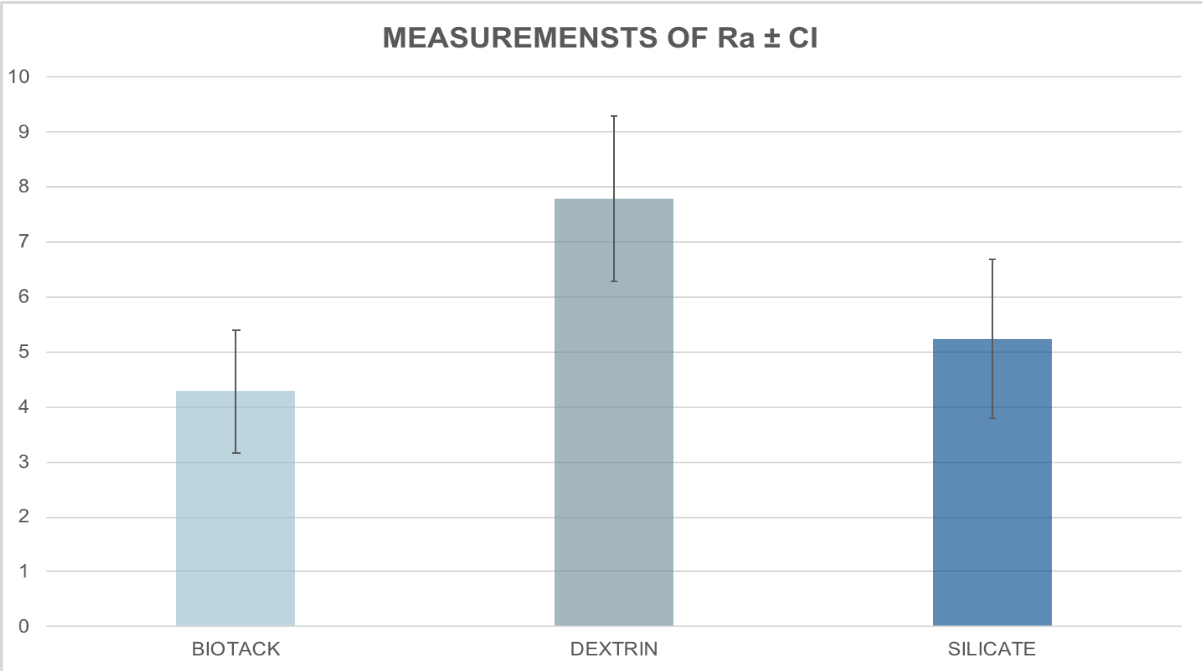


Figure 9.11: The average of the Ra measurements with a 95% confidence interval for each of the material mixtures.

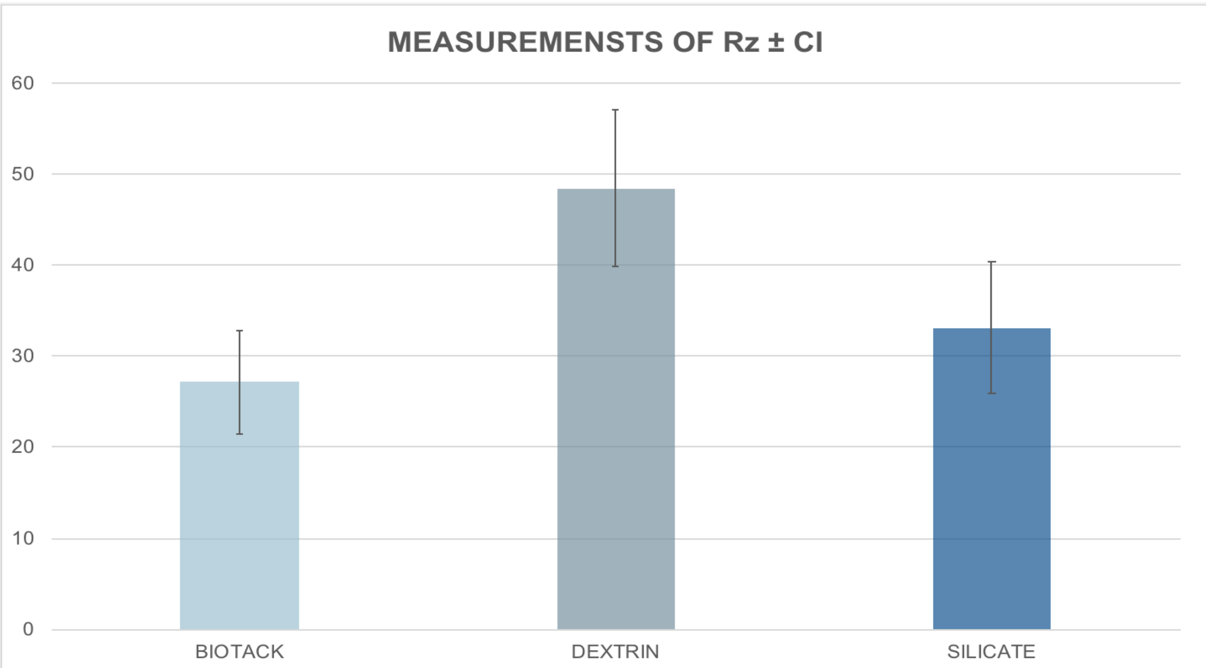


Figure 9.12: The average of the Rz measurements with a 95% confidence interval for each of the material mixtures.

The results of both the Ra and Rz measurements where run through an ANOVA analysis to check if the measurements are statistically different or not.

The analysis can be found in attachment 5. The Ra measurements shows that there are a statistically difference in every scenario, except for the comparison of Biotack and Silicate, which are not statistically difference. The Rz measurements the same results as the Ra measurements in the ANOVA analysis.

9.7 Discussion of the results

The tension properties trial indicates that Biotack is the material that can withstand the highest load before reaching the breaking point, which contributes to the highest Elasticity modulus and tensile strength. Within each of the material mixtures, there is a great variation between the results. To achieve a more concentrated result it would be preferable to conduct a higher amount of trials, if the material was to be further developed in the future.

The contact angle measurement trial shows that both the Biotack and Dextrin mixtures starts out hydrophobic but ends up hydrophilic. They are also the two mixtures with the slowest absorption rates, where Dextrin has the absolute slowest absorption. The Silicate mixture is hydrophilic from the start and has the shortest absorption time.

The contact angle trial also revealed that material swelling is an effect of the measurements taken. The swelling related to the Biotack mixture is more widespread and swells over a larger area, but don’t swell that much compared to the Dextrin mixture. The swelling seen on the panels with the Silicate mixture resembles the swelling of the Biotack mixture, but the area is more concentrated. For the Dextrin panels, the swelling is more concentrated and swells in height instead of spreading to a larger area. When the swelling is compared with the measurements of the contact angles, the trials with the longest absorption rate swell more concentrated and swells in height instead of width.

The surface roughness measurements, both Ra and Rz, indicate that the Biotack panel has the smoothest surface of the three mixtures and that Silicate panel is quite similar to the Biotack panel. Which indicates that the Dextrin panel has the roughest surface. An ANOVA analysis of the Ra measurements for all the mixtures, shows that statistically there is a difference between the panels, when a confidence interval of 95% is used. But if they are compared one to one in an ANOVA analysis, there is not a statistical difference between the Biotack panel and Silicate panel. The same results apply to the Rz measurements.

When looking at the contact angle measurements and swelling in relation to the surface roughness, the panel with the longest absorption rate is also the panel with the roughest surface and highest swelling. Which indicates that the swelling is somewhat related to the surface roughness.

All in all, the Biotack mixture stands out as the strongest panel with the smoothest surface and an absorption rate that is preferable over the silicate panel. Even though the Dextrin panel has a slower absorption rate, the amount of swelling is not preferable.

10 ROBUSTNESS, MAINTENANCES AND RECYCLING

An important part of this thesis is environment and recycling. More specific, the focus of creating value out of waste paper through the production of furniture. The robustness and quality of the product effects the product´s lifetime but also the environment. Through an analyzation of the robustness, maintenance and environmental effects of the product a great understanding of how long the product will live and how it can be recycled is created.

10.1 Robustness

That the chair is robust enough to withstand the forces applied in the worst-case scenario, is important. Based on the calculation preformed in chapter 6.3 with some adjustments for the new chair dimensions form chapter 8.2 and the tensile strength found in chapter 9.4, will the chair be checked through simplified hand calculation, if the stresses working in the chair is within the allowed stress for the material that will be used in the chair. Since the calculations are simplified, will the angle of the seat and backrest not be calculated for. The footrest is also excluded from the calculations.

The forces working from the person on the seat and backrest are still the same as in chapter 6.3. The reaction forces on the x-axis is also the same as in chapter 6.3.

$$F_{backrest} = 667.1\ N$$

$$F_{seat} = 2430.5\ N$$

$$F_{Ex} = 667.1\ N$$

Reaction forces y-axis

$$(F_{yD} \times 380mm) + (\ F_{seat} \times 190\ mm) - (F_{backrest} \times\ 885\ mm) = 0$$

$$F_{yD} = \frac{-(2403.5\ N \times 190\ mm) + (667.1\ N \times 885\ mm)}{380\ mm}$$

$$F_{yD} = 351.9\ N$$

$$F_{yD} - F_{seat} + F_{yE} = 0$$

$$F_{yE} = \ -351.9\ N + 2430\ N$$

$$F_{yE} = 2078.1\ N$$

Since there are four legs, and the front and back legs are calculated separately all the reaction forces need to be divided by two.

$$F_{Ex} = \frac{667.1\ N}{2}$$
$$F_{Ex} = 333.6\ N$$

$$F_{yD} = \frac{351.9\ N}{2}$$
$$F_{yD} = 176.0\ N$$

$$F_{yE} = \frac{2078.1\ N}{2}$$
$$F_{yE} = 1039.5\ N$$

Moment in B

$$M_{BC} - (1039.5\ N \times 0.19\ m) + (176.0\ N \times 0.38\ m) = 0$$

$$M_{BC} = 130.6\ Nm$$

$$M_{BA} - (333.6\ N \times 0.455\ m) = 0$$

$$M_{BA} = 151.8\ Nm$$

$$M_B = M_{BC} + M_{BA}$$

$$M_B = 130.6\ Nm + 151.8\ Nm$$

$$M_B = 282.4\ Nm$$

Stress in the legs

$$\sigma_{Front} = \frac{F_{yD}}{A} \qquad (2)$$

$$\sigma_{Front} = \frac{176\ N}{(40 \times 40)mm^2}$$

$$\sigma_{Front} = 0.11\ N/mm^2$$

$$\sigma_{Back} = \frac{F_{yE}}{A} \qquad (2)$$

$$\sigma_{Back} = \frac{1039.5\ N}{(40 \times 40)mm^2}$$

$$\sigma_{Back} = 0.65\ N/mm^2$$

Shear stress in the backrest

$$\tau = \frac{V}{A} \qquad (3)$$

$$\tau = \frac{667.1\ N}{(40\ \times\ 400)mm^2}$$

$$\tau = 0.0416\ N/mm^2$$

Bending moment

$$\sigma_b = \frac{M_b}{W_b} \tag{4}$$

$$\sigma_b = \frac{282400\ Nmm}{\frac{bh^2}{6}}$$

$$\sigma_b = \frac{282400\ Nmm}{\frac{(40mm \times 455^2 mm)}{6}}$$

$$\sigma_b = 0.205\ N/mm^2$$

Allowed stress for the Biotack mixture.
Since the chair is calculated for 2.5 persons, is the safety factor n = 3 and $R_m = 11.4\ MPa$

$$\sigma_{till} = \frac{R_m}{n} \tag{12}$$

$$\sigma_{till} = \frac{11.4}{3} = 3.8\ MPa$$

Based on the allowed stress for the Biotack mixture, are all the stresses within requirement and the chair will withstand the forces that is applied. It is recommended that this is double checked through a FEM analysis.

10.2 Maintenance

The material chosen for this product easily soaks up water or other liquids if it is spilled on, because of this it is important to protect the material and make it more sustainable through either laminating or coating the chair. There can also be added a water-resistant component into the material mixture.

When the paper-based material is protected, the maintenance and cleaning of the chair would require minimal attention and the chair should only be inspected now and then to look for damages in the sealing of the chair. If the paper-based material is not protected against liquids, the chair should only be dusted off and not have contact with water. The chair would also require regular maintenance to ensure that the structure hasn't been weakened by liquid spills.

10.3 Recycling

Recycling and creating a green product is an essential part of this thesis, since a part of the goal for the product is to make the chair from recycled paper. Another part of the goal is also to ensure that the chair and a major part of the product´s components will be recyclable at the end of its life. Based on this it is desirable to create an environmental-friendly production as possible and to design waste out of the system, which contributes to a positive impact.

A big part of developing and producing a product is also how the product is going to be processed at the end of its life. To ensure that the chair will be produced and processed in the best way possible a set of requirements have been established. Requirements for the product and the processing of the product:

- The chair will be produced from recycled paper and will be recycled at end of life.
- The lamination, coating or other elements added to the final chair or product mixture should be recyclable at end of life and preferably come from recycled products.
- To ensure an environmental-friendly production process as far as its possible. This can be done through the use environmental-friendly chemicals and renewable energy.

When recycling the chair, it will be necessary to take the chair apart and sort the different parts, to ensure that they will be recycled within their respective areas and not as mixed waste.

11 MANUFACTURING AND PRODUCTION COSTS

When developing a product, it is important to look into all of the different aspects of a product. From the very start, where the idea is molded, to the end, where the manufacturing and economics are considered. The different ways a product can be produced, effects both the scalability of the production and the cost of the product, which in the end will affect the potential market for the product and costumer. Through a cost calculation of the production, a rough cost estimate for the product price is established.

11.1 Production methods

The production method used to produce a product effects the production time, the production quanta and the production quality of the end product. The production method also effects the price of the product. The goal is to have a production with low production costs and that delivers a product of high quality. The paper-based chair can be produced through the use of different methods, where the parts either is produced as panels and manufactured into the desired shape or produced through the use of a cast or several moulds. There is also a choice between a water based or water free production.

The selected production method

The method for this thesis is already selected and thoroughly explained in chapter 3.3, based on the material produced for and tested in this thesis. In short, it is a waterless production method which produces paper-based panels through shredding the paper in a hammer mill, followed by mixing the glue into the mixture using a tumble-dryer and then shaping the plate using a mold before pressing them with a heat press. This process would be great for producing smaller prototypes, but for larger production quanta the production process would need to be scaled up. The tumble-dryer and the heated press would need to be redesigned to be able to handle larger batches of the paper mixture and be able to press larger panels. This method has only been tested for panel production.

Other production methods

Paper-based materials can also be produced in several other ways. For the production of furniture, a production processes which includes the use of paper-pulp would also be a good solution. In this process the waste paper is processed into pulp and can then be formed into the desired shape of the product. The shape ability of the pulp depends on how much water is added to the mixture. It can also be pressed into panels with a heated press or cold press. This method is easy to scale up, but the down side is that it uses a lot of water.

Assembly method for the chair

After the elements of the chair is produced, the next step in the production line is the assembly of the chair. This can be done in several ways and some of them are listed below.

Screws

A standard assembly method where screws and bolts are used hold the chair together. This is a simple method that is easy to implement.

Glue
Through this assembly method the chair is assembled by the use of construction glue. The method is simple but requires a high level of precision when assembling the chair due to that there are no retakes, when the chair is assembled.

Screw-less assembly
In this assembly method the chair is designed so the parts are slotted into each other like a building set. This requires a redesign of the chair and is not relevant for this thesis but is an option for another production. The assembly method is inspired by the paper furniture developed by Studio Job for Moooi.

11.2 Economic considerations

A cost calculation presents an estimate for the hours and costs connected to the thesis work and the costs of a potential prototype development of the chair or further development of the material.

The costs related to the early development of the idea, which is completed in Ethiopia and the development of the material tested in the thesis is covered by Penda Manufacturing. The costs covered by Penda include the travel cost related to the trip to Ethiopia and Denmark, the development in Denmark and all other costs associated with the development. All costs are presented in Norwegian Kroners, NOK.

The estimate of hours presented in the cost calculation for the concept development is the hours put in by the author of the thesis for the work that is done to complete it. The hours related to the machining of the test rods is performed by a CNC operator, but is included in the cost calculation since it is a part of the concept development.

Table 12.1: Cost calculation for developing the concept.

CONCEPT DEVELOPMENT	HOURS	PRICE	TOTAL
Early idea development in Ethiopia	40	600 kr	24 000 kr
Material development in Denmark	40	600 kr	24 000 kr
Assessment work	150	600 kr	90 000 kr
Concept specification	90	600 kr	54 000 kr
Function and design development	100	600 kr	60 000 kr
3D modeling	100	600 kr	60 000 kr
Machining of test rods	10	600 kr	6 000 kr
Lab work	80	600 kr	48 000 kr
Reporting	300	600 kr	180 000 kr
SUM	**910**		**546 000 kr**

The cost calculation for potentially developing a prototype of the chair is based on developing the prototype at the Technical Institute in Denmark. The post, traveling costs, include the cost of airplane tickets, living accommodation, transportation and food. The total costs of a potential prototype development will be covered by Penda if they choose to continue the project.

Table 12.2: Cost calculation for developing a prototype of the chair.

PROTOTYPE DEVELOPMENT	HOURS	PRICE	TOTAL
Technical institute in Denmark*	-	39 000 kr	39 000 kr
Materials**	-	5000 kr	5 000 kr
3D modeling	20	600 kr	12 000 kr
Traveling costs***	-	13 450 kr	13 450 kr
SUM	**20**		**69 450 kr**

*The price is collected from the Technical Institute in Denmark and equals one week of rent, which includes personnel, equipment, material in addition to the Ethiopian paper, and lunch.
**The price is an estimate of the transport cost for the material from Ethiopian to Denmark.
*** The price is an estimate based on prices for hotel, transportation and airfare collected from momondo.no and an estimate of food costs based on Danish prices.

Since developing a prototype isn't the only option going forward, a cost calculation for further development of the material is presented. The calculation is based on that the development will take place at the Technical Institute in Denmark. The post traveling costs include the cost of airplane tickets, living accommodation, transportation and food. The total costs with the further development of the material will be covered by Penda if they choose to continue the project.

Table 12.3: Cost calculation for further development of the material.

MATERIAL DEVELOPMENT	HOURS	PRICE	TOTAL
Technical institute in Denmark*	-	39 000 kr	39 000 kr
Materials**	-	5 000 kr	5 000 kr
Research	50	600 kr	30 000 kr
Traveling costs***	-	13 450 kr	13 450 kr
SUM	**50**		**87 450 kr**

*The price is collected from the Technical Institute in Denmark and equals one week of rent, which includes personnel, equipment, material in addition to the Ethiopian paper, and lunch.
**The price is an estimate of the transport cost for the material from Ethiopian to Denmark.
*** The price is an estimate based on prices for hotel, transportation and airfare collected from momondo.no and an estimate of food costs based on Danish prices.

12 PROCESS EVALUATION AND DISCUSSION

The process of writing a thesis is a development process. Through the evaluation and discussion of the self-effort put into the thesis, the work processes, the methodology that is used and how the work has been executed, is a foundation for a great learning outcome. The evaluation of the process is divided into three parts and covers the work process, the experiments and the design.

12.1 Evaluation of the work process

Obtaining information

The idea and main objective for the thesis was established quite early in the process, which guided the direction of the literature study. The literature study was started at the same as the report writing and showed to be more time consuming than initially assumed. The obtaining information regarding manufactures of paper furniture was hard to obtain at first, but after a series of searches and looking into unique designer's, relevant information was found. Obtaining information related to the theory and technology chapter was the part of the literature study that was most time consuming and was worked on throughout the thesis. This was due to lack of knowledge regarding the extensiveness of developing a good chair. The process of obtaining information created a great learning outcome and a solid foundation for the thesis but should have been started and completed earlier in the work process.

Methodology

The methodology related to product development and the use of methodology, was a well-known area due to the work completed in an earlier university course, TIP 300, Concept and product realization. While the field of experimental methodology related to material testing was a relatively unknown area, due to little experience within the field during the years of study. A lot of time was used to gather information about the different methodologies and on how the trials could be executed. This lead to a postponement of the trials.

Concept development

The process of developing the concept has been an interesting and exciting experience, with a great learning outcome. The framework for the product development was open and the only requirement that was set prior to the start of the development process, was that the product would be produced from the paper panels made in Denmark. Based on the dream to develop school furniture in collaboration with the UN, the choice was made to develop the concept around a chair for school use and the age group 12-35 years-old. This required an extensive literature study as mention under "obtaining information" and was completed alongside the development of the concept. The analysis and screening of the alternatives for strengthening the seat of the chair should have focused on the possible loads a chair would be put through in addition to the focus points at hand. This would have established a stronger foundation for the selected alternative.

Further development of the concept

The calculations preformed for the robustness of the material is extremely simplified and should be calculated in depth. The chair should also be processed through a FEM analysis to confirm the hand calculations or show the differences. The maintenance of the chair, should be looked into to find a sustainable solution that will require minimal maintenance and cleaning. The focus on recycling has been a big part of the thesis and when the potential product reaches the end of its life, it is excepted that every part of the product is recyclable. The production method for the product was decided before the thesis was started and was one of few requirements that was set.

The economic considerations for the concept development is based on the hours put into the thesis, while the prototype development and further development of the material is based on prices gathered form the Technical Institute and the traveling costs related to both the paper and the individuals that will be working on the project.

12.2 Evaluation of the experimental trials

According to the work plan the experimental trial were supposed to be performed between the February 26 and March 25. Due to the delays caused by gathering information for the literature study and about the selected trials the test period was postponed and completed between March 20 and April 20.

The preparation of the tension properties trial, offered some unforeseen problems with the material at hand. This resulted in that three out of seven material mixtures were tested. Two of the material types required test piece dimension that was so small that special testing equipment would have had to be developed to perform the trial, due to an uneven stock of material sizes. While the other two materials were too fragile to be shaped into test pieces.

The testing of the tension properties in itself gave good result. When the result was to be retrieved from the computer, something had failed in the process of saving the files and the original test result were lost. But during the completion of the trial, the results had been recorded in a separate excel file and pictures of 8 out of 9 results had been taken, which resulted in that only one of the samples load-extension diagrams was lost. This should and could have been avoided through a better routine while collecting and saving the results. The intended calculations could still be completed.

The contact angle and wettability trial were completed without any challenges, the same goes for the surface roughness trial. To get a more conclusive result within the contact angle trial, a higher number of samples should have been available, than the established requirement of three samples per material.

12.3 Evaluation of the design

The chair design was developed through a concept generation and screening where both SCAMPER and Pugh´s methodology was used, which was discussed under chapter 12.1, Evaluation of the work process. Few restrictions were set for the concept development, but the design was to fit the production method, the selected age group and the task it was selected to perform.

When the selected concept was visualized through SolidWorks, the design wasn't aesthetically pleasing. Based on this, it was decided to enhance the design through enhancing the chairs aesthetics and creating solution that fitted the production method better. Ergonomics and anthropometrics require a deeper understanding than what was obtained during the thesis work, based on this knowledge the chair design should be user tested and further developed to ensure that the chair is designed for the task it is going to perform.

13 CONCLUSION

The main objective for this thesis is to investigate, develop and test a solution for the use of recycled paper as the main component in the production of furniture in Ethiopia. This was to be accomplished through testing the selected material, and by developing and designing a concept for a chair produced from paper-based material. The work would show if the selected method is functional and whether the material is durable or not. Furthermore, a recommendation for the further work with the project will be given to Penda, based on the results from the thesis work.

Through the thesis work a concept design of a paper-based chair has been developed and experimental trials has been completed on the selected paper-based panels. The concept design resulted in a simple and functional chair for schools and educational centers, and for an age group between 12-35 years. The chair has a footrest to shorten the needed popliteal-length of the user, so the chair fits the youngest part of the age group. Further a frame was added to the design to strengthen and stabilize the seat of the chair. There were completed three different experimental trials to find the tension properties, the surface roughness and the contact angle and wettability of the paper-based panels. Three different panel mixtures were tested, which resulted in Biotack being the best mixture combination overall.

Through hand calculations it was confirmed that the selected material was strong enough to meet the load requirements of the chair. Based on these results, different recommendations will be presented under further work on how to precede with the project.

13.1 Results

The results of the thesis work are a collection of observations, experimental results and an evaluation of the design. The investigation, development and testing of a solution for the use of recycled paper in the production of furniture in Ethiopia has resulted in:

- **Dimensions of the chair:** To fit the selected age group, the chair frame has the following dimensions:
    - Seat height (front): 445 mm
    - Seat height (back): 430 mm
    - Seat width: 400 mm
    - Seat depth: 380 mm
    - Backrest height from the seat surface: 455 mm
    - Total height: 885 mm
    - Chair depth: 420 mm
    - The angle of the backrest: 5 °
    - The angle of the seat: 2.26 °

- **Seat support:** Through the use of SCAMPER and Pugh's methodology was the simple rectangular seat frame selected as the best concept. The solution was easy to implement and easy to adapt to the shape of the seat.

- **Footrest:** A single rectangular footrest was selected as the best concept for adapting a chair to a growing body. The footrest was easy to implement into the design of the chair. The concept was selected through the use of SCAMPER and Pugh´s methodology.

- **Chair design:** Through an inspiration of geometric shapes and the use of Pugh´s method the best concept was selected. When the selected chair concept was visualized through 3D-modeling in SolidWorks, the decision to alter the concept was made. The front edge of the seat and the front edge on the top of the backrest was rounded of. The backrest height was raised from 350 mm to 455 mm from the seat surface to make it more comfortable. The seat was also given an angle of 2.26 °. This was done to make the chair more aesthetic pleasing and to ensure enough support of the back for the user. At the finale design is also the seat support incorporated into the frame of the seat, and only has a visible reinforcement under the front of the seat.

- **Dimensions of the test piece for the tension properties trial:** To be able to conduct the trial to find the tension properties of the paper-based panels, test pieces of the different materials had to be dimensioned and machined. The test pieces were dimensioned to the following measurements, total length: 150 mm, gauge length: 80 mm, length between the end sections: 108 mm, length of the midsection: 60 mm, width of the end section: 30 mm, width of the midsection: 20mm and the radius: 60.

- **Tension properties trial:** Through testing the tension properties of each of the selected material mixtures, the Biotack mixture was the mixture that preformed best through the three trials. The Elasticity modulus was measured to 653.6 MPa, and the tensile strength was measured to 11.4 MPa.

- **Contact angle and wettability trial:** Through measuring the contact angle of sessile drops placed on the surfaces of each of the material mixtures, the Dextrin panels was the mixture with the slowest absorption rate. When evaluating the absorption rate in connection to the swelling, the Biotack mixtures are more preferable since the swelling is less concentrated than one the Dextrin panels.

- **Surface roughness:** The measurements from the surface roughness trials shows that the Biotack panels has the smoothest surface, but an ANOVA analysis show that there is statistically no difference between the, which is preferable if the panels will be coated or laminated.

- **Material:** As a result of the experimental trials, the Biotack mixture is selected as the material for the chair. The material was shown to be strong enough, through hand calculations, to withstand the maximum load requirements for the chair.

- **Production method:** The waterless production method for paper-based panels is selected for the further development of the material and the prototype. For further developing the material with the Technical Institute in Denmark, the cost per week is roughly calculated to 87 450kr (NOK). The cost of developing a prototype of the chair with the Technical Institute is roughly calculated to be 69 540kr (NOK).

13.2 Recommendations

If it is chosen to continue this project and further develop the material and the selected design concept for the chair, the following recommendation will be given:

- Experimental trials should be conducted to find the bending properties and compression properties of the Biotack material.
- The material should be further developed to withstand the different scenarios a chair can encounter. If the material is further developed, new material mixtures should be looked into, alongside new types of glues and the possibility to reinforce the material by using another material or by structuring the paper panels differently if needed.
- A prototype of the chair should be developed to ensure that the chair will withstand the calculated forces and a series of scenarios.
- The design concept of the chair should be user tested ensure that the chair is ergonomic and designed for the task it is supposed preform. The user test should be followed by further developing the design of chair based on the results from the user test.

13.3 Further work

The timeframe that is provided for the thesis, establishes limits and restrictions for this report. After the completion of the thesis work, it will be necessary to look into the areas of further developing the material and concept design. The various elements that may be in need of and have the potential for further work is:

- Assess the different production methods and establish if this, the waterless method, is the correct one for the company.
- Recalculate the hand calculations preformed in the thesis to ensure that they are correct.
- Preform a FEM-analysis of the chair with the Biotack mixture, to confirm the hand calculations performed in the thesis.
- Look into the assembly method for the chair, like screws, bolts, glue and pins, to assess what will be most sustainable for the area of use.
- Look into coating and lamination of the product.
- Look into the use of cushioning on the seat, to make the seat a bit softer and to distribute the weight of the person using it throughout the seat surface.
- Produce a new batch of material for further testing of the material properties, to ensure a product that is sustainable and durable. Suggested test are compression properties, bending properties and surface hardness.
- Further develop the material, by looking into the use of add-ins to make the material water repellent and to other glues if needed.
- Complete a new analysis of the alternatives for the strengthening of the seat of the chair, where the focus is on possible loads the chair will be put through, in addition to regular use.
- Further develop the chair design to ensure that the chair satisfies the anthropometric and ergonomic part of it, that the chair is designed for the task it will perform and also for the intended age group.
- Run a user test of the product to ensure that the product is designed for the task it will perform and that the chair concept is ergonomic.

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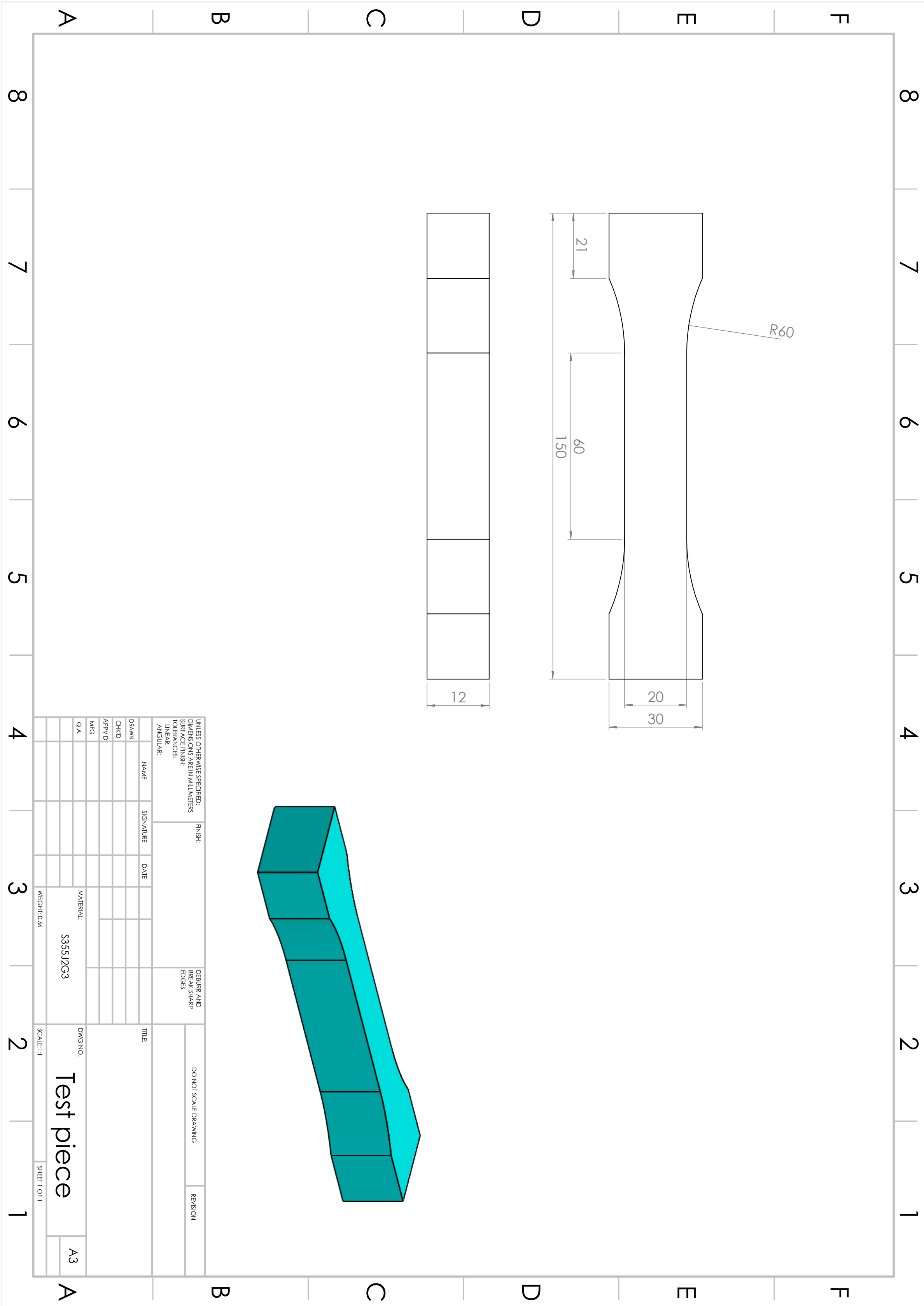
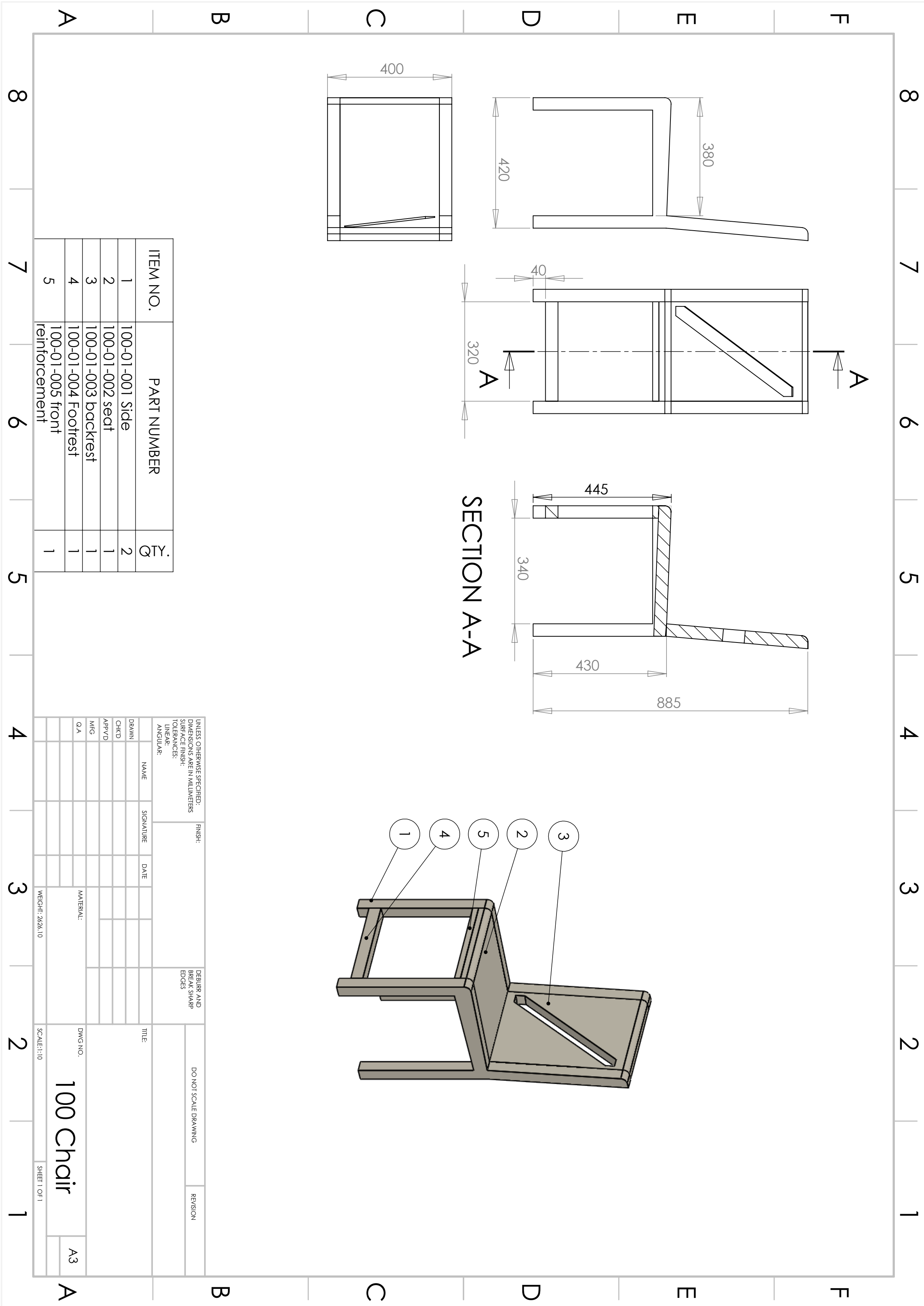
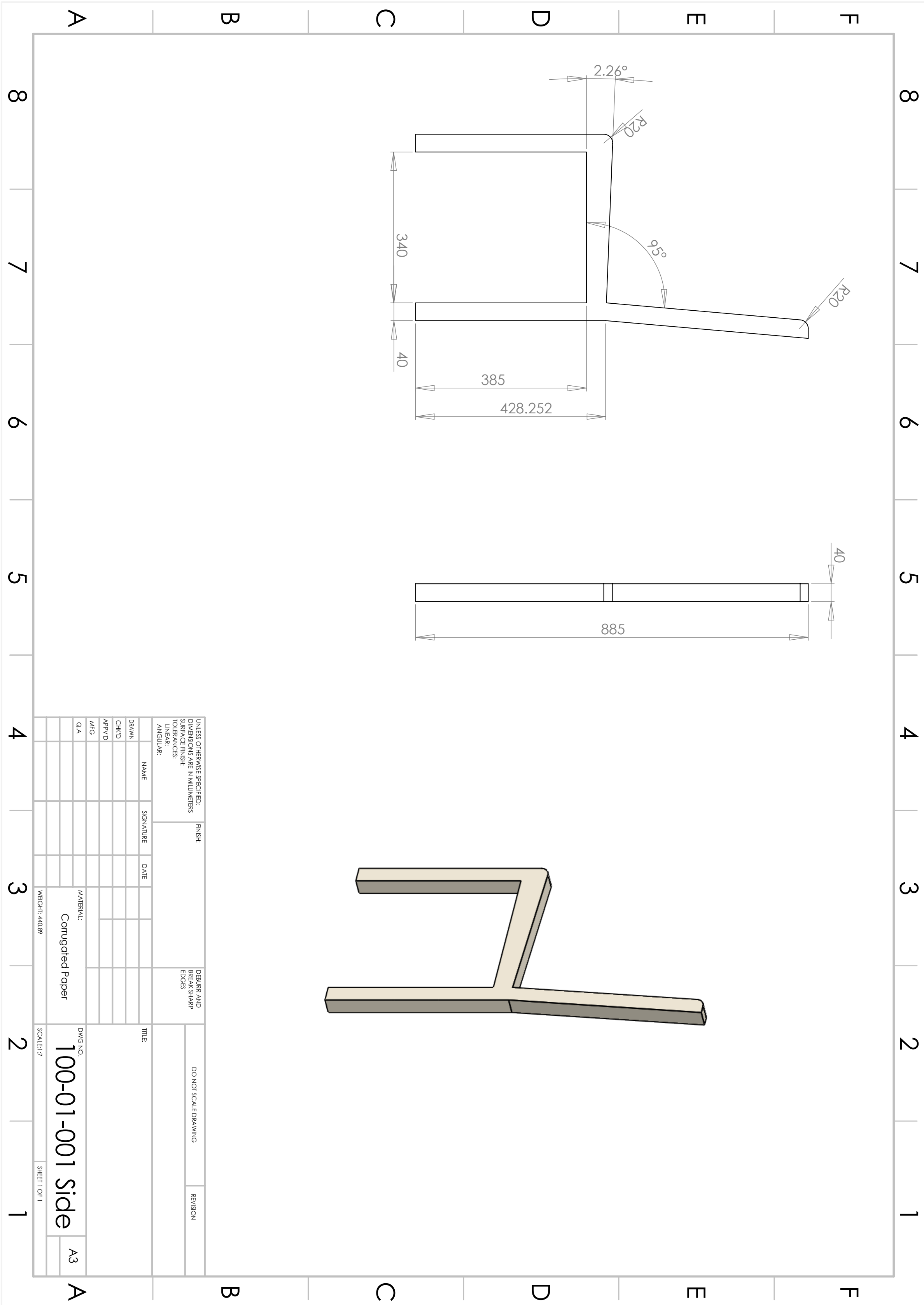
15 ATTACHMENTS

Attachment 1: ISO construction drawings of the test rods.



Attachment 2: ISO construction drawings of the chair.

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95°
R20
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TOLERANCES:
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ANGULAR:
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DEBURR AND BREAK SHARP EDGES
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NAME
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DATE
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CHK'D
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MFG
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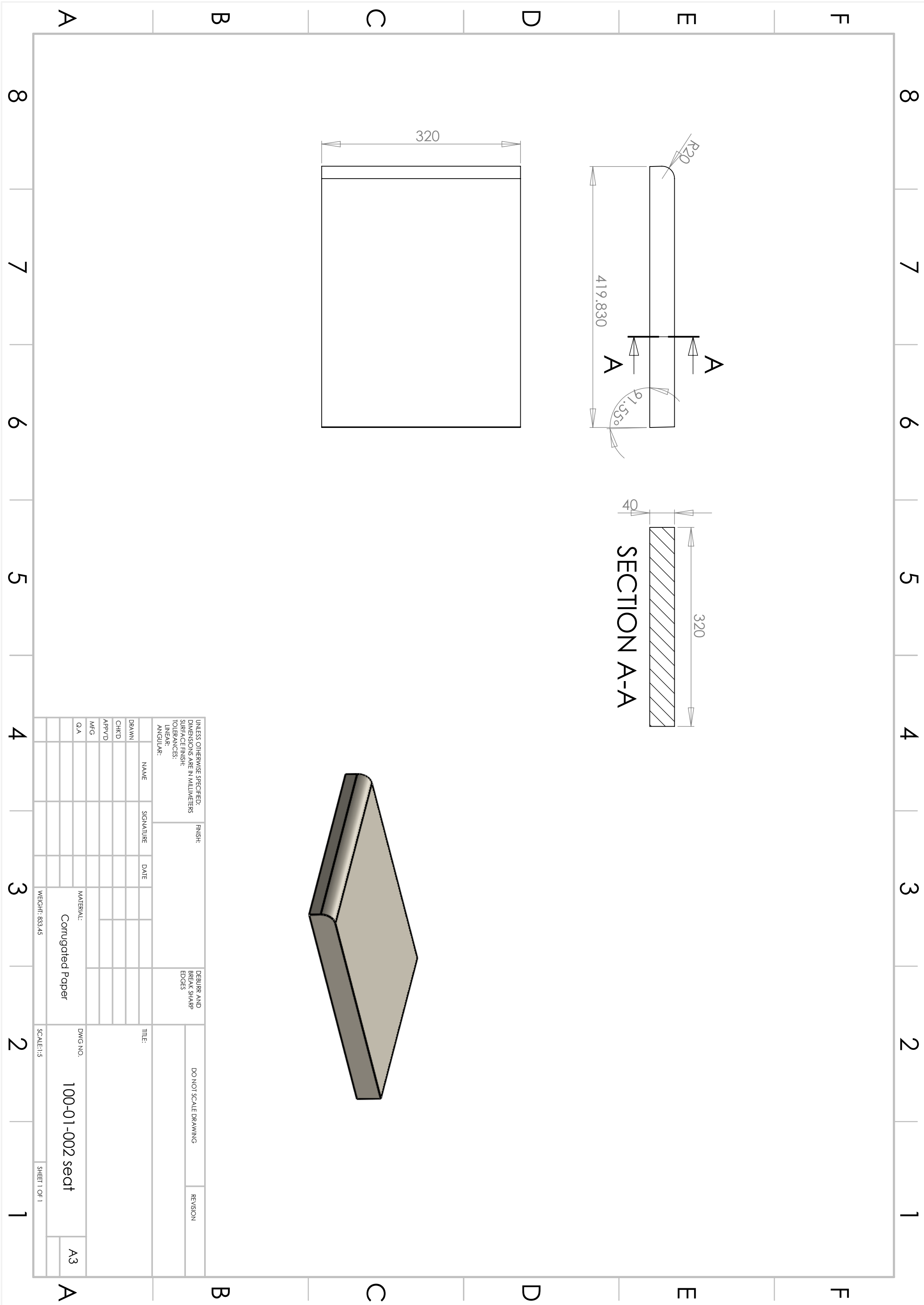
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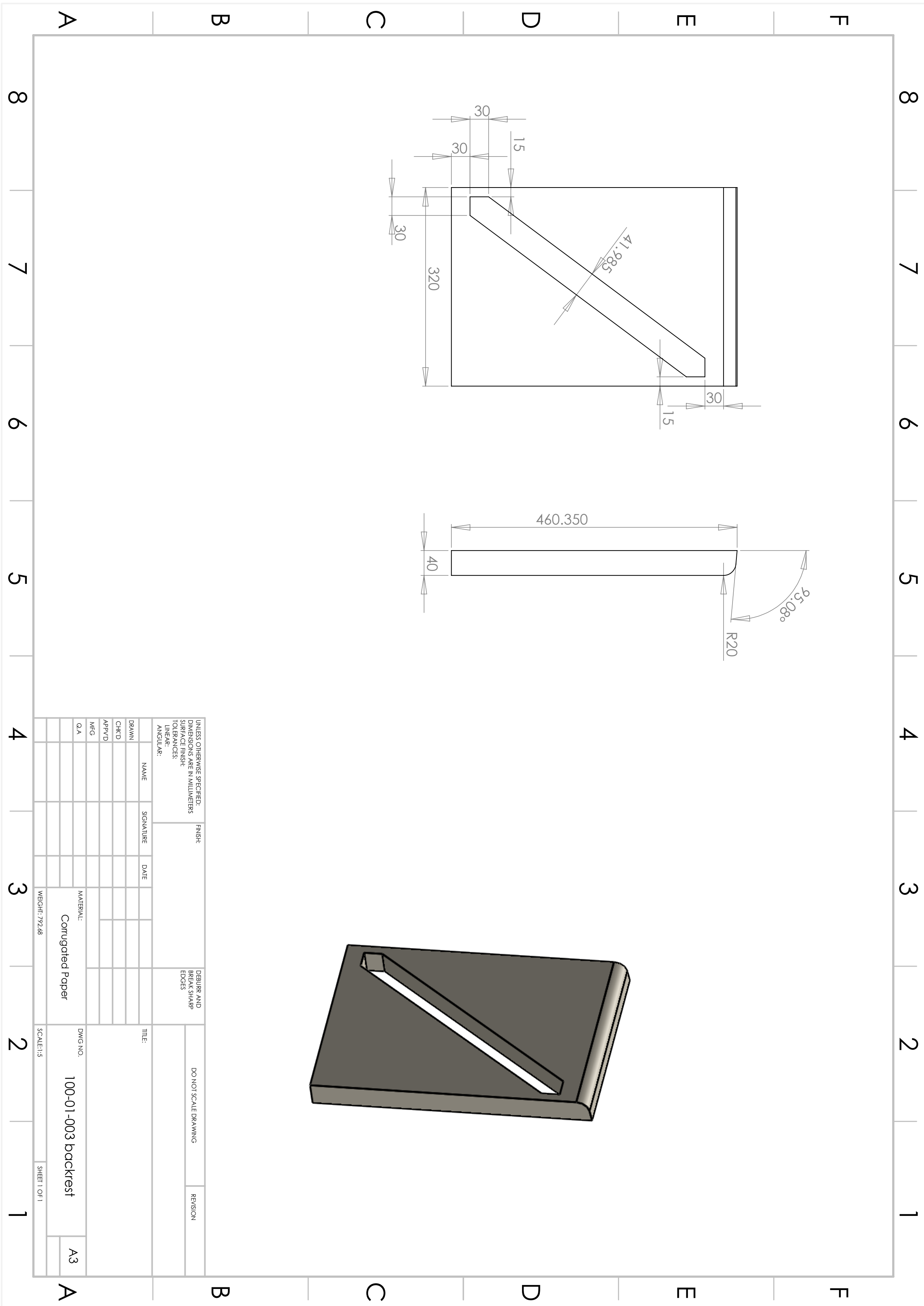
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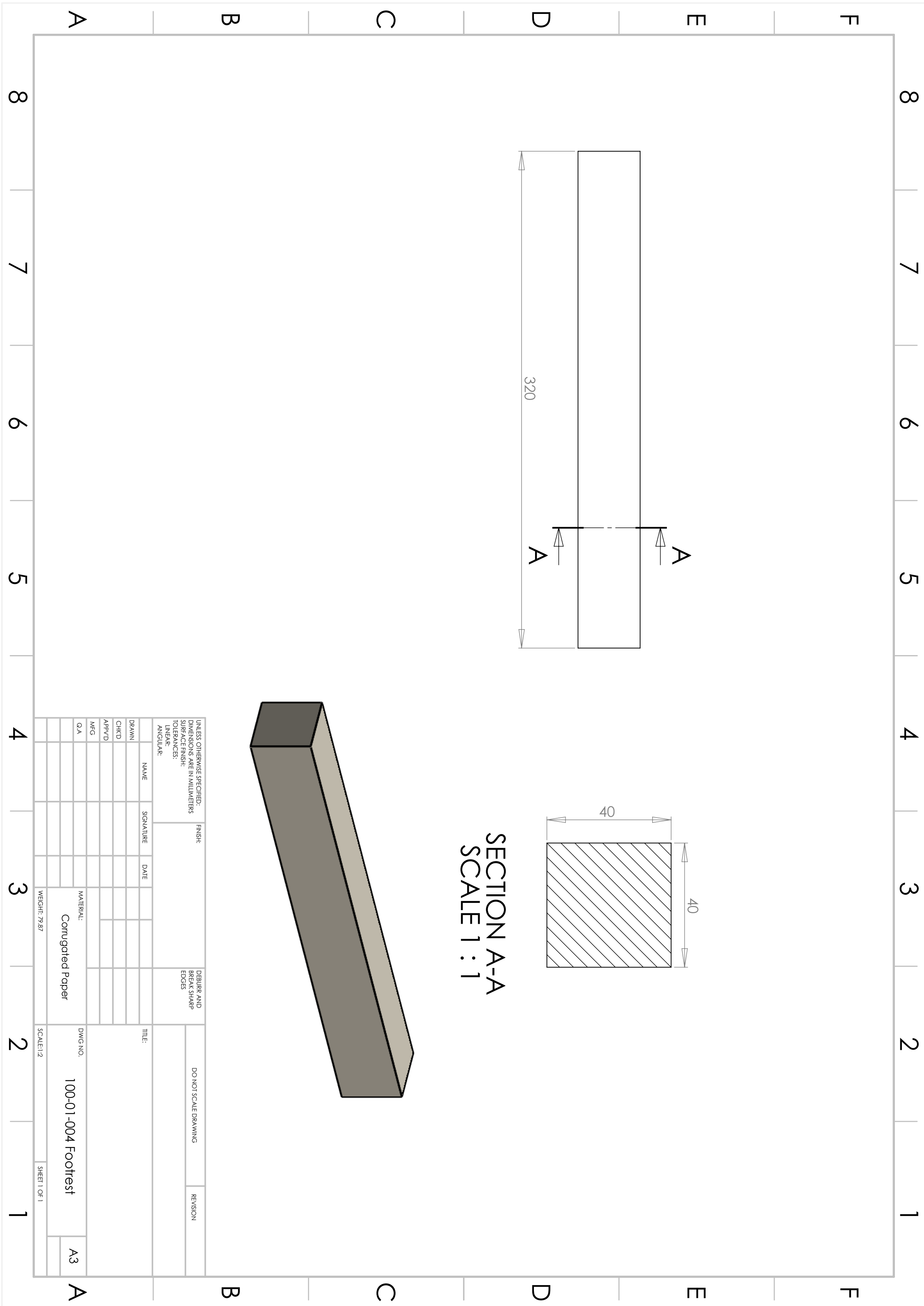
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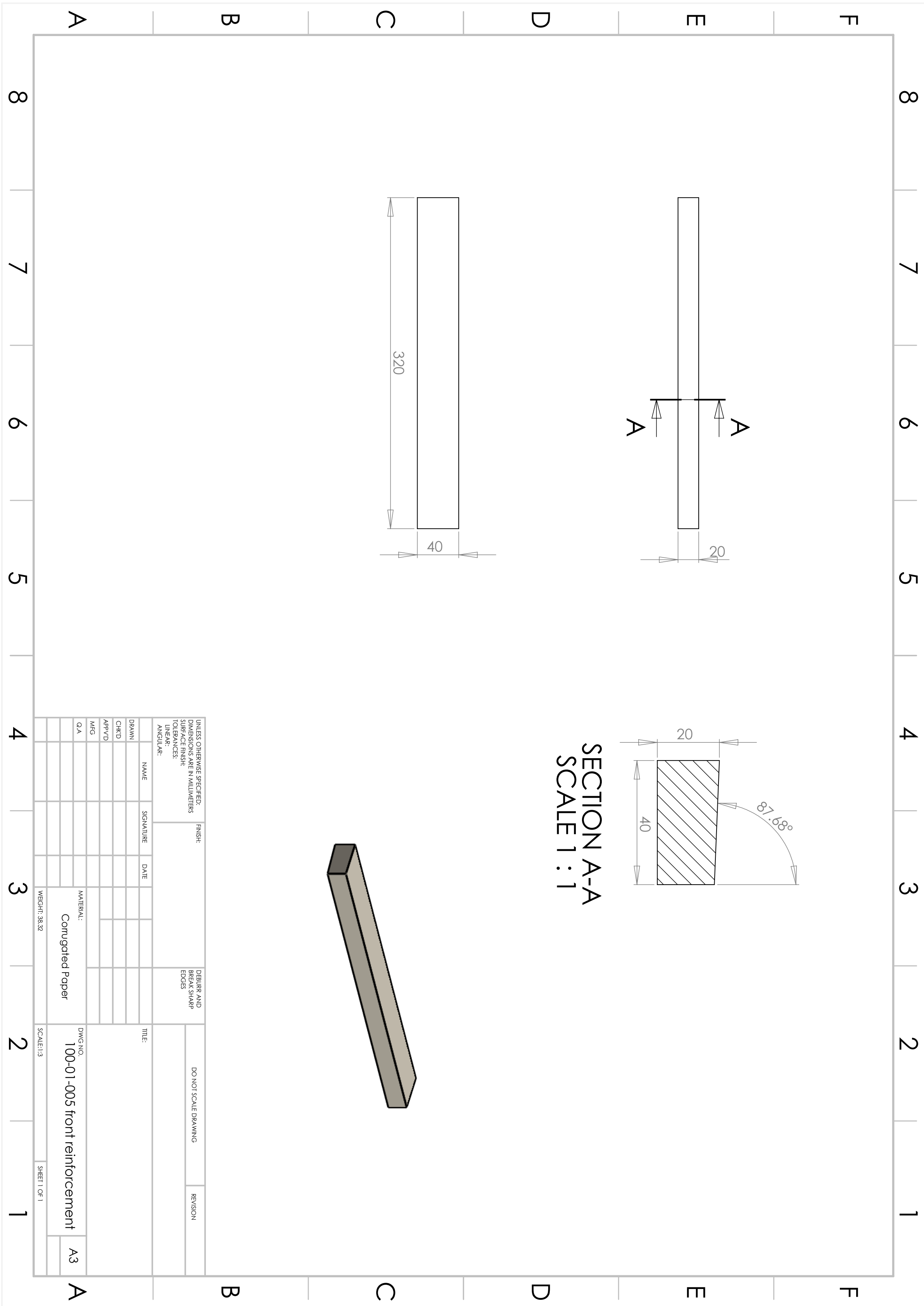
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NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
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TITLE:
DWG NO.
100-01-005 front reinforcement
A3
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SCALE:1:3
SHEET 1 OF 1

Attachment 3: Data collected from the contact angle measurements.

BIOTACK V1
Measureme CA-measurement
Device : DataPhysics OCA - Series
Customer : DataPhysics
Sample : Not Defined
Operator : nemi
Remarks : DataPhysics

Run-No	CA(M)[°]	IFT[mN/m]	Err[µm]	Vol[µL]	CA(R)[°]	CA(L)[°]	Age[ms]
1	104,31	0	0	166,27	104,34	104,29	14453
2	104,13	0	0	165,94	104,28	103,98	14688
3	103,79	0	0	165,88	103,95	103,63	14922
4	103,82	0	0	165,63	104,1	103,54	15141
5	103,86	0	0	165,55	104,22	103,5	15375
6	103,8	0	0	165,82	104,13	103,46	15610
7	103,52	0	0	165,52	103,91	103,14	15828
8	103,44	0	0	165,65	103,8	103,07	16063
9	103,34	0	0	165,76	103,94	102,74	16297
10	103,4	0	0	165,18	103,75	103,04	16516
11	103,11	0	0	165,11	103,71	102,51	16750
12	102,78	0	0	165,27	103,53	102,03	16985
13	102,68	0	0	165,18	103,3	102,06	17203
14	102,36	0	0	165,33	102,9	101,81	17438
15	102,23	0	0	165,33	102,7	101,75	17672
16	101,95	0	0	165,53	102,44	101,46	17891
17	101,81	0	0	165,33	102,26	101,35	18125
18	101,88	0	0	165,26	102,3	101,47	18360
19	101,93	0	0	165,03	102,5	101,35	18594
20	101,57	0	0	165,29	102,02	101,12	18813
21	101,31	0	0	165,23	101,7	100,92	19047
22	100,28	0	0	166,19	100,46	100,1	19281
23	99,99	0	0	166,2	100	99,98	19500
24	99,93	0	0	166,16	100,05	99,82	19735
25	99,87	0	0	165,8	99,99	99,76	19969
26	99,93	0	0	165,71	100,06	99,8	20188
27	99,83	0	0	165,46	99,88	99,78	20422
28	99,68	0	0	165,31	99,71	99,65	20656
29	99,68	0	0	165,31	99,71	99,65	20656
30	99,43	0	0	165,08	99,52	99,33	20875
31	99,48	0	0	164,8	99,57	99,4	21110
32	99,19	0	0	165,06	99,38	99	21344
33	99,4	0	0	164,74	99,7	99,09	21563
34	99,22	0	0	164,29	99,48	98,95	21797
35	98,98	0	0	164,37	99,22	98,74	22031
36	98,86	0	0	164,11	99,11	98,62	22266
37	98,61	0	0	163,85	98,85	98,37	22485
38	98,34	0	0	163,69	98,55	98,12	22719
39	98,22	0	0	163,28	98,52	97,92	22953
40	98,14	0	0	162,99	98,4	97,88	23172
41	97,97	0	0	162,55	98,28	97,67	23406
42	97,77	0	0	162,05	98,06	97,49	23641

43	97,68	0	0	161,99	98,04	97,31	23860
44	97,59	0	0	161,5	97,9	97,28	24094
45	97,42	0	0	161,16	97,86	96,99	24328
46	97,34	0	0	160,65	97,66	97,02	24547
47	97,01	0	0	160,47	97,53	96,49	24781
48	96,81	0	0	160,14	97,28	96,34	25016
49	96,44	0	0	159,74	96,89	95,99	25235
50	96,3	0	0	156,55	96,85	95,74	24781
51	96,14	0	0	156,2	96,66	95,63	25016
52	95,98	0	0	155,74	96,54	95,43	25235
53	95,84	0	0	155,31	96,42	95,27	25469
54	95,81	0	0	154,84	96,44	95,18	25703
55	95,52	0	0	154,47	96,21	94,83	25938
56	95,41	0	0	154,07	96,07	94,76	26156
57	95,19	0	0	153,45	95,9	94,49	26391
58	95,17	0	0	153,02	95,86	94,47	26625
59	95,09	0	0	152,43	95,78	94,4	26844
60	94,95	0	0	151,82	95,64	94,26	27078
61	94,82	0	0	151,08	95,59	94,05	27313
62	94,57	0	0	150,3	95,29	93,86	27531
63	94,51	0	0	149,68	95,22	93,8	27766
64	94,22	0	0	149,06	94,96	93,49	28000
65	94,06	0	0	148,28	94,7	93,42	28219
66	93,7	0	0	147,43	94,44	92,96	28453
67	93,31	0	0	146,53	94,03	92,59	28688
68	92,89	0	0	145,6	93,59	92,2	28906
69	92,42	0	0	144,66	92,96	91,89	29141
70	91,92	0	0	143,7	92,46	91,39	29375
71	91,38	0	0	142,4	91,88	90,88	29610
72	90,72	0	0	141,4	91,19	90,25	29828
73	90,04	0	0	140,35	90,34	89,74	30063
74	89,32	0	0	139,05	89,59	89,04	30297
75	86,61	0	0	141,19	85,86	87,37	30516
76	85,76	0	0	140,42	84,89	86,63	30750
77	84,96	0	0	139,61	83,83	86,1	30985
78	83,88	0	0	138,51	82,59	85,18	31203
79	82,93	0	0	137,12	81,56	84,3	31438
80	82,07	0	0	136	80,5	83,63	31672
81	81,08	0	0	135,46	79,35	82,81	31891
82	80,41	0	0	134,4	78,73	82,09	32125
83	79,63	0	0	132,94	77,83	81,42	32360
84	78,9	0	0	131,41	77,05	80,76	32578
85	78,87	0	0	118,94	77,55	80,18	32578
86	78,13	0	0	116,87	76,65	79,6	32813
87	77,13	0	0	114,99	75,64	78,62	33047
88	76,7	0	0	113,36	75,09	78,3	33281
89	75,68	0	0	111,55	73,99	77,37	33500
90	75,19	0	0	109,77	73,44	76,93	33735
91	74,41	0	0	107,76	72,56	76,26	33969
92	73,33	0	0	105,85	71,35	75,31	34188
93	72,74	0	0	103,8	70,69	74,78	34422
94	71,42	0	0	101,67	69,23	73,61	34656

95	70,58	0	0	99,69	68,31	72,85	34875
96	69,28	0	0	97,37	67,07	71,49	35110
97	67,14	0	0	95,38	65,26	69,02	35344
98	65,69	0	0	93,13	63,87	67,5	35563
99	64,03	0	0	90,93	62,42	65,65	35797
100	64,28	0	0	81,08	62,17	66,38	35797
101	62,94	0	0	78,81	60,84	65,03	36031
102	61,51	0	0	76,56	59,4	63,63	36250
103	60,05	0	0	74,28	57,97	62,13	36485
104	58,36	0	0	72,17	56,28	60,44	36719
105	56,77	0	0	70	54,72	58,81	36938
106	54,99	0	0	67,83	53	56,97	37172
107	53,3	0	0	65,69	51,31	55,28	37406
108	50,93	0	0	63,56	48,89	52,97	37641
109	49,1	0	0	61,56	47,17	51,03	37860
110	46,99	0	0	59,54	45,29	48,68	38094
111	44,86	0	0	57,41	43,17	46,54	38328
112	42,58	0	0	55,12	41,05	44,11	38547
113	38,87	0	0	53,88	35,49	42,25	38781
114	37,48	0	0	52,3	33,19	41,77	39016
115	38,88	0	0	38,97	38,88	38,88	39016
116	36,73	0	0	36,91	36,73	36,73	39235
117	34,31	0	0	34,83	34,31	34,31	39469
118	31,91	0	0	32,71	31,91	31,91	39703
119	31,91	0	0	32,71	31,91	31,91	39703
120	29,34	0	0	30,59	29,34	29,34	39922
121	26,78	0	0	28,49	26,78	26,78	40156
122	23,1	0	0	26,51	22,76	23,45	40391
123	22,59	0	0	23,94	20,47	24,72	40610
124	16,81	0	0	86,23	16,81	16,81	45438
125	0	0	0	0	0	0	NA

BIOTACK V2
Measureme CA-measurement
Device : DataPhysics OCA - Series
Customer : DataPhysics
Sample : Not Defined
Operator : nemi
Remarks : DataPhysics

Run-No	CA(M)[°]	IFT[mN/m]	Err[µm]	Vol[µL]	CA(R)[°]	CA(L)[°]	Age[ms]
1	102,03	0	0	159,15	102,13	101,93	8250
2	101,08	0	0	153,48	101,35	100,8	8672
3	100,03	0	0	147,34	100,58	99,47	9078
4	99,34	0	0	143,31	99,74	98,93	9500
5	98,63	0	0	139,37	99,39	97,87	9906
6	97,78	0	0	135,92	97,85	97,7	10328
7	96,6	0	0	132,46	97,05	96,16	10735
8	95,73	0	0	129,15	96,45	95,01	11141
9	94,35	0	0	125,75	95,28	93,43	11563
10	93,52	0	0	122,13	94,57	92,47	11969
11	91,8	0	0	118,85	92,4	91,21	12391
12	90,13	0	0	115,27	90,75	89,51	12797
13	88,22	0	0	111,43	88,65	87,79	13219
14	86,37	0	0	107,8	86,74	86	13625
15	84,86	0	0	104,13	85,2	84,51	14031
16	82,73	0	0	100,67	83,19	82,27	14453
17	80,91	0	0	96,93	81,28	80,53	14860
18	78,5	0	0	93,22	78,58	78,42	15281
19	76,71	0	0	89,47	76,88	76,54	15688
20	73,96	0	0	85,59	73,94	73,98	16110
21	67,52	0	0	62,17	68,18	66,86	16516
22	64,4	0	0	57,66	64,84	63,95	16938
23	60,85	0	0	52,89	61,47	60,24	17344
24	56,78	0	0	48,04	57,31	56,26	17750
25	49,13	0	0	43,74	48,3	49,95	18172
26	47,87	0	0	38,18	48,18	47,55	18578
27	41,84	0	0	31,36	41,98	41,7	19000
28	36,91	0	0	26,11	37,14	36,68	19406
29	31,32	0	0	21,24	31,61	31,02	19828
30	22,65	0	0	11,53	23,1	22,2	20235
31	14,69	0	0	6,92	13,61	15,77	20641
32	0	0	0	0	0	0	22719
33	0	0	0	0	0	0	NA

BIOTACK V3
Measureme CA-measurement
Device : DataPhysics OCA - Series
Customer : DataPhysics
Sample : Not Defined
Operator : nemi
Remarks : DataPhysics

Run-No	CA(M)[°]	IFT[mN/m]	Err[µm]	Vol[µL]	CA(R)[°]	CA(L)[°]	Age[ms]
1	97,43	0	0	198,13	95,32	99,55	8672
2	97,14	0	0	195,84	94,94	99,34	9078
3	96,19	0	0	192,35	93,76	98,63	9500
4	96,07	0	0	189,93	93,45	98,7	9907
5	92,85	0	0	186,7	90,45	95,25	10313
6	92,22	0	0	184,1	89,24	95,21	10735
7	89,81	0	0	177,22	86,51	93,11	11141
8	89,68	0	0	175,24	87,26	92,1	11563
9	87,69	0	0	171,77	85,09	90,3	11969
10	87,56	0	0	168,5	84,78	90,35	12391
11	86,14	0	0	165,17	83,76	88,51	12797
12	86,12	0	0	161,53	83,19	89,05	13219
13	84,94	0	0	157,76	82,38	87,49	13625
14	84,3	0	0	154,11	81,44	87,16	14032
15	80,9	0	0	148,53	78,1	83,69	14453
16	79,75	0	0	141,06	77,01	82,49	14860
17	76,72	0	0	134,25	73,43	80,01	15282
18	75,06	0	0	130,54	72,21	77,9	15688
19	73,32	0	0	125,21	70,45	76,18	16110
20	71,32	0	0	119,63	68,29	74,34	16516
21	70,27	0	0	113,72	66,83	73,71	16922
22	67,94	0	0	107,96	64,43	71,45	17344
23	64,63	0	0	102,71	60,89	68,36	17750
24	62,52	0	0	96,77	59,06	65,98	18172
25	60,38	0	0	91,14	56,71	64,04	18578
26	53,23	0	0	64,52	50,07	56,39	19000
27	49,85	0	0	57,98	46,66	53,05	19407
28	45,96	0	0	51,8	41,55	50,37	19813
29	40,74	0	0	45,07	36,51	44,97	20235
30	35,13	0	0	39,06	29,38	40,88	20641
31	32,46	0	0	35,38	25,74	39,17	21063
32	30,93	0	0	33,73	24,07	37,79	21063
33	24,42	0	0	94,65	24,42	24,42	25188
34	0	0	0	0	0	0	NA

DEXTRIN V1
Measureme CA-measurement
Device : DataPhysics OCA - Series
Customer : DataPhysics
Sample : Not Defined
Operator : nemi
Remarks : DataPhysics

Run-No	CA(M)[°]	IFT[mN/m]	Err[µm]	Vol[µL]	CA(R)[°]	CA(L)[°]	Age[ms]
1	107,03	0	0	234,56	107,06	107	19187
2	107,01	0	0	233,81	107,02	106,99	19625
3	106,98	0	0	232,87	106,93	107,03	20062
4	106,72	0	0	231,09	106,55	106,9	20500
5	106,05	0	0	225,31	105,68	106,42	20937
6	105,61	0	0	221,11	105,36	105,86	21375
7	105,6	0	0	219,24	105,16	106,04	21797
8	104,87	0	0	217,47	104,5	105,24	22234
9	104,65	0	0	216,23	104,29	105	22672
10	104,32	0	0	214,82	103,96	104,68	23109
11	103,97	0	0	213,32	103,54	104,4	23547
12	103,64	0	0	212,61	103,23	104,06	23984
13	103,39	0	0	210,69	103,06	103,72	24422
14	103,16	0	0	209,89	102,78	103,55	24859
15	102,88	0	0	207,53	102,58	103,17	25297
16	102,15	0	0	206,58	101,93	102,36	25734
17	101,69	0	0	205,11	101,64	101,75	26156
18	101,03	0	0	204,35	100,94	101,13	26594
19	100,79	0	0	203,57	100,84	100,74	27031
20	100,21	0	0	203,33	100,23	100,18	27469
21	99,81	0	0	202,66	99,93	99,68	27906
22	99,36	0	0	201,76	99,47	99,26	28344
23	99,26	0	0	200,87	99,37	99,15	28781
24	99,12	0	0	200,17	99,22	99,02	29219
25	98,95	0	0	199,29	98,99	98,92	29656
26	98,18	0	0	195,46	98,29	98,06	30094
27	97,7	0	0	192,2	97,75	97,66	30531
28	97,23	0	0	190,82	97,25	97,22	30953
29	96,8	0	0	189,39	96,68	96,92	31391
30	95,42	0	0	188,21	95,39	95,45	31828
31	93,62	0	0	186,2	93,75	93,48	32266
32	92,97	0	0	184,3	92,93	93,01	32703
33	92,71	0	0	183,26	92,68	92,74	33141
34	92,47	0	0	181,63	92,33	92,6	33578
35	92,25	0	0	180,68	92,15	92,34	34016
36	92,02	0	0	179,82	91,82	92,22	34453
37	90,98	0	0	179,51	90,93	91,03	34891
38	90,51	0	0	178,72	90,52	90,51	35312
39	90,36	0	0	177,73	90,36	90,36	35750
40	89,73	0	0	176,93	89,74	89,71	36187
41	89,38	0	0	176,23	89,34	89,42	36625
42	88,91	0	0	175,2	88,92	88,9	37062

43	88,7	0	0	174,33	88,65	88,76	37500
44	88,4	0	0	173,74	88,43	88,37	37937
45	88,17	0	0	173,36	88,16	88,19	38375
46	87,96	0	0	172,67	87,97	87,95	38812
47	87,64	0	0	172,2	87,67	87,6	39250
48	87,46	0	0	171,73	87,48	87,43	39687
49	87,14	0	0	170,92	87,17	87,1	40109
50	86,9	0	0	170,01	86,9	86,9	40547
51	86,8	0	0	169,44	86,82	86,77	40984
52	86,57	0	0	168,82	86,55	86,59	41422
53	86,47	0	0	168,18	86,51	86,43	41859
54	86,14	0	0	167,52	86,19	86,09	42297
55	85,98	0	0	166,34	86,04	85,92	42734
56	85,85	0	0	165,71	85,88	85,83	43172
57	85,74	0	0	165,07	85,79	85,69	43609
58	85,64	0	0	164,51	85,66	85,62	44047
59	85,58	0	0	163,92	85,6	85,57	44469
60	85,35	0	0	163,21	85,38	85,32	44906
61	85,19	0	0	162,72	85,15	85,22	45344
62	85,05	0	0	162,04	85,06	85,03	45781
63	84,86	0	0	161,53	84,84	84,87	46219
64	84,7	0	0	160,79	84,74	84,66	46656
65	84,64	0	0	160,2	84,66	84,62	47094
66	84,59	0	0	159,57	84,68	84,5	47531
67	84,47	0	0	158,98	84,56	84,38	47969
68	84,34	0	0	157,81	84,62	84,06	48406
69	84,38	0	0	157,15	84,78	83,98	48844
70	84,15	0	0	156,86	84,68	83,62	49266
71	83,99	0	0	156,47	84,61	83,37	49703
72	83,8	0	0	155,84	84,45	83,15	50141
73	83,57	0	0	154,91	84,3	82,84	50578
74	83,27	0	0	153,89	83,93	82,61	51016
75	83,06	0	0	152,89	83,76	82,35	51453
76	82,82	0	0	152,29	83,5	82,13	51891
77	82,77	0	0	151,75	83,52	82,02	52328
78	82,56	0	0	151,15	83,27	81,86	52766
79	82,41	0	0	150,64	83,16	81,67	53203
80	82,03	0	0	150,21	82,79	81,27	53625
81	81,25	0	0	150,01	82,2	80,3	54062
82	81,06	0	0	149,33	82	80,12	54500
83	80,88	0	0	148,74	81,79	79,97	54937
84	80,72	0	0	147,76	81,72	79,72	55375
85	80,69	0	0	146,94	81,67	79,7	55812
86	80,53	0	0	146,42	81,59	79,47	56250
87	80,27	0	0	145,53	81,31	79,22	56687
88	80,32	0	0	144,6	81,32	79,31	57125
89	80,3	0	0	143,97	81,34	79,25	57562
90	80,2	0	0	143,26	81,31	79,09	58000
91	80,01	0	0	142,46	81,12	78,9	58422
92	79,72	0	0	140,93	80,8	78,64	58859
93	79,39	0	0	140,25	80,52	78,26	59297
94	79,09	0	0	139,48	80,22	77,95	59734

95	78,62	0	0	137,7	79,82	77,41	60172
96	77,89	0	0	137,06	79,29	76,49	60609
97	77,31	0	0	136,29	78,84	75,78	61047
98	76,95	0	0	135,27	78,53	75,37	61484
99	76,55	0	0	133,98	78,11	74,99	61922
100	76,3	0	0	132,96	77,87	74,73	62359
101	75,87	0	0	131,82	77,46	74,27	62781
102	75,64	0	0	130,88	77,18	74,09	63219
103	75,34	0	0	129,91	76,95	73,74	63656
104	75,21	0	0	128,85	76,83	73,58	64094
105	74,97	0	0	127,87	76,58	73,35	64531
106	74,67	0	0	126,74	76,28	73,06	64969
107	74,43	0	0	125,7	76,1	72,77	65406
108	74,17	0	0	124,64	75,8	72,53	65844
109	73,81	0	0	123,42	75,45	72,16	66281
110	73,53	0	0	122,4	75,22	71,84	66719
111	73,3	0	0	121,35	75,01	71,59	67156
112	72,88	0	0	120,18	74,52	71,23	67578
113	72,57	0	0	119,08	74,19	70,96	68016
114	72,13	0	0	118,03	73,69	70,56	68453
115	71,89	0	0	116,87	73,47	70,31	68891
116	71,52	0	0	115,63	73,08	69,96	69328
117	71,1	0	0	114,34	72,62	69,59	69766
118	70,69	0	0	113,36	72,16	69,21	70203
119	70,39	0	0	112,25	71,79	68,99	70641
120	69,88	0	0	111,16	71,24	68,53	71078
121	68,89	0	0	110,34	69,96	67,82	71516
122	68,6	0	0	109,41	69,58	67,62	71937
123	68,21	0	0	108,37	69,21	67,21	72375
124	67,99	0	0	107,36	68,96	67,03	72812
125	67,64	0	0	106,33	68,58	66,69	73250
126	67,41	0	0	105,43	68,34	66,49	73687
127	67,06	0	0	104,42	68	66,13	74125
128	66,79	0	0	103,43	67,72	65,85	74562
129	66,44	0	0	102,52	67,3	65,58	75000
130	66,2	0	0	101,55	67,05	65,34	75437
131	65,88	0	0	100,65	66,71	65,05	75875
132	65,64	0	0	99,81	66,45	64,84	76312
133	65,41	0	0	98,86	66,17	64,65	76734
134	65,1	0	0	98	65,82	64,38	77172
135	64,82	0	0	97,01	65,46	64,17	77609
136	64,43	0	0	96,12	64,96	63,89	78047
137	64,34	0	0	94,97	64,93	63,74	78484
138	64,16	0	0	93,99	64,77	63,55	78922
139	63,85	0	0	93,01	64,38	63,31	79359
140	63,53	0	0	92,11	63,98	63,08	79797
141	63,24	0	0	91,23	63,61	62,87	80234
142	62,91	0	0	90,31	63,24	62,58	80672
143	62,54	0	0	89,36	62,81	62,27	81094
144	62,26	0	0	88,42	62,46	62,06	81531
145	61,97	0	0	87,48	62,13	61,81	81969
146	61,61	0	0	86,51	61,73	61,5	82406

147	61,14	0	0	85,54	61,15	61,12	82844
148	60,76	0	0	84,53	60,72	60,8	83281
149	60,45	0	0	83,72	60,38	60,53	83719
150	60,07	0	0	82,82	59,93	60,22	84156
151	59,78	0	0	81,97	59,6	59,97	84594
152	59,48	0	0	81,18	59,24	59,71	85031
153	59,14	0	0	80,2	58,87	59,42	85469
154	58,71	0	0	79,43	58,4	59,03	85891
155	58,48	0	0	78,6	58,09	58,88	86328
156	58,03	0	0	77,81	57,65	58,41	86766
157	57,84	0	0	77,06	57,39	58,29	87203
158	57,46	0	0	76,26	56,95	57,97	87641
159	57,15	0	0	75,54	56,56	57,75	88078
160	56,9	0	0	74,73	56,24	57,56	88516
161	56,62	0	0	73,9	55,93	57,31	88953
162	56,2	0	0	73,1	55,41	56,99	89391
163	55,89	0	0	72,41	55,08	56,69	89828
164	55,26	0	0	71,75	54,38	56,14	90250
165	54,88	0	0	70,81	53,93	55,82	90688
166	54,6	0	0	69,94	53,68	55,52	91125
167	54,34	0	0	69,04	53,34	55,34	91563
168	54,05	0	0	68,16	52,89	55,21	92000
169	53,83	0	0	66,98	52,67	54,98	92875
170	53,45	0	0	66,29	52,19	54,72	93313
171	53,17	0	0	65,53	51,78	54,55	93750
172	52,84	0	0	64,77	51,34	54,34	94188
173	52,08	0	0	62,8	50,39	53,77	94188
174	51,81	0	0	61,91	50,02	53,6	94625
175	51,46	0	0	61,15	49,55	53,36	95047
176	51,19	0	0	60,35	49,18	53,21	95484
177	50,78	0	0	59,43	48,64	52,92	95922
178	50,32	0	0	58,58	48,04	52,6	96359
179	50,28	0	0	57,66	47,79	52,77	96797
180	49,77	0	0	56,85	47,2	52,35	97234
181	40,55	0	0	28,53	50,5	30,6	115109
182	0	0	0	0	0	0	NA

DEXTRIN V2
Measureme CA-measurement
Device : DataPhysics OCA - Series
Customer : DataPhysics
Sample : Not Defined
Operator : nemi
Remarks : DataPhysics

Run-No	CA(M)[°]	IFT[mN/m]	Err[µm]	Vol[µL]	CA(R)[°]	CA(L)[°]	Age[ms]
1	108,04	0	0	223,38	109,18	106,91	10469
2	106,65	0	0	221,41	108,07	105,23	10891
3	105,99	0	0	218,02	107,61	104,38	11328
4	104,48	0	0	216,25	105,94	103,01	11766
5	103,54	0	0	213,66	104,84	102,24	12203
6	102,83	0	0	210,62	104,07	101,58	12641
7	102,06	0	0	208,21	103,34	100,77	13078
8	101,52	0	0	205,72	102,73	100,3	13516
9	101,19	0	0	203,54	102,36	100,01	13953
10	100,88	0	0	201,57	102,03	99,73	14391
11	100,58	0	0	199,87	101,63	99,53	14828
12	100,11	0	0	198,49	101,23	98,99	15266
13	99,81	0	0	197,06	100,99	98,63	15688
14	99,48	0	0	195,62	100,76	98,2	16125
15	99,3	0	0	193,97	100,62	97,98	16563
16	98,91	0	0	193,18	100,29	97,54	17000
17	98,51	0	0	191,43	99,95	97,08	17438
18	97,83	0	0	190,2	99,35	96,3	17875
19	97,48	0	0	189,02	99,03	95,93	18313
20	97,17	0	0	187,73	98,7	95,64	18750
21	96,88	0	0	186,41	98,38	95,39	19188
22	96,33	0	0	183,99	97,97	94,69	19625
23	95,85	0	0	182,59	97,56	94,13	20047
24	95,44	0	0	181,38	97,18	93,7	20485
25	94,77	0	0	180,34	96,7	92,84	20922
26	94,26	0	0	179,34	96,3	92,22	21360
27	93,8	0	0	178,82	95,85	91,75	21797
28	93,39	0	0	177,78	95,43	91,35	22235
29	92,91	0	0	176,59	94,97	90,84	22672
30	92,36	0	0	175,01	94,39	90,32	23110
31	91,76	0	0	173,89	93,85	89,66	23547
32	91,29	0	0	172,95	93,39	89,19	23985
33	90,75	0	0	172,37	92,95	88,55	24422
34	89,73	0	0	171,89	92,11	87,34	24844
35	89,14	0	0	171,16	91,57	86,7	25282
36	88,44	0	0	170,65	90,99	85,89	25719
37	87,83	0	0	169,74	90,48	85,19	26157
38	87,02	0	0	168,91	89,65	84,4	26594
39	86,4	0	0	167,87	89,17	83,63	27032
40	85,72	0	0	166,79	88,57	82,88	27469
41	85,19	0	0	165,73	88,03	82,34	27907
42	84,5	0	0	164,64	87,4	81,61	28344

43	83,75	0	0	163,38	86,69	80,81	28782
44	83,11	0	0	162,33	86,1	80,12	29203
45	82,29	0	0	160,8	85,36	79,21	29641
46	81,33	0	0	158,89	84,48	78,18	30078
47	80,57	0	0	157,74	83,76	77,37	30516
48	79,89	0	0	156,7	83,13	76,65	30953
49	79,3	0	0	155,63	82,65	75,94	31391
50	78,42	0	0	154,24	81,87	74,97	31828
51	77,34	0	0	152,73	80,86	73,82	32266
52	76,39	0	0	151,34	79,95	72,83	32703
53	75,82	0	0	150,14	79,51	72,14	33141
54	75,09	0	0	148,92	78,87	71,32	33578
55	74,27	0	0	147,71	78,17	70,38	34000
56	73,24	0	0	146,45	77,19	69,28	34438
57	72,38	0	0	145,26	76,43	68,33	34875
58	71,36	0	0	144,07	75,62	67,11	35313
59	70,31	0	0	142,54	74,74	65,89	35750
60	69,21	0	0	141,17	73,71	64,71	36188
61	68,27	0	0	139,69	72,87	63,68	36625
62	67,23	0	0	138,23	71,9	62,56	37063
63	66,37	0	0	136,82	71,19	61,55	37500
64	65,6	0	0	135,51	70,6	60,59	37938
65	64,74	0	0	134,21	69,92	59,57	38360
66	63,52	0	0	132,91	68,9	58,13	38797
67	62,59	0	0	131,5	68,3	56,88	39235
68	61,37	0	0	130,22	67,4	55,34	39672
69	60,52	0	0	128,9	66,77	54,26	40110
70	59,71	0	0	127,54	66,33	53,1	40547
71	59,3	0	0	121,02	66,12	52,48	40547
72	58,58	0	0	119,6	65,69	51,47	40985
73	58,23	0	0	118,29	65,44	51,02	41422
74	58,18	0	0	117,13	65,52	50,85	41860
75	37,95	0	0	124,74	37,95	37,95	57985
76	37,88	0	0	124,26	37,88	37,88	58422
77	0	0	0	0	0	0	NA

DEXTRIN V3

Measureme CA-measurement

Device : DataPhysics OCA - Series

Customer : DataPhysics

Sample : Not Defined

Operator : nemi

Remarks : DataPhysics

Run-No	CA(M)[°]	IFT[mN/m]	Err[µm]	Vol[µL]	CA(R)[°]	CA(L)[°]	Age[ms]
1	94,09	0	0	188,48	94,72	93,45	9078
2	91,07	0	0	180,97	92,02	90,11	9500
3	89,02	0	0	177,13	90,16	87,89	9906
4	88,05	0	0	174,8	89,19	86,92	10328
5	86,97	0	0	169,48	88,21	85,72	10734
6	86	0	0	164,93	87,05	84,95	11156
7	85,05	0	0	160,37	85,98	84,12	11562
8	84,43	0	0	156,59	85,39	83,47	11984
9	84,05	0	0	152,47	84,97	83,14	12391
10	83,2	0	0	148,5	84,45	81,95	12797
11	82,12	0	0	144,44	83,62	80,62	13219
12	81,05	0	0	141,78	82,8	79,29	13625
13	80,31	0	0	139,28	82,14	78,48	14047
14	79,66	0	0	136,27	81,65	77,67	14453
15	79	0	0	132,86	81,16	76,84	14875
16	78,11	0	0	128,79	80,51	75,7	15281
17	77,41	0	0	125,41	80,04	74,78	15687
18	76,77	0	0	122,06	79,71	73,83	16109
19	76,06	0	0	118,75	79,22	72,9	16516
20	74,86	0	0	115,94	78,3	71,41	16937
21	73,25	0	0	112,55	76,86	69,63	17344
22	69,91	0	0	109,79	72,89	66,93	17766
23	66,82	0	0	106,89	69,18	64,46	18172
24	64,73	0	0	104,26	66,63	62,84	18594
25	63,32	0	0	101,1	64,93	61,71	19000
26	62,46	0	0	97,72	63,97	60,95	19406
27	58,49	0	0	95,34	58,61	58,37	19828
28	56,75	0	0	91,9	56,66	56,84	20234
29	54,04	0	0	88,37	53,9	54,18	20656
30	51,85	0	0	84,2	51,79	51,91	21062
31	49,21	0	0	80,89	49,14	49,28	21484
32	46,86	0	0	77,06	46,59	47,13	21891
33	44,63	0	0	73,35	44,11	45,15	22297
34	42,47	0	0	69,24	41,74	43,2	22719
35	40,84	0	0	65,27	39,88	41,79	23125
36	39,28	0	0	61,17	37,97	40,59	23547
37	37,6	0	0	57,18	35,86	39,34	23953
38	35,73	0	0	53,17	33,68	37,79	24375
39	33,76	0	0	49,28	31,4	36,12	24781
40	31,8	0	0	45,61	28,96	34,64	25187
41	29,49	0	0	41,87	26,21	32,77	25609
42	26,81	0	0	38,16	23,26	30,35	26016
43	24,72	0	0	34,3	20,82	28,63	26437
44	23,72	0	0	30,71	19,63	27,81	26844
46	0	0	0	0	0	0	27672
47	0	0	0	0	0	0	971991

SILICATE V1
Measureme CA-measurement
Device : DataPhysics OCA - Series
Customer : DataPhysics
Sample : Not Defined
Operator : nemi
Remarks : DataPhysics

Run-No	CA(M)[°]	IFT[mN/m]	Err[µm]	Vol[µL]	CA(R)[°]	CA(L)[°]	Age[ms]
1	73,39	0	0	109,15	73,31	73,46	25891
2	65,31	0	0	96,21	65,66	64,96	25953
3	60,65	0	0	83,46	60,73	60,57	26031
4	55,15	0	0	71,12	55,06	55,24	26094
5	47,67	0	0	52,21	47,16	48,17	26172
6	41,24	0	0	40,37	40,98	41,49	26234
7	32,75	0	0	26,96	32,46	33,03	26297
8	21,98	0	0	13,61	21,42	22,55	26375
9	0	0	0	0	0	0	NA

SILICATE V2
Measureme CA-measurement
Device : DataPhysics OCA - Series
Customer : DataPhysics
Sample : Not Defined
Operator : nemi
Remarks : DataPhysics

Run-No	CA(M)[°]	IFT[mN/m]	Err[µm]	Vol[µL]	CA(R)[°]	CA(L)[°]	Age[ms]
1	83,47	0	0	176,69	85,69	81,25	14813
2	75,33	0	0	164,65	76	74,67	14875
3	66,66	0	0	154,4	67,76	65,57	14938
4	52,81	0	0	119,41	57,13	48,48	15016
5	45,91	0	0	108,45	48,95	42,87	15078
6	43,76	0	0	94,07	46,36	41,17	15156
7	0	0	0	0	0	0	15703
8	0	0	0	0	0	0	NA

SILICATE V3
Measureme CA-measurement
Device : DataPhysics OCA - Series
Customer : DataPhysics
Sample : Not Defined
Operator : nemi
Remarks : DataPhysics

Run-No	CA(M)[°]	IFT[mN/m]	Err[µm]	Vol[µL]	CA(R)[°]	CA(L)[°]	Age[ms]
1	77,97	0	0	141,41	78,82	77,11	20047
2	74,21	0	0	133,61	75,29	73,13	20110
3	70,27	0	0	125,76	71,27	69,26	20172
4	64,82	0	0	115,1	66,36	63,27	20250
5	61,36	0	0	103,82	63,3	59,41	20313
6	40,31	0	0	76,12	32,05	48,58	20391
7	47,14	0	0	59,16	48,39	45,9	20391
8	35,41	0	0	45,01	37,64	33,18	20453
9	27,63	0	0	30,82	27,63	27,63	20516
10	0	0	0	0	0	0	20735
11	0	0	0	0	0	0	NA

Attachment 4: Data collected through the surface roughness trial.

THE RESULTS FROM THE SURFACE ROUGHNESS TRIAL

Mixture	**Ra**	**CI**	**CI**
BIOTACK	4,277	1,129	1,129
DEXTRIN	7,792	1,508	1,508
SILICATE	5,239	1,457	1,457

Mixture	**Rz**	**CI**	**CI**
BIOTACK	27,148	5,7	5,7
DEXTRIN	48,453	8,616	8,616
SILICATE	33,136	7,208	7,208

CALCULATION OF THE AVERAGE FOR Ra AND Rz

Biotack	**Ra**	**Rz**
Trial 1	3,564	23,123
	2,694	17,246
	2,844	19,089
	2,898	19,358
	3,429	23,467
	3,822	26,858
Trial 2	4,871	30,855
	4,177	26,071
	12,72	68,6
	4,093	26,527
	3,525	20,536
	8,604	46,751
Trial 3	2,804	18,814
	3,749	28,429
	2,592	16,165
	3,483	23,992
	2,659	17,919
	4,455	34,855
Average	**4,27683333**	**27,1475**

Dextrin	**Ra**	**Rz**
Trial 1	4,115	29,276
	5,481	36,272
	6,177	37,012
	10,25	61,06
	6,586	40,345

	7,846	45,091
Trial 2	8,245	52,05
	13,475	82,301
	3,618	25,175
	4,737	29,244
	8,385	50,042
	11,304	66,377
Trial 2	11,185	73,907
	14,644	85,658
	3,81	23,637
	5,725	43,808
	4,894	33,285
	9,777	57,613
Average	**7,79188889**	**48,4529444**

Silicate	**Ra**	**Rz**
Trial 1	5,638	34,198
	4,873	38,514
	16,639	89,176
	3,402	25,481
	3,733	26,044
	8,981	49,687
Trial 2	3,63	25,721
	3,202	22,243
	3,429	26,175
	3,657	23,921
	4,033	28,713
	6,352	39,739
Trial 3		
	5,491	32,933
	6,861	40,579
	3,636	25,586
	4,123	25,068
	3,23	20,223
	3,385	22,452
Average	**5,23861111**	**33,1362778**

CALCULATION OF THE CONFIDENCE INTERVAL IN RELATION TO Ra.

Biotack	**Ra**	**Average (m)**	**(Ra - m)**	**(Ra - m)^2**

Trial 1	3,564	-4,277	-0,713	0,508369
	2,694	-4,277	-1,583	2,505889
	2,844	-4,277	-1,433	2,053489
	2,898	-4,277	-1,379	1,901641
	3,429	-4,277	-0,848	0,719104
	3,822	-4,277	-0,455	0,207025
Trial 2	4,871	-4,277	0,594	0,352836
	4,177	-4,277	-0,1	0,01
	12,72	-4,277	8,443	71,284249
	4,093	-4,277	-0,184	0,033856
	3,525	-4,277	-0,752	0,565504
	8,604	-4,277	4,327	18,722929
Trial 3	2,804	-4,277	-1,473	2,169729
	3,749	-4,277	-0,528	0,278784
	2,592	-4,277	-1,685	2,839225
	3,483	-4,277	-0,794	0,630436
	2,659	-4,277	-1,618	2,617924
	4,455	-4,277	0,178	0,031684
			tot	107,432673
			(tot/18)	5,96848183
			stdev	2,443
			CI	**1,129**

Dextrin	**Ra**	**Average (m)**	**(Ra - m)**	**(Ra - m)^2**
Trial 1	4,115	-7,792	-3,677	13,520329
	5,481	-7,792	-2,311	5,340721
	6,177	-7,792	-1,615	2,608225
	10,25	-7,792	2,458	6,041764
	6,586	-7,792	-1,206	1,454436
	7,846	-7,792	0,054	0,002916
Trial 2	8,245	-7,792	0,453	0,205209
	13,475	-7,792	5,683	32,296489
	3,618	-7,792	-4,174	17,422276
	4,737	-7,792	-3,055	9,333025
	8,385	-7,792	0,593	0,351649
	11,304	-7,792	3,512	12,334144
Trial 3	11,185	-7,792	3,393	11,512449
	14,644	-7,792	6,852	46,949904
	3,81	-7,792	-3,982	15,856324
	5,725	-7,792	-2,067	4,272489
	4,894	-7,792	-2,898	8,398404
	9,777	-7,792	1,985	3,940225
			tot	191,840978

			(tot/18)	10,657832
			stdev	3,265
			CI	**1,508**

Silicate	Ra	Average (m)	(Ra - m)	(Ra - m)^2
Trial 1	5,638	-5,239	0,399	0,159201
	4,873	-5,239	-0,366	0,133956
	16,639	-5,239	11,4	129,96
	3,402	-5,239	-1,837	3,374569
	3,733	-5,239	-1,506	2,268036
	8,981	-5,239	3,742	14,002564
Trial 2	3,63	-5,239	-1,609	2,588881
	3,202	-5,239	-2,037	4,149369
	3,429	-5,239	-1,81	3,2761
	3,657	-5,239	-1,582	2,502724
	4,033	-5,239	-1,206	1,454436
	6,352	-5,239	1,113	1,238769
Trial 3	5,491	-5,239	0,252	0,063504
	6,861	-5,239	1,622	2,630884
	3,636	-5,239	-1,603	2,569609
	4,123	-5,239	-1,116	1,245456
	3,23	-5,239	-2,009	4,036081
	3,385	-5,239	-1,854	3,437316
			tot	179,091455
			(tot/18)	9,9495253
			stdev	3,154
			CI	**1,457**

CALCULATION OF THE CONFIDENCE INTERVAL IN RELATION TO Rz.

Biotack	Rz	Average (m)	(Rz - m)	(Rz - m)^2
Trial 1	23,123	-27,148	-4,025	16,200625
	17,246	-27,148	-9,902	98,049604
	19,089	-27,148	-8,059	64,947481
	19,358	-27,148	-7,79	60,6841
	23,467	-27,148	-3,681	13,549761
	26,858	-27,148	-0,29	0,0841
Trial 2	30,855	-27,148	3,707	13,741849
	26,071	-27,148	-1,077	1,159929
	68,6	-27,148	41,452	1718,2683
	26,527	-27,148	-0,621	0,385641
	20,536	-27,148	-6,612	43,718544

	46,751	-27,148	19,603	384,277609
Trial 3	18,814	-27,148	-8,334	69,455556
	28,429	-27,148	1,281	1,640961
	16,165	-27,148	-10,983	120,626289
	23,992	-27,148	-3,156	9,960336
	17,919	-27,148	-9,229	85,174441
	34,855	-27,148	6,211	38,576521
			tot	2740,50165
			(tot/18)	152,250092
			stdev	12,339
			CI	**5,7**

Dextrin	**Rz**	**Average (m)**	**(Rz - m)**	**(Rz - m)^2**
Trial 1	29,276	-48,453	-19,177	367,757329
	36,272	-48,453	-12,181	148,376761
	37,012	-48,453	-11,441	130,896481
	61,06	-48,453	12,607	158,936449
	40,345	-48,453	-8,108	65,739664
	45,091	-48,453	-3,362	11,303044
Trial 2	52,05	-48,453	3,597	12,938409
	82,301	-48,453	33,848	1145,6871
	25,175	-48,453	-23,278	541,865284
	29,244	-48,453	-19,209	368,985681
	50,042	-48,453	1,589	2,524921
	66,377	-48,453	17,924	321,269776
Trial 3	73,907	-48,453	25,454	647,906116
	85,658	-48,453	37,205	1384,21203
	23,637	-48,453	-24,816	615,833856
	43,808	-48,453	-4,645	21,576025
	33,285	-48,453	-15,168	230,068224
	57,613	-48,453	-9,161	83,923921
			tot	6259,80107
			(tot/18)	347,766726
			stdev	18,649
			CI	**8,616**

Silicate	**Rz**	**Average (m)**	**(Rz - m)**	**(Rz - m)^2**
Trial 1	34,198	-33,136	1,062	1,127844
	38,514	-33,136	5,378	28,922884
	89,176	-33,136	56,04	3140,4816
	25,481	-33,136	-7,655	58,599025
	26,044	-33,136	-7,092	50,296464
	49,687	-33,136	16,551	273,935601

Trial 2	25,721	-33,136	-7,415	54,982225
	22,243	-33,136	-10,893	118,657449
	26,175	-33,136	-6,961	48,455521
	23,921	-33,136	-9,215	84,916225
	28,713	-33,136	-4,423	19,562929
	39,739	-33,136	6,603	43,599609
Trial 3	32,933	-33,136	-0,203	0,041209
	40,579	-33,136	7,443	55,398249
	25,586	-33,136	-7,55	57,0025
	25,068	-33,136	-8,068	65,092624
	20,223	-33,136	-12,913	166,745569
	22,452	-33,136	10,689	114,254721
			tot	4382,07225
			(tot/18)	243,448458
			stdev	15,603
			CI	**7,208**

Attachment 5: ANOVA analysis for the roughness measurements Ra and Rz.

ANOVA analysis based on the Ra measurments.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Biotack	18	76,983	4,276833333	6,31956897
Dextrin	18	140,254	7,791888889	11,2847634
Silicate	18	94,295	5,238611111	10,5347913

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	118,799157	2	59,39957839	6,33277487	0,00349522	3,17879929
Within Groups	478,365103	51	9,379707893			
Total	597,164259	53				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Biotack	18	76,983	4,276833333	6,31956897
Dextrin	18	140,254	7,791888889	11,2847634

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	111,20054	1	111,20054	12,6333152	0,00113713	4,13001775
Within Groups	299,27365	34	8,802166185			
Total	410,47419	35				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Dextrin	18	140,254	7,791888889	11,2847634
Silicate	18	94,295	5,238611111	10,5347913

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	58,6730467	1	58,67304669	5,37802421	0,02653473	4,13001775
Within Groups	370,93243	34	10,90977735			
Total	429,605477	35				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Biotack	18	76,983	4,276833333	6,31956897
Silicate	18	94,295	5,238611111	10,5347913

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8,32514844	1	8,325148444	0,98789255	0,32727939	4,13001775
Within Groups	286,524125	34	8,427180141			
Total	294,849273	35				

ANOVA analysis based on the Rz measurments.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Biotack	18	488,655	27,1475	162,430763
Dextrin	18	872,153	48,45294444	368,222515
Silicate	18	596,453	33,13627778	257,76267

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4346,3262	2	2173,1631	8,26909872	0,0007754	3,17879929
Within Groups	13403,0711	51	262,8053158			
Total	17749,3973	53				

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Biotack	18	488,655	27,1475	162,430763
Dextrin	18	872,153	48,45294444	368,222515

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4085,29767	1	4085,297667	15,397239	0,00040249	4,13001775
Within Groups	9021,10572	34	265,3266389			
Total	13106,4034	35				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Biotack	18	488,655	27,1475	162,430763
Dextrin	18	872,153	48,45294444	368,222515

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4085,29767	1	4085,297667	15,397239	0,00040249	4,13001775
Within Groups	9021,10572	34	265,3266389			
Total	13106,4034	35				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Biotack	18	488,655	27,1475	162,430763
Silicate	18	596,453	33,13627778	257,76267

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	322,789133	1	322,7891334	1,53638352	0,22364469	4,13001775
Within Groups	7143,28836	34	210,0967164			
Total	7466,07749	35				

Attachment 6: Data collected from the tension properties trial.

DATA COLLECTED FROM THE TENSION PROPERTIES TRIAL

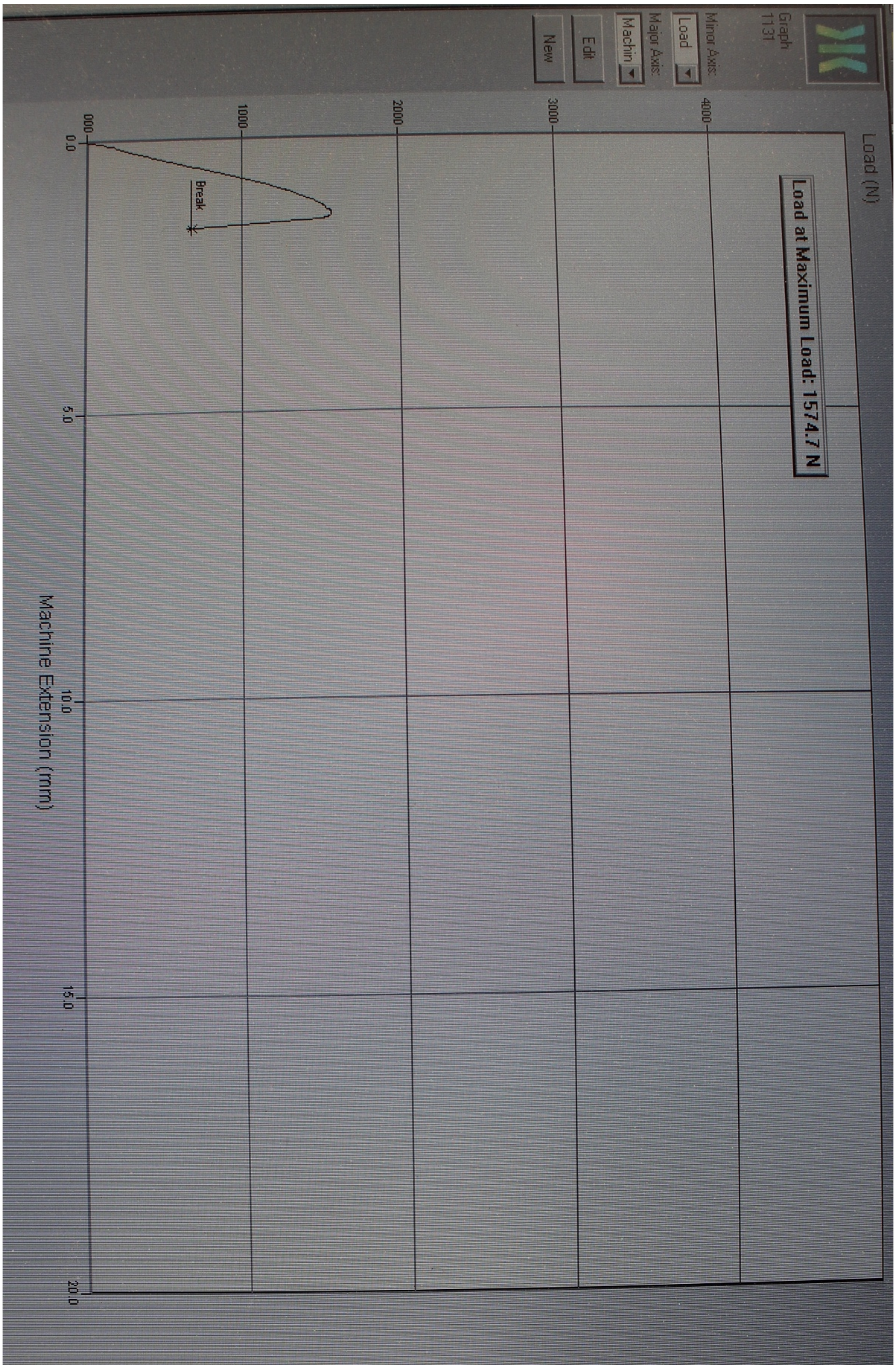
DEXTRIN	**l**	**b**	**LOAD**
1.	20.00 mm	12.00 mm	1575.0 N
2.	20.10 mm	11.95 mm	1418.0 N
3.	20.00 mm	12.00 mm	1712.8 N

SILICATE	**l**	**b**	**LOAD**
1.	20.10 mm	11.80 mm	930.34 N
2.	20.10 mm	11.80 mm	1046.8 N
3.	20.10 mm	11.80 mm	1023.7N

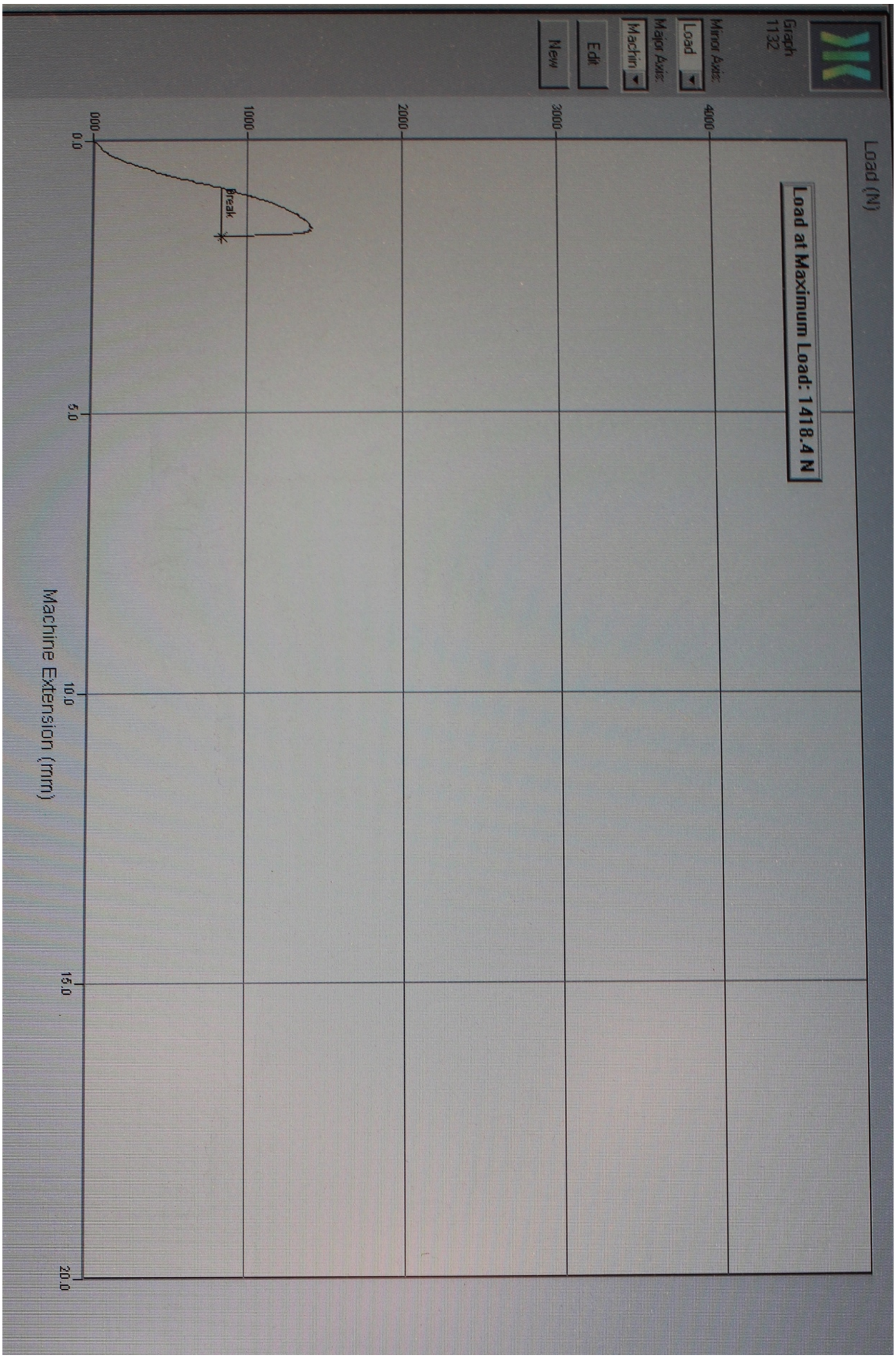
BIOTACK	**l**	**b**	**LOAD**
1.	20.50 mm	11.98 mm	2678.9 N
2.	20.30 mm	12.00 mm	2766,4 N
3.	20.30 mm	11.95 mm	3247.6 N

Attachment 7: Load – Extension diagram from the tension properties trial.

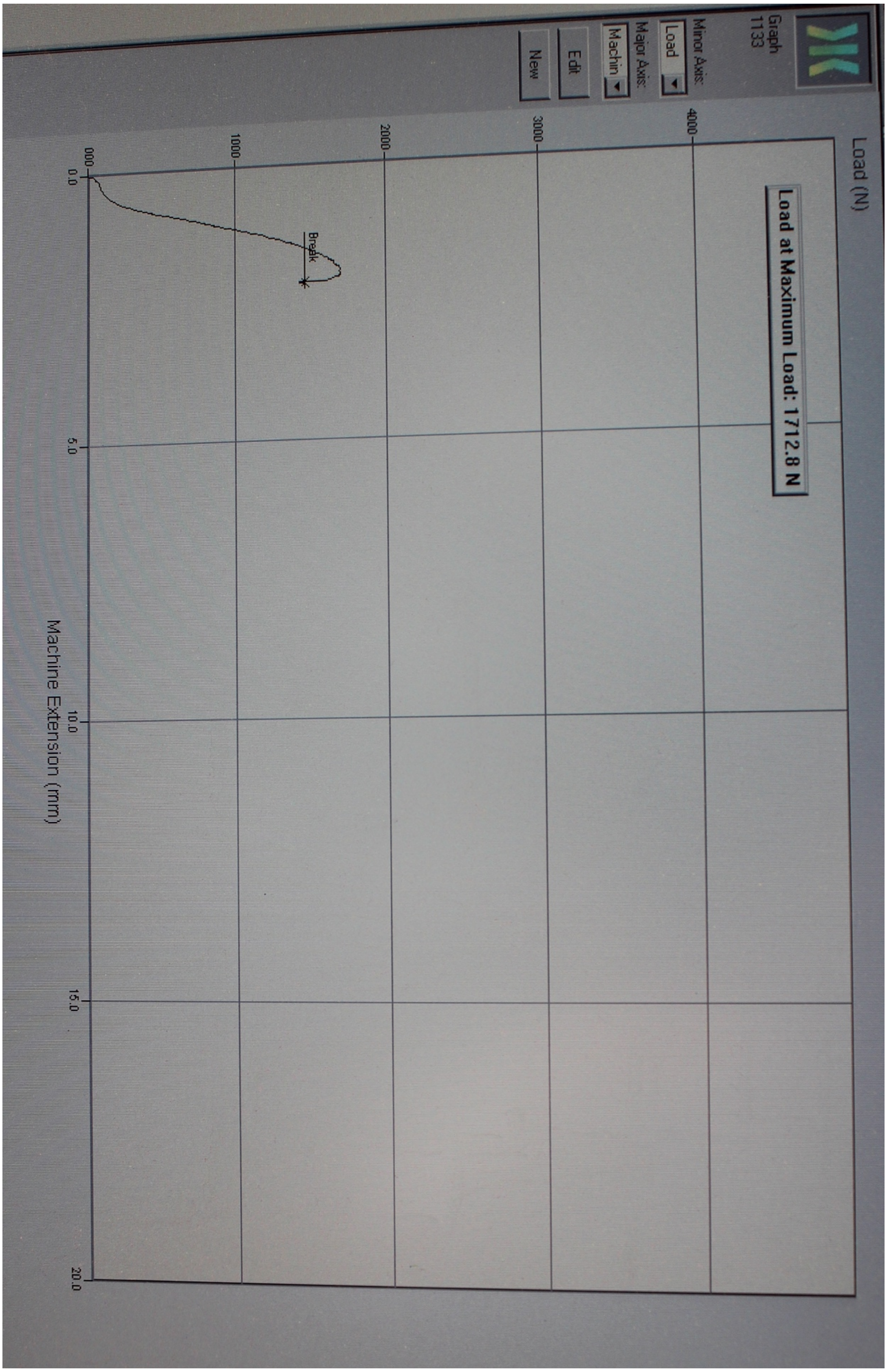
DEXTRIN
Sample 1



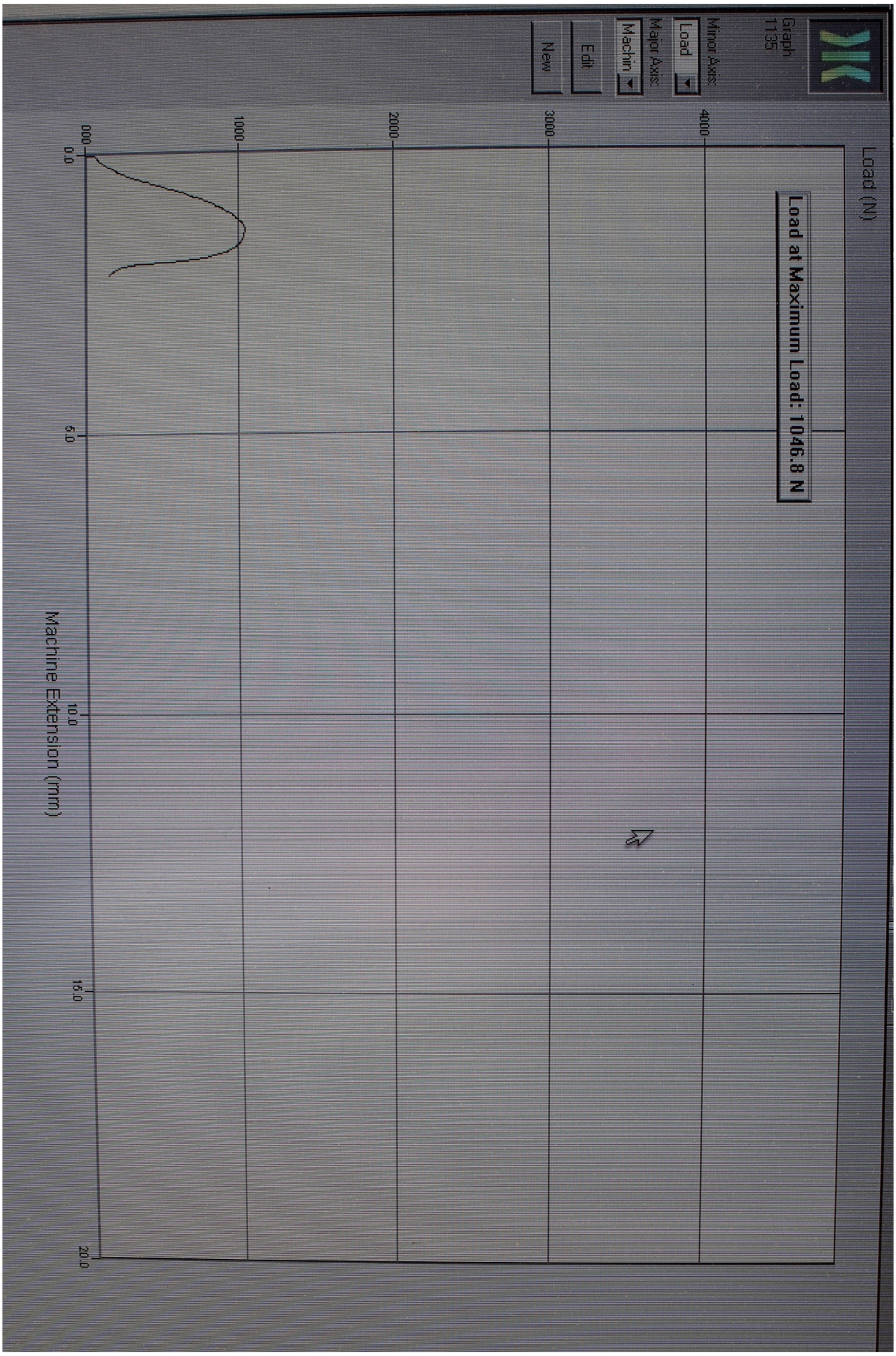
DEXTRIN
Sample 2



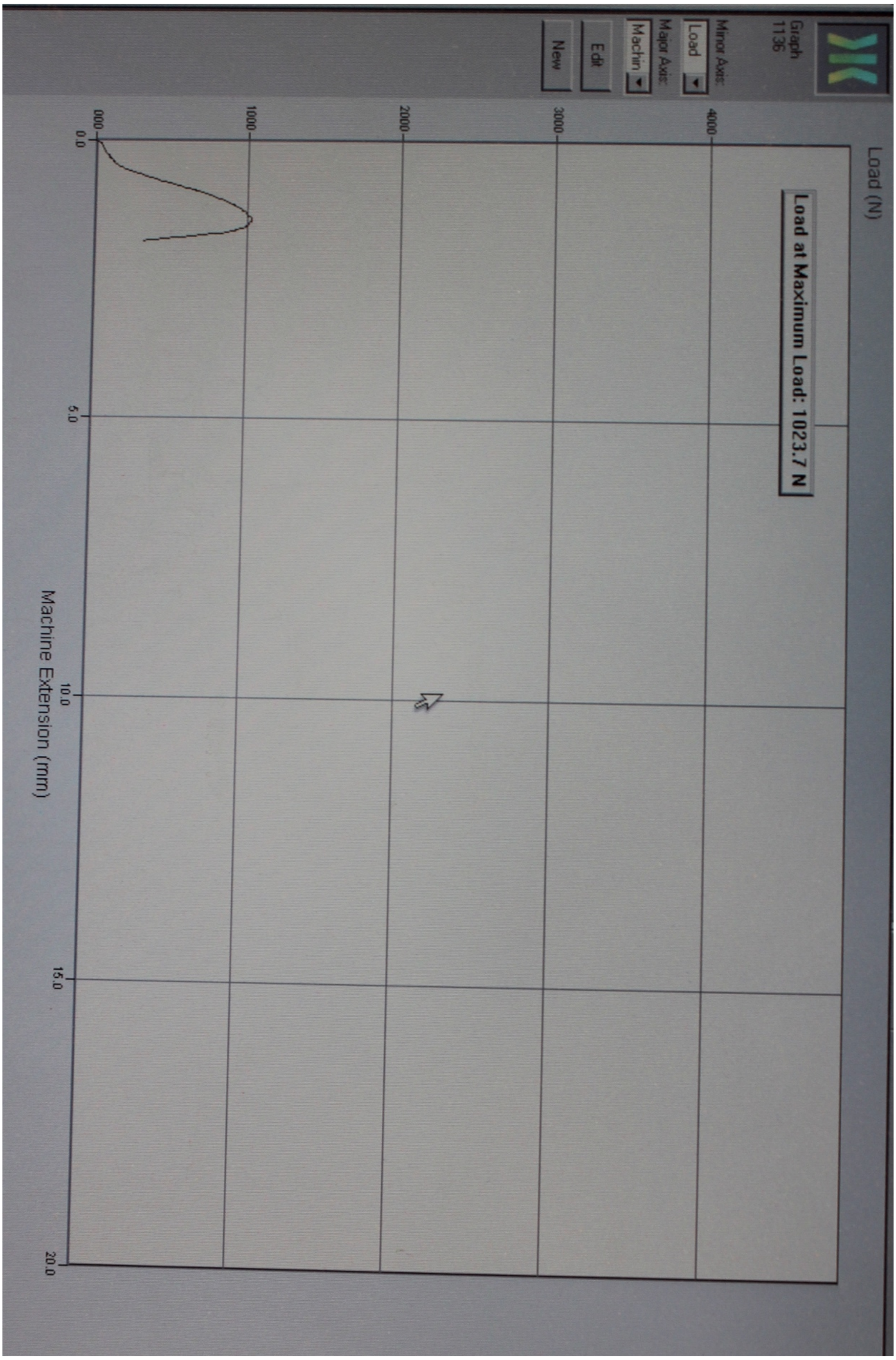
DEXTRIN
Sample 3



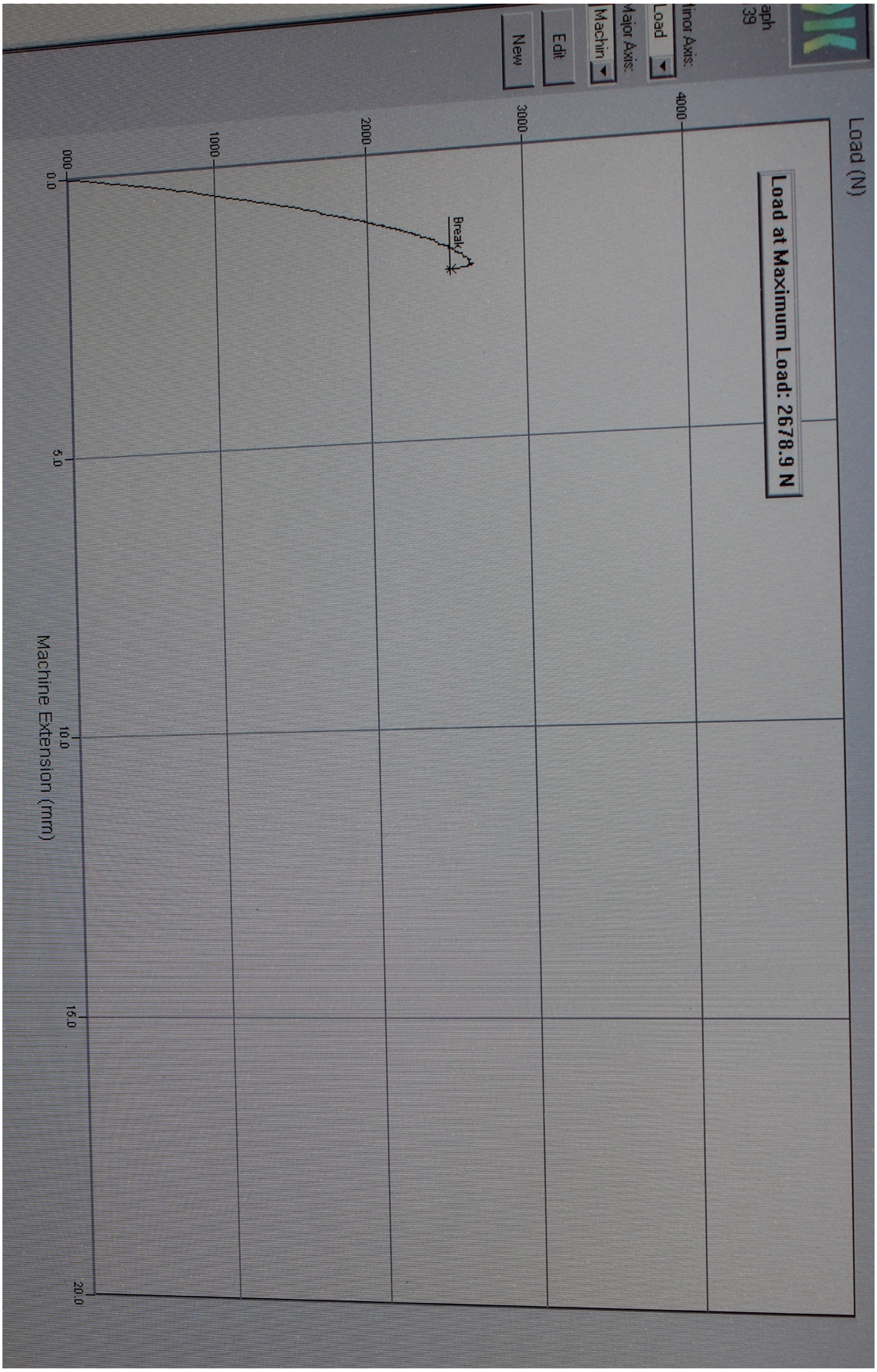
SILICATE
Sample 2



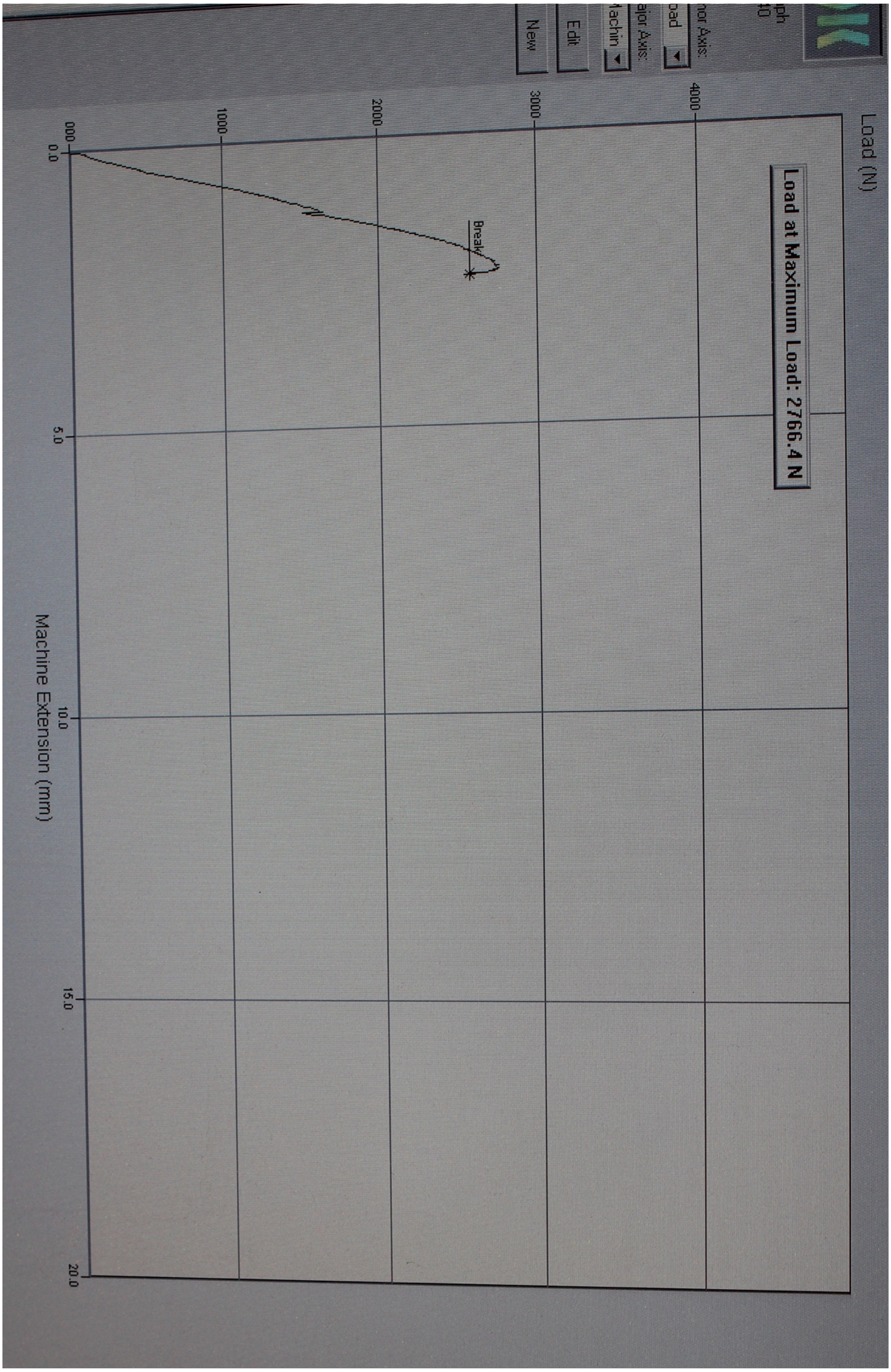
SILICATE
Sample 3



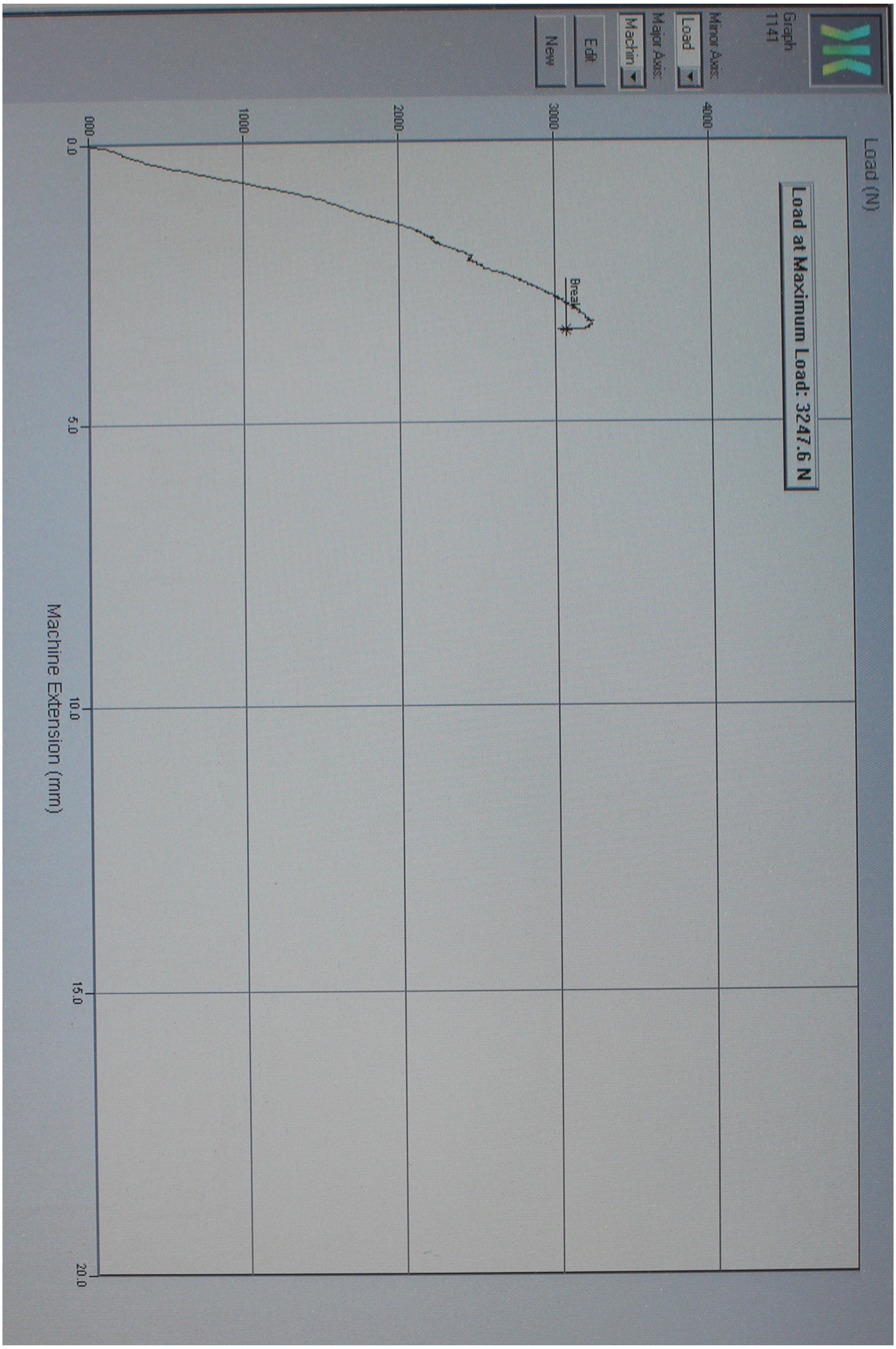
BIOTACK
Sample 1



BIOTACK
Sample 2



BIOTACK
Sample 3



Attachment 8: Calculations from the tension properties trial.

TENSION PROPERTIES TRIAL

CALCULATIONS OF THE ELASTICITY MODULUS

ΔF is based on multiplying $0.4F_{max} - 0.1F_{max}$, which gives all the samples the same base for each of the calculations.

BIOTACK
Sample 1

$$E = \frac{\Delta F \times l_1}{A \times \Delta l}$$

$$\Delta F = F_2 - F_1$$
$$\Delta F = 1071.56\ N - 267.89\ N$$
$$\Delta F = 803.67\ N$$

$$l_1 = 80.00\ mm$$

$$A = l \times b$$
$$A = 20.50\ mm \times 11.98\ mm$$
$$\mathrm{A} = 245.59\ \mathrm{mm}^2$$

$$\Delta l = l_2 - l_1$$
$$\Delta l = 0.506\ mm - 0.127\ mm$$
$$\Delta l = 0.379\ mm$$

$$E = \frac{803.67\ N \times 80.00\ mm}{245.59\ mm^2 \times 0.397 mm}$$

$$E = 609.75\ MPa$$

BIOTACK
Sample 2

$$E = \frac{\Delta F \times l_1}{A \times \Delta l}$$

$$\Delta F = F_2 - F_1$$
$$\Delta F = 1106.56\ N - 276.64\ N$$
$$\Delta F = 829.92\ N$$

$$l_1 = 80.00\ mm$$

$$A = l \times b$$
$$A = 20.30\ mm\ \times\ 12.00\ mm$$
$$A = 243.60\ mm^2$$

$$\Delta l =\ l_2 - l_1$$
$$\Delta l = 0.774\ mm - 0.357\ mm$$
$$\Delta l = 0.417\ mm$$

$$E\ = \frac{829.92\ N \times 80.00\ mm}{243.60\ \ mm^2 \times 0.417 mm}$$

$$E\ = 653.6\ MPa$$

BIOTACK
Sample 3

$$E\ = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l}$$

$$\Delta F\ =\ F_2 - F_1$$
$$\Delta F\ = 1299.04\ N - 324.76\ N$$
$$\Delta F\ \ = 974.28\ N$$

$$l_1\ = 80.00\ mm$$

$$\mathrm{A}\ \ = l \times b$$
$$\mathrm{A} = 20.30\ mm\ \times\ 11.95\ mm$$
$$\mathrm{A}\ \ = 242.59\ mm^2$$

$$\Delta l =\ l_2 - l_1$$
$$\Delta l =\ 0.882\ mm - 0.294\ mm$$
$$\Delta l = 0.588\ mm$$

$$E\ = \frac{974.28\ N \times 80.00\ mm}{242.59\ mm^2 \times 0.588\ mm}$$

$$E\ = 546.41\ MPa$$

SILICATE
Sample 2

$$E\ = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l}$$

$$\Delta F\ =\ F_2 - F_1$$
$$\Delta F\ = 418.72\ N - 104.68\ N$$
$$\Delta F\ \ = 314.04\ N$$

$$l_1 = 80.00\ mm$$

$$\mathrm{A} = l \times b$$
$$\mathrm{A} = 20.10\ mm \times 11.80\ mm$$
$$\mathrm{A} = 237.18\ mm^2$$

$$\Delta l = l_2 - l_1$$
$$\Delta l = 0.500\ mm - 0.125\ mm$$
$$\Delta l = 0.375\ mm$$

$$E = \frac{314.04\ N \times 80.00\ mm}{237.18\ mm^2 \times 0.375\ mm}$$

$$E = 282.47\ MPa$$

SILICATE
Sample 3

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l}$$

$$\Delta F = F_2 - F_1$$
$$\Delta F = 409.48\ N - 102.37\ N$$
$$\Delta F = 307.11\ N$$

$$l_1 = 80.00\ mm$$

$$\mathrm{A} = l \times b$$
$$\mathrm{A} = 20.10\ mm \times 11.80\ mm$$
$$\mathrm{A} = 237.18\ mm^2$$

$$\Delta l = l_2 - l_1$$
$$\Delta l = 0.685\ mm - 0.411\ mm$$
$$\Delta l = 0.274\ mm$$

$$E = \frac{307.11\ N \times 80.00\ mm}{237.18\ mm^2 \times 0.274\ mm}$$

$$E = 373.61\ MPa$$

DEXTRIN
Sample 1

$$E = \frac{\Delta F \times l_1}{\mathrm{A} \times \Delta l}$$

$$\Delta F = F_2 - F_1$$
$$\Delta F = 630.00\ N - 157.50\ N$$
$$\Delta F = 472.50\ N$$

$$l_1 = 80.00\ mm$$

$$A = l \times b$$
$$A = 20.00\ mm \times 12.00\ mm$$
$$A = 240.00\ mm^2$$

$$\Delta l = l_2 - l_1$$
$$\Delta l = 0.479\ mm - 0.137\ mm$$
$$\Delta l = 0.342\ mm$$

$$E = \frac{472.50\ N \times 80.00\ mm}{240.00\ mm^2 \times 0.342\ mm}$$

$$E = 460.50\ MPa$$

DEXTRIN
Sample 2

$$E = \frac{\Delta F \times l_1}{A \times \Delta l}$$

$$\Delta F = F_2 - F_1$$
$$\Delta F = 567.36\ N - 141.84\ N$$
$$\Delta F = 425.52\ N$$

$$l_1 = 80.00\ mm$$

$$A = l \times b$$
$$A = 20.10\ mm \times 11.95\ mm$$
$$A = 240.20\ mm^2$$

$$\Delta l = l_2 - l_1$$
$$\Delta l = 0.685\ mm - 0.146\ mm$$
$$\Delta l = 0.539\ mm$$

$$E = \frac{425.52\ N \times 80.00\ mm}{240.20\ mm^2 \times 0.539\ mm}$$

$$E = 262.90\ MPa$$

DEXTRIN
Sample 3

$$E = \frac{\Delta F \times l_1}{A \times \Delta l}$$

$$\Delta F = F_2 - F_1$$
$$\Delta F = 685.12\ N - 171.28\ N$$
$$\Delta F = 513.84\ N$$

$$l_1 = 80.00\ mm$$

$$A = l \times b$$
$$A = 20.00\ mm \times 12.00\ mm$$
$$A = 240.00\ mm^2$$

$$\Delta l = l_2 - l_1$$
$$\Delta l = 0.867\ mm - 0.533\ mm$$
$$\Delta l = 0.334\ mm$$

$$E = \frac{513.84\ N \times 80.00\ mm}{240.00\ mm^2 \times 0.334\ mm}$$

$$E = 512.8\ MPa$$

TENSION STRENGTH

BIOTACK
Sample 1

$$f_t = \frac{F_{max}}{A}$$

$$F_{max} = 2678.9\ N$$

$$A = l \times b$$
$$A = 20.50\ mm \times 11.98\ mm$$
$$A = 245.59\ mm^2$$

$$f_t = \frac{2678.9\ N}{245.59\ mm^2}$$

$$f_t = 10.90\ MPa$$

BIOTACK
Sample 2

$$f_t = \frac{F_{max}}{A}$$

$$F_{max} = 2766.4\ N$$

$$A = l \times b$$
$$A = 20.30\ mm \times 12.00\ mm$$
$$A = 243.60\ mm^2$$

$$f_t = \frac{2766.4\ N}{243.60\ mm^2}$$

$$f_t = 11.36\ MPa$$

BIOTACK
Sample 3

$$f_t = \frac{F_{max}}{A}$$

$$F_{max} = 3247.6\ N$$

$$A = l \times b$$
$$A = 20.30\ mm \times 11.95\ mm$$
$$\mathrm{A} = 242.59\ \mathrm{mm}^2$$

$$f_t = \frac{3247.6\ N}{242.59\ mm^2}$$

$$f_t = 13.39\ MPa$$

SILICATE
Sample 1

$$f_t = \frac{F_{max}}{A}$$

$$F_{max} = 930.34\ N$$

$$A = l \times b$$
$$A = 20.10\ mm \times 11.80\ mm$$
$$\mathrm{A} = 237.18\ \mathrm{mm}^2$$

$$f_t = \frac{930.34\ N}{237.18\ mm^2}$$

$$f_t = 3.92\ MPa$$

SILICATE
Sample 2

$$f_t = \frac{F_{max}}{A}$$

$$F_{max} = 1046.8\ N$$

$$A = l \times b$$
$$A = 20.10\ mm\ \times\ 11.80\ mm$$
$$\mathrm{A} = 237.18\ \mathrm{mm}^2$$

$$f_t\ = \frac{1046.8\ N}{237.18\ mm^2}$$

$$f_t\ = 4.41\ MPa$$

SILICATE
Sample 3

$$f_t\ = \frac{F_{max}}{A}$$

$$F_{max}\ = 1023.7\ N$$

$$A = l \times b$$
$$A = 20.10\ mm\ \times\ 11.80\ mm$$
$$\mathrm{A} = 237.18\ \mathrm{mm}^2$$

$$f_t\ = \frac{1023.7\ N}{237.18\ mm^2}$$

$$f_t\ = 4.32\ MPa$$

DEXTRIN
Sample 1

$$f_t\ = \frac{F_{max}}{A}$$

$$F_{max}\ = 1575.0\ N$$

$$\mathrm{A}\ = l \times b$$
$$\mathrm{A} = 20.00\ mm\ \times\ 12.00\ mm$$
$$\mathrm{A}\ = 240.00\ mm^2$$

$$f_t\ = \frac{1575.0\ N}{240.00\ mm^2}$$

$$f_t\ = 6.56\ MPa$$

DEXTRIN
Sample 2

$$f_t = \frac{F_{max}}{A}$$

$$F_{max} = 1418.0\ N$$

$$A = l \times b$$
$$A = 20.10\ mm \times 11.95\ mm$$
$$\mathrm{A} = 240.20\ \mathrm{mm}^2$$

$$f_t = \frac{1418.0\ N}{240.2\ mm^2}$$

$$f_t = 5.90\ MPa$$

DEXTRIN
Sample 3

$$f_t = \frac{F_{max}}{A}$$

$$F_{max} = 1712.8\ N$$

$$\mathrm{A} = l \times b$$
$$\mathrm{A} = 20.00\ mm \times 12.00\ mm$$
$$\mathrm{A} = 240.00\ mm^2$$

$$f_t = \frac{1712.8\ N}{240.00\ mm^2}$$

$$f_t = 7.14\ MPa$$

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