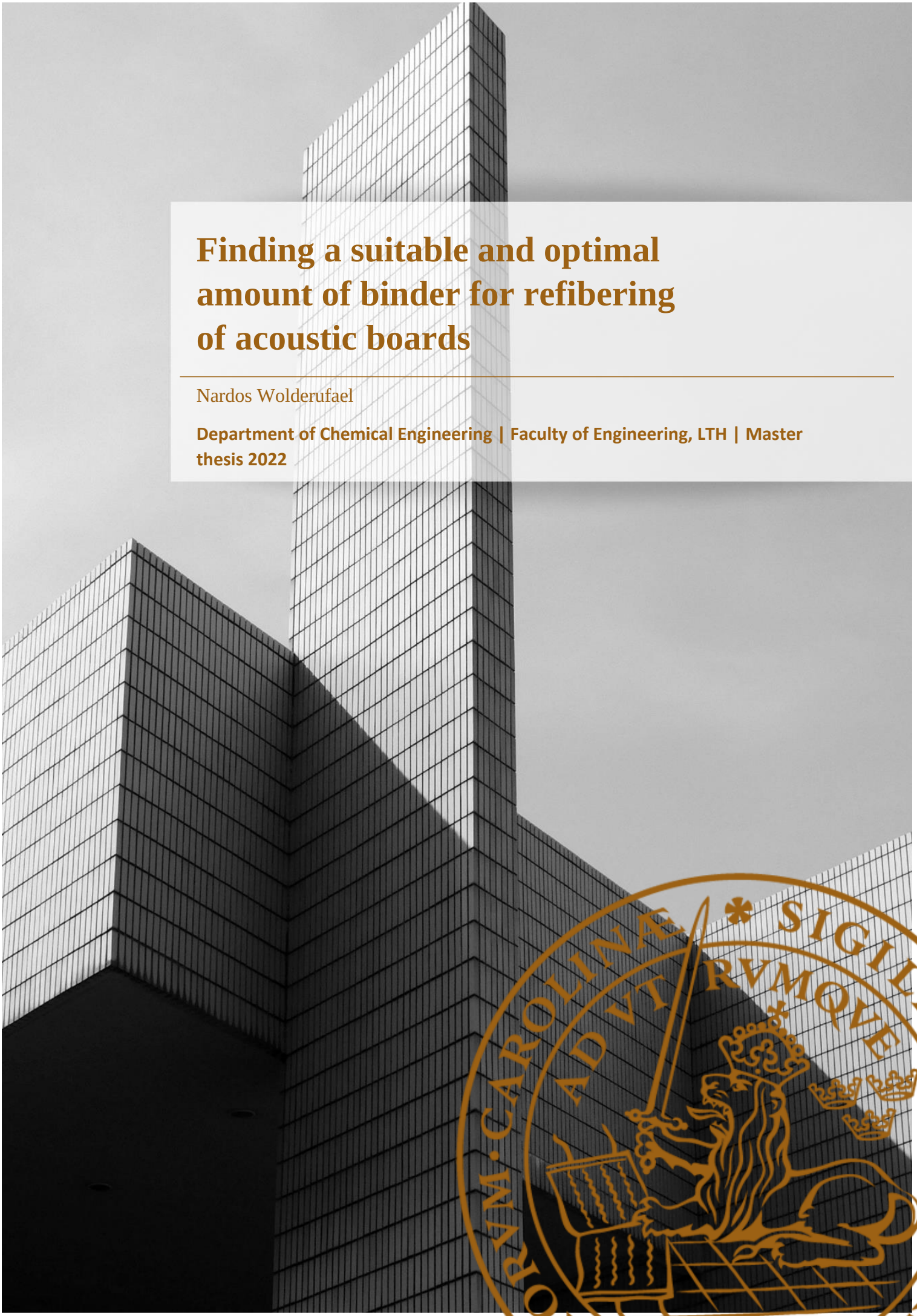

Finding a suitable and optimal amount of binder for refibering of acoustic boards

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Department of Chemical Engineering | Faculty of Engineering, LTH | Master thesis 2022

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Saint-Gobain Ecophon

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Abstract

Ecophon are one of the world leaders in the construction market and they have a strong focus on sustainability and innovation. Ecophon produce and advances in acoustic products and systems with the aim to create an environment that is suitable for the human ear. The acoustic tiles are made from porous glass fiber wool that is held together with a binder.

With the ambition to contribute to a sustainable development, Ecophon have started a project with the aim to recycle and reuse acoustic tiles. The idea behind the project is to shredd acoustic tiles that come from waste product or simply just worn out old tiles, and make them into new fresh acoustic tiles. In order to achieve this, a sutible binder is needed to hold the acoustic tiles together. The aim of this thesis was to evaluate different binder types as well as to try to find the optimal amount of binder for the product that is being developed. The different properties that were evaluated includes, fire, mechanical and acoustic properties of the product. In this thesis both liquid binders, (e.g. Acrylc binders), as well as solid binders(e.g. bicomponent fibers) are evaluated.

The questions that were investigated include:

-Is it possible recycle and reuse acoustic tiles made of glass fiber wool by optimizing the binder and binder amount?
-Is there a significant difference on the environmental impact between a virgin and recycled product?

The experiments showed that it is in fact possible to recycle and reuse acoustic tiles, and still manage to reach adequate properties

of the tiles. The environmental impact is also less for recycled tiles. However there is still alot more studies that needs to be conducted in order to achieve a perfect product.

sammanfattning

Ecophon är en av världsledarna inom byggmarknaden och de har ett stort fokus på hållbarhet och innovation. Ecophon producerar och utvecklar akustiska produkter och system med syftet att skapa en behaglig miljö. Akustikplattorna är gjorda av glasfiberull som hålls samman med ett bindemedel.

Med ambitionen att bidra till en hållbar utveckling har Ecophon startat ett projekt där syftet är att återvinna och återanvända akustikplattor. Tanken bakom projektet är att riva akustikplattor som kommer från restprodukter eller akustikplattor som helt enkelt blivit utslitna och gamla och återanvända dessa. För att uppnå detta behövs ett lämpligt bindemedel för att hålla ihop plattorna. Syftet med detta examensarbete var att utvärdera olika bindemedelstyper samt att försöka hitta den optimala mängden bindemedel för produkten. De olika egenskaperna som utvärderades var, produktens brandegenskaper, samt mekaniska och akustiska egenskaper. I denna avhandling utvärderades både flytande bindemedel, (t.ex. akrylbindemedel), såväl som fasta bindemedel (t.ex. Bi-komponent fiber).

Frågeställningen löd;

-Är det möjligt att återvinna och återanvända akustikplattor gjorda på glasfiber ull genom att optimera bindemedel och bindemedelsmängd?
-Finns det en betydande skillnad på miljöpåverkan mellan en helt ny och återvunnen produkt?

Experimenten visade att det faktiskt är möjligt att återvinna och återanvända akustikplattor, och ändå lyckas uppnå adekvata egenskaper hos plattorna. Miljöpåverkan är också mindre för återvunna

akustikplattor. Dock måste djupare studier genomföras för att uppnå en perfekt produkt.

Acknowledgement

First and foremost, I would like to express my deepest gratitude to my supervisor Tommy Månsson, for his continuous support, encouragement, and his enthusiasm to help me with this thesis. I could not have asked for a better supervisor and mentor for this project.

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Contents

Abbreviation

AFR -Air flow resistance

Bico-fiber -Bi-component fiber

Board -Base board

FP - Fiber Partner

FP bio - PrimaLoft Bio

FV - Fiber vision

IL -Intraloc

Plus 2580 -Acrodur plus 2580

SS -Sodium silicate

Terms

Base board -Base board is the glass wool board used to make the acoustic tiles

Prototype - Hand made base boards with different binders.

virgin base boards - Freshly produced base boards, i.e. boards made at Isover (Not recycled)

Chapter 1

Introduction

This section will give a brief introduction of the company and the project, as well as the question at issue. A disposition is also included to give an overview of the structure of the report

1.1 Ecophon

Ecophon is a subsidiary of the French multinational corporation Saint-Gobain. Saint-Gobain was established in 1665 in Paris and they produce a variety of different construction and high performance materials. They are one of the world leaders in the construction market and have a strong focus on sustainability and innovation [28].
Ecophon produces and advances in acoustic products and systems that contribute to people's well being. The promise the company makes is, "A sound effect on people " which is the cornerstone of the company. The purpose of their products is to create an environment that is suitable for the human ear. Schools, offices and hospitals are prime examples of where good sound quality is needed to achieve good results of the work.
Ecophon has around 800 employees and business units in 14 countries, and then delegations in 30 other countries. The head office is however based in Hyllinge, Sweden[29].

The acoustic boards produced by Ecophon are made of porous glass fiber wool. The glass fiber wool is a very light weight material and has great sound absorption properties in the middle and high range frequencies. The glass wool that Ecophon use for their products consists of 70% recycled glass. The products can either be made of 2nd generation glass wool that is bound with a phenolic based binder or 3rd generation glass wool with a plant based binder. The products made from the 2nd generation wool is used in markets with specific climate conditions, meanwhile the 3rd generation products are used for the remaining markets [33]. Ecophon are constantly working on minimizing the effect of their activity on the environment, and so far they claim to have the lowest CO_2 emissions in the business, per produced square metre of acoustic tile [33].

1.2 History

Billesholm Glasulls AB was founded in 1933 and at this time, using glass wool as an isolation material was still a new concept. In 1967 the brand changed name from Billesholm Glasull to Gullfiber, and in 1986 the french corporation Saint-Gobain became the owners of Gullfiber.
Jan Lövström who were an engineer and entrepreneur, worked at Gullfiber when he by a coincidence discovered the acoustic properties of glass wool. He then established the subsidary, Gullfiber Akustik AB together with a small team, and in 1988 the company changed name to Ecophon. The company name Ecophon was bought as a brand from Denmark, and with that purchase they also got a factory in Næstved, Denmark[38].

1.3 Products

The glass wool for the products are retrieved from facilities near the production sites, e.g Saint-Gobain Isover. The glass wool, also called base board, has a rectangular shape and during the manufacturing of an acoustic tile, the base board is cut and shaped into the desired dimensions and then coated with paint for aesthetic reasons.

Ecophon offers a range of different product families, each of these consists of various systems that meets up to different requirements based on its properties, edge design, form and shape. Each system has its specific property and has been developed to fit a specific end use [32].

1.4 Sound circularity project

Managing the resources of the world has become an important aspect to consider during product development. It is something that require environmental awareness, as well as knowledge and continuous improvement of the products. The base board that is used at Ecophon is made of 70% recycled glass , and the rest consist of newly produced glass from sand [32]. The grids used for the ceiling tiles are also produced at Ecophon and they are made of 50% recycled steel. The ceiling tiles are completely recyclable and there are several projects on how the recycled material can be used. All of this is incorporated into the SoundCircularity project at Ecophon. The idea of this program is to develop methods that makes it possible to achieve a circular business model which in turn would reduce the environmental footprint, see figure 1.1[34].

Figure 1.1: Sound circularity business idea [33]

1.5 Problem description

This thesis will be directly linked to the re-fiber project that is currently in run at Ecophon. The aim of the thesis is to find a suitable binder for recycled acoustic tiles, that is, tiles that have been shredded and minced to smaller pieces. Finding a suitable binder will include, the brand, type, and amount of binder that is used for the end product. The environmental impact of the recycled product will also be compared to a virgin board (freshly produced baseboards, i.e. boards made at Isover). The chosen binder needs to fulfill the demands and standards that Ecophon has on their product. The primary focus will be on finding a binder that can reach a high fire class standard, in other words making a board that has an acceptable fire classification for ceiling and wall linings applications in buildings. Another crucial aspect that needs to be considered is the mechanical properties of the board. The boards need to have the proper mechanical properties in order to form and process the boards into acoustic tiles. The mechanical strength of

the board is also necessary for the installation of the acoustic tiles. The acoustic properties of the board will also be evaluated.
In order to evaluate the binders, small prototypes of the boards are made. This thesis will therefor include the process to find the ideal way to create the prototypes. This process needs to be relevant to the way the baseboards will be manufactured henceforward. The aim of the project is to develop a sustainable prototype made of recycled and shredded glass wool that can reach a high fire class standard, but that also fulfill other demands such as the mechanical and acoustic properties.

Question at issue:

- *Is it possible recycle and reuse acoustic tiles made of glass fiber wool by optimizing the binder and binder amount?*
- *Is there a significant difference on the environmental impact between a virgin and recycled product?*

1.6 Limitation

This project needs to be conducted within the time limit of this thesis which is 6 month. Another constraint is the number of binders that will be evaluated. This depends on the respond time of each binder supplier as well as the delivery time. The process to make the prototypes will differ from how these will be produced once the productions are scaled up.

1.7 Disposition

1.7.1 Introduction

This section will provide some background information and history of the company and the products that they offer. The problem description of the project is also included.

1.7.2 Method

The method section will incorporate explanations on how the literature study and the experimental part is planed to be conducted.

1.7.3 Literature study

The literature study presented in this thesis will cover the information needed in order to make the right choices aimed for this project. It also provides some basic information for the reader.

1.7.4 Analyzing methods

This section will provide information about the chosen analysis methods, cone calorimeter, three-point flexural test, air flow resistance measurement, and thermal analysis. Brief description of, how each analysis technique work as well as the aim will be presented in this section.

1.7.5 Material and tools

All material and tools used to make the prototypes are shown in this section.

1.7.6 prototypes

Detailed information on how the prototypes are made will be found in this section. It will also include some issues that were encountered and how these were resolved, the experimental plan and a quick evaluation of the binders, before any further analysis is carried out.

1.7.7 Results and Discussion

The result from each analysis technique will be provided in this section. This will include results from the TGA, DSC, cone calorimeter, Air flow resistvity, three point flexural test as well as CO_2 estimation of the product. The CO_2 estimation of the product will give a an overview of the environmental impact of the refiber product.

1.7.8 Conclusion and future work

In this section the result will be compiled and the question at issue will be answered. Some suggestions for future work will also be mentioned.

Chapter 2

Method

This section will give a brief description and explanation to the research design choices that were used in this thesis

2.1 Literature study

The first part of this project included a literature study on the overall research question of the thesis. This was necessary to get a broader understanding of the topic as well as to gain information on previous study made within the field. Making a comprehensive literature study on related topics was crucial to have a stable foundation to build the thesis on. The main strategy was to review different research papers, both internal and external resources, but also discussing the matter with relevant people within the field.

2.2 Research on binders

Conducting a thorough research on the available binder types was a central part of this project. This step made it possible to be selective of the binder types which was necessary in order to finish the project at the set time limit. Internal sources set the groundwork for the rest of the research making it easier to know what to look for. When

searching for binders the most important factors to consider given that the binder is suitable for the wool, is if the binder constitutes any health risks and if the fire properties would be good enough. The environmental impact of the binder was also considered, meaning a bio based or or a binder with recycled components was preferred.

2.3 Prototypes

In order to evaluate the selected binders it was essential to make prototypes. Creating smaller prototypes of the baseboard made it possible to try several different binders and combinations with the tools that were available at Ecophon without using a redundant amount of material and money. Making prototypes also sped up the evaluation process rapidly. The finished prototypes could then be used in different testing methods to assess the binders.

2.4 Evaluation methods

Different evaluation methods were used in order to asses the properties of the binders. Each binder was first analyzed with a differential scanning calorimeter (DSC) as well as a thermogravimetrical analyzer (TGA) in order to understand the thermal properties of the binders.
The finished prototypes, were then used to make fire tests, using a cone calorimeter, three point bending test to evaluate the mechanical strength of the board, followed by air flow resistance tests (AFR) to check the acoustic properties.

2.5 The Loop Factory

The re-fiber project at Ecophon is in collaboration with a small company called The Loop Factory (TLF) which is based in Varberg, Sweden. TLF focus on technology for sustainable material development where a low carbon impact is fundamental, as well as

the recourse efficiency.
Scaled up trial runs made for previous studies within the refiber project have been conducted at The Loop Factory where they offer an airlay machine to create the base boards. A study visit to TLF is done early on during this project to get an enhanced understanding of the process.

2.6 CO_2 estimation of the products

A CO_2 estimation is done on the products in order to compare the environmental impact. The calculation of the CO_2 amounts are based on numbers from, life cycle assessments (LCA). LCA is a tool used to evaluate the environmental impact of a product over its life cycle. The numbers are presented with the unit, kg CO_2/m^2 material. The numbers are taken from the life cycle assessment database, GaBi.

Chapter 3

Literature study

This section will provide information needed to get a better understanding of the purpose, process and aim of the project. The standards and regulations that Ecophon follows will also be included in this section in order to gain a deeper understanding of the demands on the products.

3.1 Sustainability

The term "sustainability" has been given much notice the last couple of years. There is no set definition of the word "sustainability" and there are many different opinions on this concept. A suggested definition of the word was set by the World Commission on Environment and Development, as follows:

A process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations[1]

The impact of our activity on the environment have resulted in changes, many of these are damaging changes and as the global population has grown the demands on the resources of the earth continue to grow [22] In order to preserve the environment and keep

using the assets, it is important to find sustainable ways to do so. The responsibility doesn't only lay on governments and organisations but corporations as well. So it is of priority to minimize the impact a product have on the earth [1].

With the intention of reducing the environmental impact, many countries have incorporated laws and regulations in order to govern the human activity. By fulfilling these laws and regulations the environmental footprint has reduced drastically [22]. The regulations and standards followed by Ecophon will be presented in section 3.3.

3.1.1 Life cycle assessment- LCA

A commonly used tool to help assist for sustainable decision making and product development is a LCA, which stands for life cycle assessment. A LCA is conducted in order to evaluate the impact of a product, process or activity. It accounts for both direct and indirect environmental impacts during the full life cycle of a product, from raw material, to manufacturing, end use and finally the disposal, see figure 3.1. In a LCA the material and process steps which pose the greatest impact on the environment and human health as well as the steps which require the most material are identified. This makes it easier to choose the most effective solution when one is needed [22].

Figure 3.1: System of LCA [22]

3.1.2 Environmental product declaration EPD

An environmental product declaration (EPD) is a document that contains environmental information for products and their applications. An EPD is based on LCA calculations, and it is expressed in information modules which makes it easy to compare different products at different stages [36].

According to the SS-EN 1504:2012 standard provided by the Swedish Institute for Standards, the modulus for construction material can be divided into A1-A3,A4-A5,B1-B7 C1-C4 and module D, see figure 3.2.

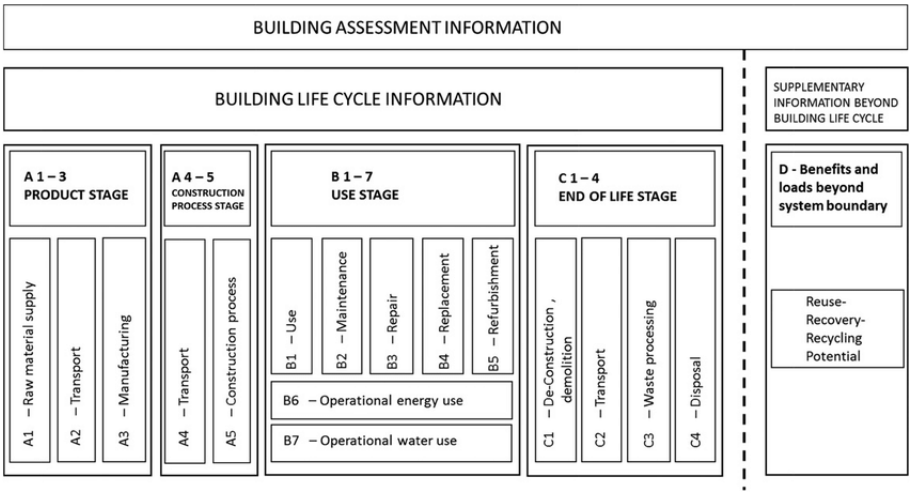


Figure 3.2: Different modulus with respect to LCA stages [15]

Information modules A1-A3 are called the production stage. The production stage consists of:

- A1- Raw material, extraction and processing, processing of secondary material such as recycled material.
- A2- Transportation to the manufacturer
- A3-Manufacturing

Stages A4-A5 are called the construction process stage, this include:

- A4- Transport to the building site
- A5-Installation into the building.

Stages B1-B7 are called the use stage, which include:

- B1- Use or application of the installed product
- B2- Maintenance of the product
- B3- Repair

- B4 Replacement
- B5- Refurbishment
- B6-Operational energy use
- B7- Operational water use

C1-C4-End of life stage:

- C1-De-construction
- C2-Transport to waste processing
- C3- Waste processing for reuse
- C4-Disposal

Module D is considered beyond the system boundary of the LCA, and it includes recover/recycling potentials [36].

The relevant part for this thesis will be module A1-A3, given that this is a new product that is still in the development stage.

3.2 Performance requirement

Following subsections will describe the product performance requirement that Ecophon has on their products. These can work as important guidelines during product development by recognizing the demands on the finished product, hence making it easier to choose materials to work with.

3.2.1 Fire properties

When developing construction material it is of priory to consider the fire properties of the chosen components. A fire can develop very fast and therefor it is important to consider the fire safety of the material. The requirement of the fire protection for the suspended ceiling (A secondary ceiling, hung below the main ceiling)

varies depending on the building. According to Boverket's building regulation (BBR, Swedish regulation) a building should have either class, Br1, Br2 or Br3, where Br1 is the highest class. Buildings where a fire could cause a higher risk of injures, are required to have the highest class, Br1. This include buildings with three or more floors. At the initiation of the fire, that is before the material catch on fire, there is mainly three demands on the product that should be met in order for the ceiling tiles to have good fire properties [32].

1. The suspended ceiling should not have a meaningful contribution to the fire and smoke development.
2.The ceiling tiles should not fall down meanwhile people are evacuating or when rescue operation is ongoing. In order to fulfill this demand, the product should withstand a temperature of 300 °C for around 10 minutes.
3. The ceiling tiles should prevent the combustible material behind it to catch on fire [32].

A fully developed fire in a room can be divided into different phases. The first phase is the initiation phase, which is dependent on the size and properties of the ignition source. The second phase is the growth phase, this when the fire gets bigger and starts affecting surrounding materials as well. Both heat and smoke starts to develop, and when the temperature of the smoke reaches 500-600 degree C, the intensity of the fire is so high that all combustible material in the room catch on fire. Once this happens the fire reaches its maximum and is fully developed. The time and intensity of the fire will primarily depend on the amount of oxygen and combustible material that is available. Eventually the cooling phase is reached, this is when the fire cease and the temperature decreases [32].

Building regulations are usually national and differ from country to country, meanwhile standards can be international, such as the EN- or ISO-standards. The classification system for surfaces and material in Europe is called Euro-class. There are a total of 39 classes divided into seven subgroups, A1, A2,B,C,D,E and F, where A1 is the highest grade and F means non classified. The subgroups can also have additional classes applicable for the smoke development and the presence of falling flaming pieces of material. The addition for smoke development is divided into classes called s1, s2, and s3,

where s1 is the best. The classes for burning particles and droplets are called, d0, d1 and d2 where d0 is the best. However BBR only use five of these classes, A1, A2-s1,d0, B-s1,d0, C-s1,d0, D-s2,d0 and class E [32].

3.2.2 Indoor environment

The indoor environment has a great impact on the overall human health. A bad indoor environment that consists of dust and emissions have contributed to the increase of allergies and stress related diseases. Having a good indoor environment is therefor of priority when assembling new buildings or during reconstruction. The quality of the indoor air can depend on several different factors, e.g. pollution of the air. Indoor air pollution can be caused by natural release of particles from the materials used indoors. These particles are called volatile organic compounds (VOCs). Construction material can have a big effect on the indoor environment, thus it's critical to chose material with low emissions [32].

There are different certifications that represents the quality of construction material and its contribution to the indoor environment. Indeklima-mærkning (DIM) (see figure 3.3) is a type of certification for the product, which means that the material is controlled with regards to emissions and its decay time. The measurements are performed in order to indicate how long it takes for emissions of ammonia, formaldehyde , VOCs, particles and fibers to decrease to the levels that are acceptable [32].

Figure 3.3: Indeklima-mærkning (DIM) [32]

3.2.3 Mechanical strength

The mechanical properties of the board refer to the load and stress that the tile can handle. The acoustic system which consist of both the grids as well as the tiles (see figure 3.4), are both subjected to different type of stress. During the development it is important to consider all type of mechanical stress the system can be exposed to [32].

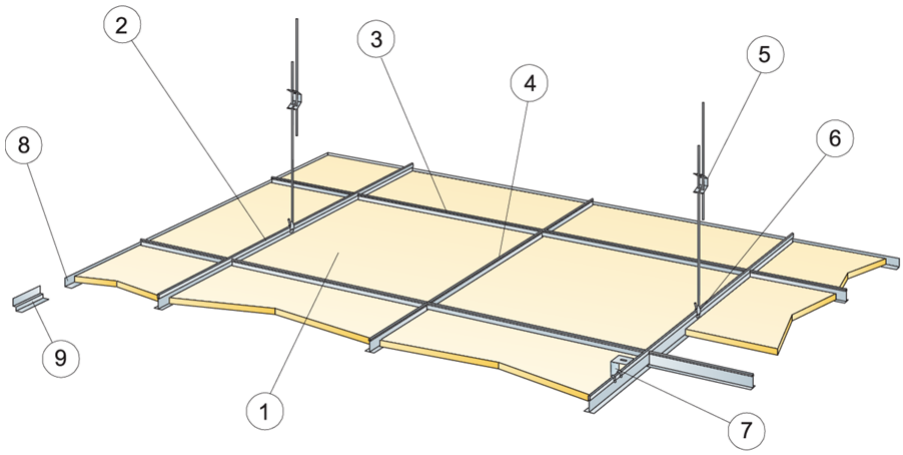


Figure 3.4: Ceiling tiles together with corresponding grid system [32]

Fundamentally the tiles should not be exposed to any stress except to its own weight. All of the excess load such as ceiling vents should be placed on the rigs. However ceiling tiles with the dimensions 600X600 mm and 1200X600 mm should be able to bear small loads such as spotlights. Ceiling tiles that are 20 mm or thicker, the maximum load is 500 g and an opening diameter of maximum 100 mm (see figure 3.5) . Tiles that are 15 mm thick the maximum weight is 300 g. Soundabsorbers that exceeds the dimension of 1200x600mm should not be subjected to any load at all [32].

The dynamic loading capacity is a measurement of how many hits/knocks a tile can withstand. The requirement of having tiles with a high dynamic loading capacity depends on what type of environment the tiles are installed in. The dynamic load could be caused by such as, single hits from balls but it could also be the pressure difference in

a room that is caused by doors being opened and closed.
There are several ways to evaluate the resistance of the tiles. Ecophon use a method called Ballwurfsicherheit according to EN13964 and also some internal methods. The methods involve a ball hitting the system and then evaluating the tiles visually [32].

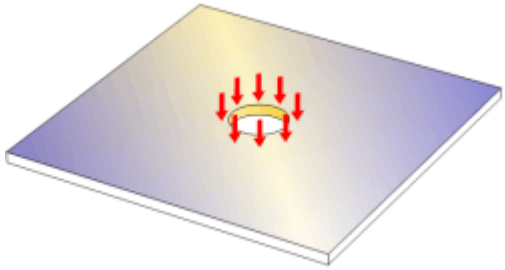


Figure 3.5: opening hole on a tile.The load should be evenly distributed around the opening to avoid any dents [32].

3.2.4 Acoustics

Noise is defined as unwanted or disturbing sound. Several studies has shown that constantly being exposed to noise has a negative effect on the human health as well as other organisms. Sound, which is measured in decibels, ranges between 0dB which is almost total silence up to 120dB which is the threshold of pain. Being exposed to noise for long periods of time could lead to health problems such as, hearing loss, high blood pressure, heart disease, sleep disturbances, and stress. This is relevant for people of all ages but particularly children. Children that lives near noisy streets can develop stress, impairments in memory, and a reduced attention level. [25]

When speaking about a room with good acoustic environment, it usually means that the wanted sound is enhanced meanwhile noise is eliminated or suppressed. This means that there needs to be a balance between the reverberation time (The reverberation time is defined as the time it takes for the sound to decrease with 60 dB.), background sound, and speech intelligibility, and at the same time having an efficient sound isolation. Good acoustic in a room, is usually linked directly to a short reverberation time. The total sound absorption and hence the reverberation time are important

factors for the speech intelligibility and the sound levels. There are different methods to measure both the reverberation time as well as the absorption. The sound absorption properties are classified according to the EN-ISO 11654 which gives the sound absorption classes A-E, where A is the highest class, see figure 3.6. [32].

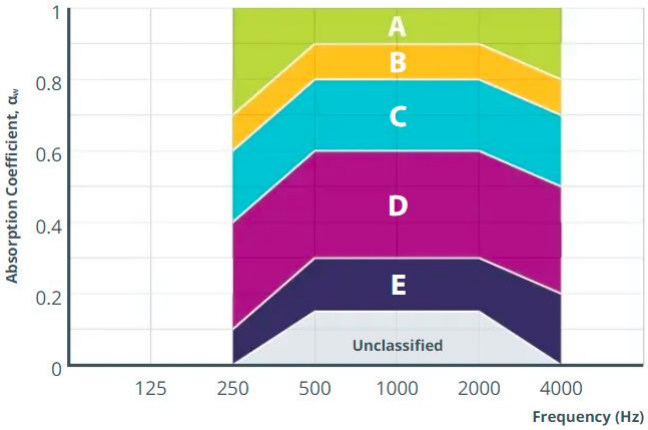


Figure 3.6: Sound absorbing classes according to the standard EN-ISO 11564 [2]

ISO 9053-1:2018, is another standard that is used by Ecophon for the acoustic measurements. The ISO 9053-1:2018 describes how to determine the airflow resistance of porous materials for acoustical applications [17].

The air flow resistance is defined as the pressure difference across the test specimen divided by the volumetric airflow rate passing through the test specimen, see equation 3.1

$$R = \frac{\Delta P}{q_v} \tag{3.1}$$

The unit is expressed in pascal second per cubic meter.

The specific airflow resistance can then be defined as,

$$R_s = R \times A \tag{3.2}$$

Where A is the cross section area of the specimen. The unit is

expressed as pascal second per metre [17]. From the specific airflow resistance the airflow resistivity can be calculated as,

$$\sigma = \frac{R_s}{d} \tag{3.3}$$

Where d is the thickness of the test specimen. The unit is given in pascal second per square metre [17].

For this thesis the airflow resistivity, σ is of interest. The air flow resistivity can also be used to get an approximation of the absorption coefficient, α_w.

The airflow resistivity should be in a specific range depending on what density the product has. Following values are given (see table 3.1)

Table 3.1: Recommended values for AFR-measurements [13]

Density [kg/m^3]	Air flow resistivity [Pa*s/m^2]
$\rho \leq 35$	8 700-19 000
$54 \leq \rho \geq 65$	30 000- 43 000
$75 \leq \rho \geq 85$	42 000- 62 000
$90 \leq \rho \geq 110$	52 000- 75 000
$100 \leq \rho \geq 120$	72 000-95 000

3.3 Acoustics

This subsection will cover some basic knowledge about acoustics and its significant impact on the human health.

3.3.1 Basic knowledge

We spend approximately 90% of our time indoors, meaning the importance of creating an ideal acoustic environment is more important now than ever. An ideal sound environment can be explained as something that comes as close to the acoustic environment of the

nature, which means that there are no sound reflections from ceiling and walls. This is due to the fact that the human auditory sense is adapted to an outdoor environment and not the typical indoor environment [30].

The easiest way to get a large sound-absorbing surface area, is by incorporating a wall-to-wall acoustic ceiling. This will minimize the strength of the sound as well as the reverberation time and it will increase the speech clarity as well as the hearing comfort. A further approach to reach optimal sound environment would be to place the sound absorbers more strategically throughout the space [30].

Figure 3.7 shows what happens with the sound energy once it hits a surface in the room. Some of the energy penetrates the surface leading to absorption and transmission and some of the energy is reflected back into the space. Absorbed energy is converted to heat energy in the material and the amount of energy that is absorbed depends on the properties of the material. The sound absorption properties of a material can be described by the absorption coefficient α as a function of the frequency of the sound. α can have a value between zero which is total reflection and one which is total absorption in the material [31].

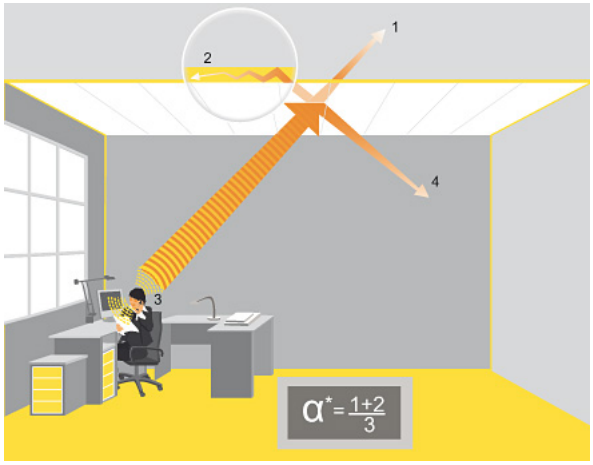


Figure 3.7: Shows what happens to sound wave when it hits an object; 1.Transmitted energy. 2. Absorbed energy. 3.Incident energy. 4;Reflected energy. α = absorption coefficient [31].

Another option to characterizing the acoustic properties is by mea-

suring the air flow resistance of the material. The air flow resistance is defined as the resistance of an air particle penetrating the material. This can be described as the ratio between the pressure difference on both side of the specimen to the airflow, see equation 3.1. The sound absorption characteristic of a material is improved with a higher resistivity up to a certain value, and the absorption decreases once the resistvity is greater than this value. The same goes for a small air flow resistvity value. The resisitvity value is closly related to the fiber morphology, size, density, porosity, and arrangements [27].

3.4 Polymers

Polymers are large organic molecules that are made of smaller units called monomers. Polymers can be found in most of the everyday essentials, such as rubber, plastic, adhesives, and paint. The length of a polymer can vary between 10-1000 nm, hence the molar mass also varies. Polymers consist of different sized molecules, consequently polymers are characterized by their average molar mass [9].
Polymer chains can either have a random orientation, this state is called the amorphous state, or they can have a well organized structure and this is known as the crystalline state. Polymers are usually never fully crystalline, but a mixture of the two, this is called the semi crystalline state, see figure 3.8.
Above the glass transition temperature, T_g, the amorphous part of the polymer tuns rubbery and soft, and at the melting temperature the polymer turns into liquid [9]. Additionally the polymers can be characterized by their properties, e.g thermoplastics and thermosets, see section 3.4.2 and 3.4.3.

3.4.1 Synthesis of polymer

Polymers are synthesised when thousands of monomer units are joint together end to end by covalent bonds. This can happen through different reaction mechanisms such as polyaddition and polycondensation.

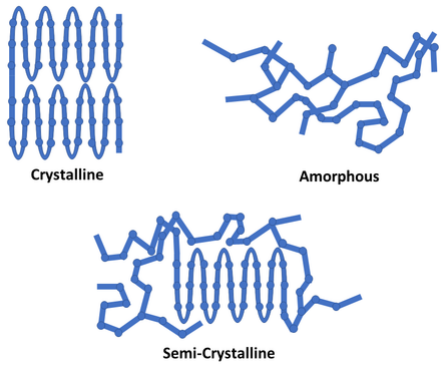


Figure 3.8: Schematic figure of amorphous, crystalline and semi-crystalline polymer[8].

A polymer that consist of only one type of repeating unit is called a homopolymer and if it consist of more than one type of monomer it is called a copolymer. The type of monomer and the distribution of the monomers are two important factors for the properties of the polymer, see figure 3.9. For instance, a random polymer only exhibits one T_g, meanwhile block and graft polymers have a T_g for each element involved [9].

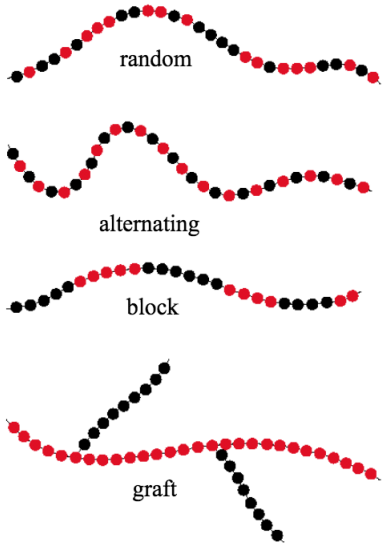


Figure 3.9: Different types of copolymers [19]

There are different types of reaction mechanisms when synthesising polymers. One of them is called polyaddition, where the polymerization reactions arises as a reaction between functional groups such as, hydroxyl, amino, or epoxy groups. The monomers are added together in behalf of the oxygen or nitrogen atoms, and the reaction continuous as long as there are any remaining reactive groups on each monomer.
Another type of mechanism is polycondensation. In the process the monomers are linked together meanwhile a low molecular substance such as water or methanol is eliminated [9].

3.4.2 Thermoplastics

Polymers which soften and melts upon heating are also known as thermoplastics. Because of their ability to melt, these polymers can be molded and recycled. The polymer chains are held together with Van der Waals forces and entanglements, and the absence of cross links results in a polymer that can easily stretch under load. The mechanical properties of a thermoplastic is highly dependant on the temperature. Below the glass transition temperature,T_g the polymers have a glass like property, once the temperature passes, T_g the thermoplastic acts more rubbery, and at very high temperatures the polymers are more or less fluid, see figure 3.10. In table 3.2 the T_g and melting temperature of some common thermoplastics are presented.

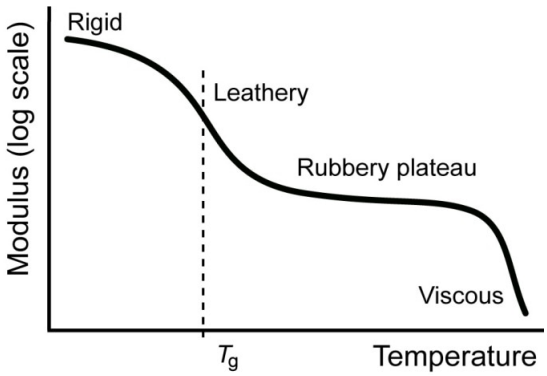


Figure 3.10: The elastic modulus as a function of temperature[9].

Polymer	Glass transition temperature	Melting temperature
Polyethylene	-120 °C	115 °C
Polyvinylchoride (PVC)	87°C	175-212 °C
Polystyrene (PS)	85-125°C	240°C
Polypropylene (PP)	-16°C	168-176°C
Polyester (PET)	75°C	255°C

Table 3.2: Glass transition temperature T_g and melting temperature for some common thermoplastics [9].

3.4.3 Thermoset

Unlike thermoplastics, thermosets form a 3D structure by cross linking. The macromolecules are joint together by a strong force, making the movement of individual macromolecules almost impossible. This results in a rigid and brittle material with an exceptional structural strength. Once the thermoset has cured, it is no longer possible to thermally mold it again, which means that it can not be recycled. Some significant thermosets are

- Phenolic resins.
- Melamine-formaldehyde resins.
- Epoxy resins [9].

3.4.4 Additives

If a specific property is desired for a polymer, additives can be used to enhance these properties. Some common additives that are used are, fillers which can be used to increase the strength of the polymer as well as reduce the costs, pigments, stabilizers that prevents decomposition of the polymer in different environmental conditions, and flame retardants (FR) [9]. Flame retardants are used to decrease the flammability of many polymers, however the disadvantage of many FR are that they contain halogenated compounds which have a negative effect both on the environment as well as the human health. These FR are therefor usually avoided [35].

3.5 Binder types

The binders that are mentioned in this subsection include, binders that are currently in use, tested or considered for this project.

3.5.1 Phenolic formaldehyde resins

Phenolic resins are the traditional thermoset binders that are used both in mineral wool and in other applications. Phenolic resins have the best result when it comes to the ratio of cost to performance [20]. It consist of the two monomers- phenol and formaldehyde. These two monomers react and result in two types of phenol formaldehyde resins (PF)- Novolac and Resole type resins, see figure 3.11. Resoles crosslink once heat is applied and novolacs is crosslinked by adding a curing agent [4]. The main difference between these two is the process of how it is produced. Novolac is produced with excess phenol and an acid or metal catalyst and Resoles are produced with excess formaldehyde with a basic catalyst. Urea is usually also added to the PF-resin. It acts as a formaldehyde scavenger and also improves the fire resistance of the binder [20].

The advantages of using PF-resin in mineral wool is the fact that it contributes to a high mechanical strength that prevents delamination of the wool, it has a great moisture resistance which means it can be stored outside for a longer period of time without the wool losing its properties. PF-resins also have have a good thermal stability and low flammability. Further more, the PF-resin makes it a non ideal environment for the growth of mold and bacteria [20].
Despite the good properties of PF-resins, the health and environmental concerns dominates, making it desirable to replace it with something more eco-friendly. One major concern when using PF-resin in mineral wool is the fact that the formaldehyde has a very high vapor pressure which causes some of the chemicals being released into the indoor air. Formaldehyde is suspected to be carcinogenic, so minimizing the formaldehyde amount is of great interest[20].

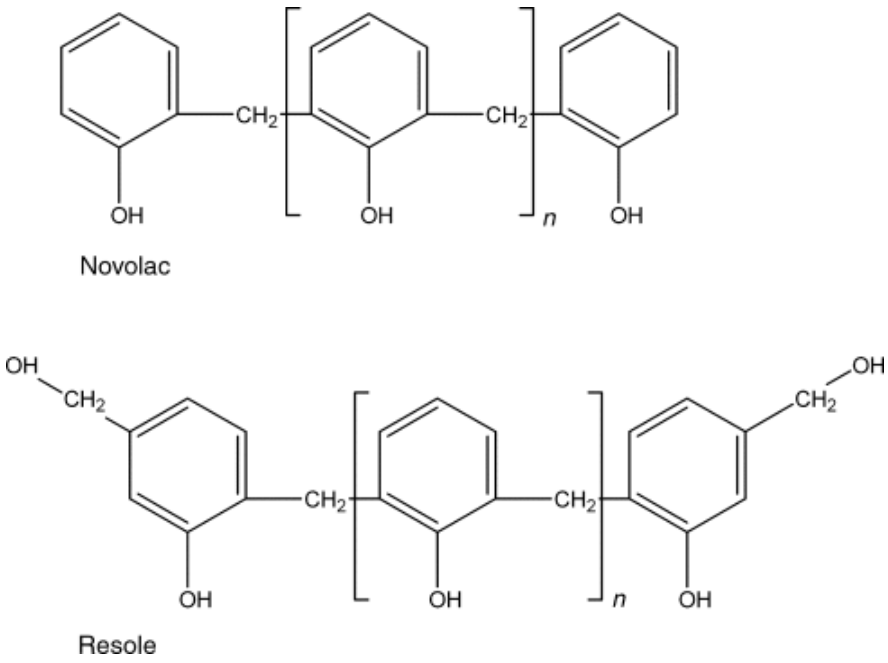


Figure 3.11: Novolac and resole type resin [4]

3.5.2 Bio-based binders-Lignin

As mentioned previously, the conventional binders that are used today in mineral wool and many other products are phenolic resins. But due to the toxicity and non biodegradability of the resin, the interest of bio-based binders has increased. Thanks to the increasing interests of sustainability and the growing knowledge about the importance of environmental impact, researchers are currently working on developing bio-based binders that do not come with the disadvantage of phenolic resins [20].

The most commonly used bio-polymers for binder applications are lignin, functionalized lignin and other lignin derived compounds. Lignin is an essential polymer found in plants, and it functions as a natural binder to hold the cellulosic fibers together, and in that way it provides the plant with rigidity and strength. Lignin has a phenolic nature which makes it useful as a substitute in phenolic-formaldehyde resins. Lignin in its natural state in woods and plants,

is almost colorless, while commercial lignin or lignosulfonate has a dark color.
It is possible to improve the characteristic's of the lignin, by varying the functional groups, with e.g methoxyl, phenol propane, carbonyl etc [21].

The extraction process plays a part in the type of lignin one can obtain. The lignin can either contain sulfur or be sulfur free. Lignin that contain sulfur includes Kraft lignin (KL) and lignosulphonate (LS), and the sulfur-free lignin include, organosolv and alkali lignin [21].
The main difference between these two, is that lingosulfonate contains more sulphur groups making it more anionically charged and water soluble [5].

There are two hydroxyl groups in lignin, a phenolic and an aliphatic hydroxyl group. The phenolic hydroxyl group is a reactive functional group, meaning that phenolation can occur (condensation reaction with phenol and the lignin). Phenolation will increase the reactivity of the lignin and it's potential as a lignin-based phenol binder. Figure 3.12 shows the crosslinking between lignin and formaldehyde [21].

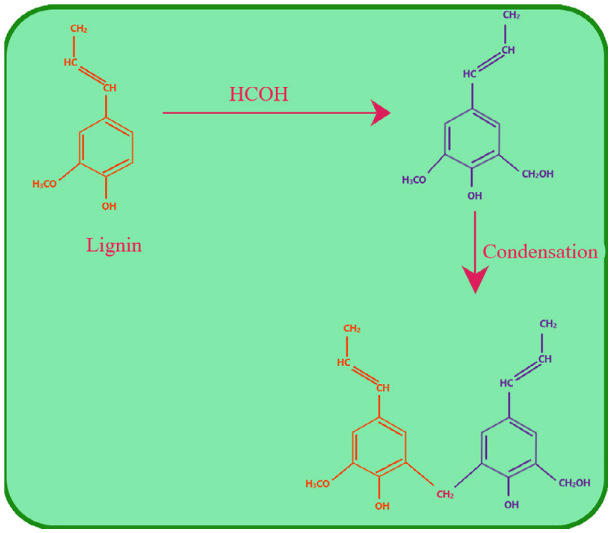


Figure 3.12: Crosslinking between lignin and formaldehyde [21]

Note that there are companies that offer formaldehyde free lignin binder as well.

3.5.3 Bicofiber

Bicomponent fibers, also known as bico-fibers are synthetic fibers that consist of two components with different chemical properties. A common classification is according to the fibers cross section. There are three typical types of cross section, side by side, core/shell (CS) and Matrix/protofibril, see figure 3.13 [39]. For this project the focus will lay on CS bico fibers.

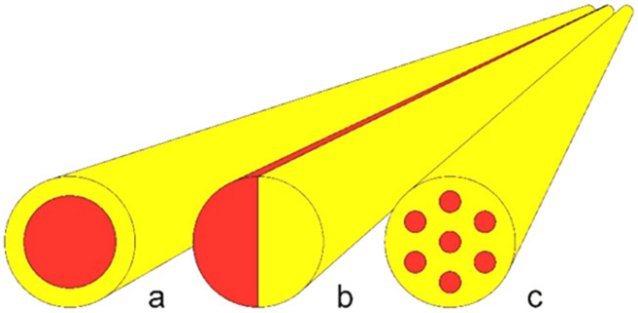


Figure 3.13: Typical cross section of a bicomponent fiber. From left to right, Core/shell, side by side, matrix/protofibril [24]

The core/shell bicomponent fibers are a suitable option to use as a binder. The sheath of the bico-fiber consist of a polymer with a lower melting temperature than the core polymer. This means that during the curing, the sheath will melt and the core will stay intact and create a 3D network. Some common bico-fibers are PE/PP, PE/PET and PP/PET [39]. The conventional way to produce CS fibers is via melt spinning. Two polymers are melted and pressurized in an extruder. They then come together at the outlet of the spinner, see figure 3.14 [39].

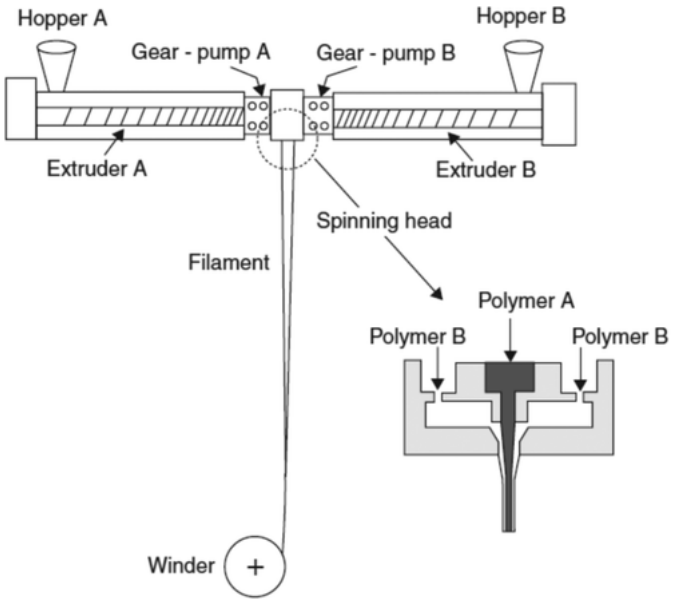


Figure 3.14: Schematic view of a bico-fiber spinner [24].

3.5.4 Polycarboxylate based binders

Polycarboxylate based binders are thermosets which are made of macromolecular carboxylate and a low molecular weight polyol crosslinking agent. These type of binders have a relatively high curing temperature (>150 °C), they cure under acidic conditions, and upon curing ester bonds are formed. The polycarboxylate can be a homopolymer or copolymer made from unsaturated carboxylic acids, unsaturated anhydrides, or a mix of these. Some examples of carboxylic monomers are, acrylic acid and methacrylic acid. Anhydrides can for instance be maleic anhydride and methacrylic anhydride. The polyols that are used usually have low molecular weight with at least two hydroxyl groups, e.g. ethylene glycol and triethanolamine (see figure 3.15) [7].

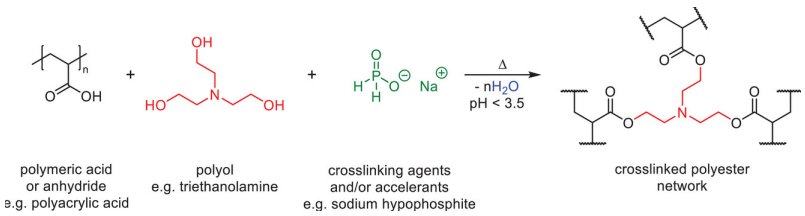


Figure 3.15: How a common polycarboxylate binder formulation can look like [7] *Note*: This is not the exact reaction for the chosen binders, but only an example of how the crosslinking can happen for these type of binders

Polycarboxylate binders are formaldehyde free and they have enough mechanical properties to be used as a binder for mineral wool. The disadvantage is however the high viscosity. A binder with lower viscosity is easier to handle (e.g. pumping, mixing and spraying), and it also makes it possible for the binder to penetrate the fibers, this in turn makes it attainable to get an even distribution of the binder. If the concentration of the binder is reduced (e.g. via dilution) the mechanical properties of the binder decreases and the curing time increases[7].

In comparison to PF binders, polycarboxylates need a longer curing time as well as a higher curing temperature. The binders are also more acidic which increases the possibility of corrosion of the equipment. In brief, polycarboxylate can replace conventional PF binders for mineral wool, but the manufacturing costs could easily become higher [7].

3.5.5 Sodium silicate adhesive

Sodium silicate also known as water glass (see figure 3.16) is an adhesive used mainly to bond porous substrates such as paper, cardboards, and glass wool. The advantages of sodium silicate is it's versatility as well as the low cost. It is also possible to combine the sodium silicate with different additives in order to achieve the desired properties, such as the toughness [12].

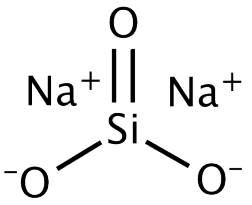


Figure 3.16: Chemical formula of sodium silicate [23]

Sodium silicate can either come in powder form or as a liquid. For the powder, water must be used in order to activate the binder. The adhesive bonds form when the water evaporates or by chemical reactions, and pressure must be applied until the bond forms. Some further advantages of sodium silicate is it's good flame and water resistance, however if the bonds do not form completely the outcome can be a brittle and water sensitive material[12].

Sodium silicate is generally manufactured by reacting sand (SiO_2) with soda ash, see figure 3.17. By varying the proportions of the starting material different properties can be achieved for the adhesive [12].

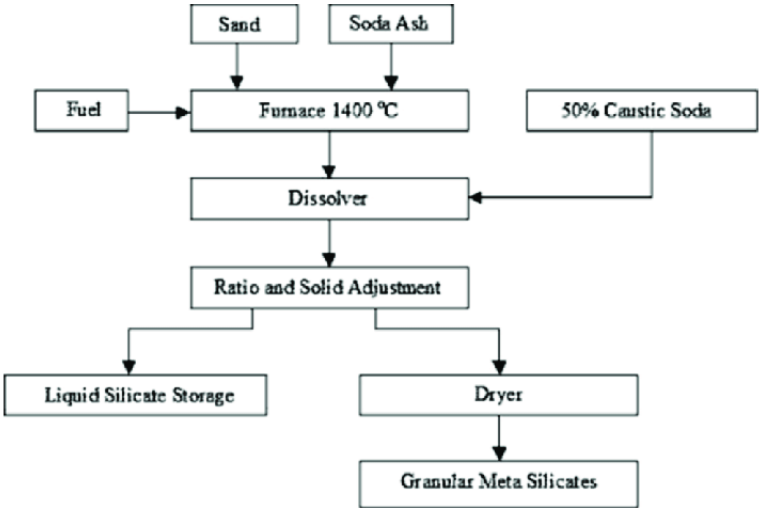


Figure 3.17: Manufacturing process of sodium silicate [3]

3.6 Production of glass wool

The process used to manufacture the glass wool at Isover Saint Gobain is presented in figure 3.18.

1. In the first process step the raw material, which consist of sand, soda-ash, limestone and recycled glass are weighed and then poured into a furnace.
2. In the second step the mixture is heated up to over 1400 °C. The temperature is set high enough for the mixture to melt.
3. The melted mixture is then passed to the spinner. The material becomes fiberized once it comes out of the nozzle of the spinner. Simultaneously the binder is applied to the fibers, via spray application. The water in the binder evaporates and at the same time it cools down the fibers.
4. The lose fibers are then cured in an oven. This can also include compression of the fibers to achieve the right thickens of the product.
5. The glass wool is then cut into the desired width and length, and excess material is recycled.
6. During the packaging step the glass wool can either be rolled if the end product is a mat, or stacked if the end product is a board [18].

Figure 3.18: The process for glass wool manufacturing at Isover Saint-Gobain [18]

3.7 Airlay technique

The airlay-technique will have a significant role during this thesis. The refiber boards will be manufactured in a similar process to the airlay technique. This means that the prototypes, as well as the binder needs to be suitable for such process.

In order to use this process to recycle acoustic tiles, the material needs to be shredded into smaller pieces. The shredded material can then be used in the air-lay process which can be divided into three stages, the web formation, web bonding and the finishing treatments. During the web formation the fibers are arranged in a sheet or web, see figure 3.19. The shredded material is feed into a hammer mill in order to get a rather homogeneous mixture. Thermofusible fibres (such as bicofibers) are added to the mixture before it is carded

and deposited on to the moving belt [11].

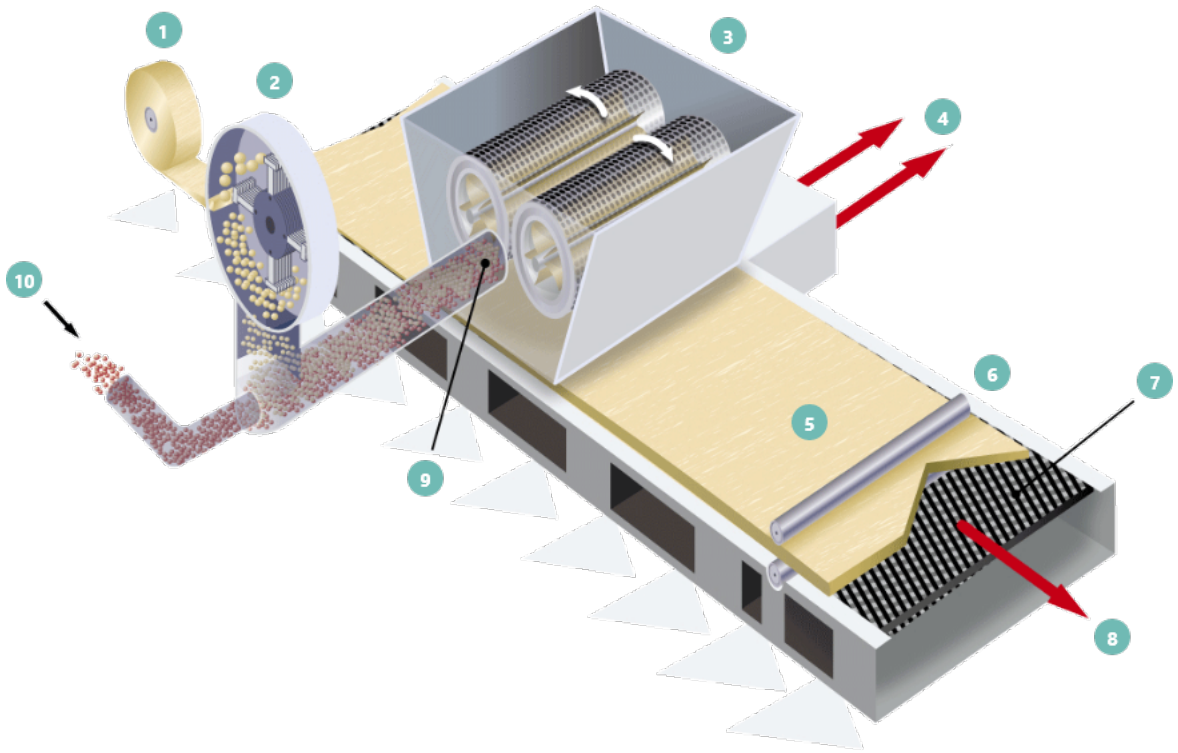


Figure 3.19: Web formation of small fibers using air-lay technique.
1. Fiber feed 2. Hammer mill 3. Carding machine 4. Air leaving 5. Formed web 6. Compactor 7. Moving belt 8. Further bonding 9. Fiber mix + Air in 10. Thermofusible fibers. [11]

There are different types of web bonding processes. The relevant bonding process for this project is, thermal bonding, see figure 3.20. In order to use thermal bonding some type of thermoplastic fibers are used to form bonds under controlled heating. In figure 3.20 heat is combined with high pressure to weld the webs together. Another option is to use hot air streams, but the result will be a bulkier product [11].

During the finishing treatment the product can be tailored to get the desired properties. The finishing treatments could be either mechanical (e.g stretching) or chemical. A chemical finishing treatment

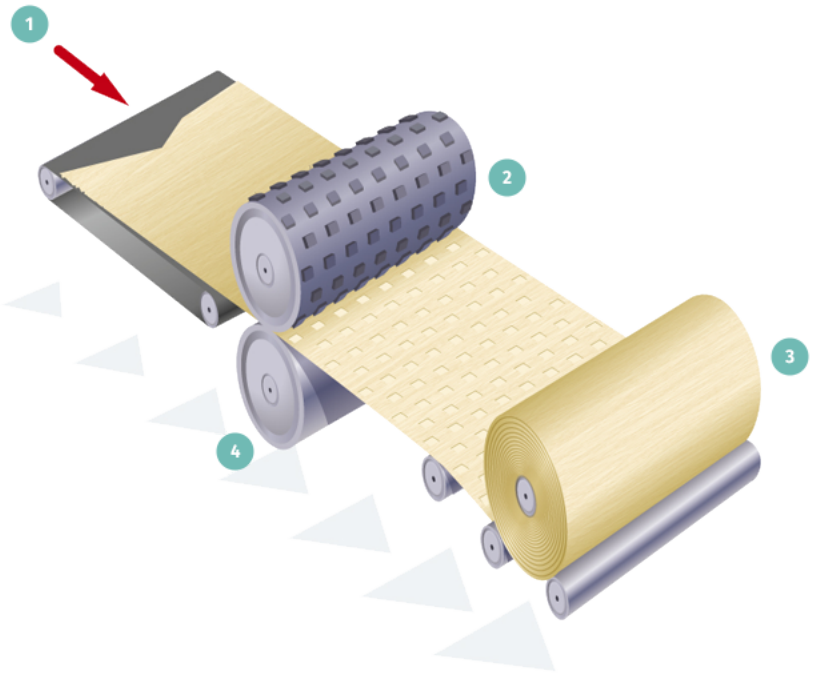


Figure 3.20: Thermal bonding for airlay process. 1.Formed web. 2-4.Hot cylinders. 3.windup (not relevant for base boards)[11].

means that the surface of the web is modified to get conductive, flame retardant or water repellent web [11].

Chapter 4

Analyzing methods

This following section will provide a description of the chosen analyzing methods for this theses.

4.1 Analyzing methods

The following subsections will give a brief description of the evaluation methods that will be used for this thesis. The chosen analyzing methods are well suitable for the question at issue and it will also cover all the necessary aspects that needs to be considered.

4.1.1 Fire test-Cone calorimeter

In order to classify and evaluate the fire properties of the samples a cone calorimeter test is conducted, see figure 4.1. The samples are cut and prepared to fit the sample holder, 10X10 cm. The samples are then subjected to radiating heat with 35 kW/m^2 intensity, with the sampling time of 1 second. The cone heater can be adjusted to deliver a specific heat flux to the sample surface. The developed gases from the sample during a test are ignited using a pilot spark . The combustion products will go from the surface through the cone heater and into the ventilation duct. In the ventilation duct the,

O_2, CO_2, and CO content of the developed gases are analyzed, and the smoke production is measured through optical density [10].

The result from the cone calorimeter test is evaluated using a software program. The program indicates which Euro-class the product could possibly achieve in a standardised ISO 5660-1:2019 test [10].

Two, 10x10 samples are cut from each prototype. This is because of the in-homogeneity of the prototypes and an attempt to minimize the uncertainties of the result. If any of the binder would show an acceptable fire class, A or B more studies and experiments will be done on this type of binder. The fire tests is conducted externally at Lunds tekniska Högskola. [10]

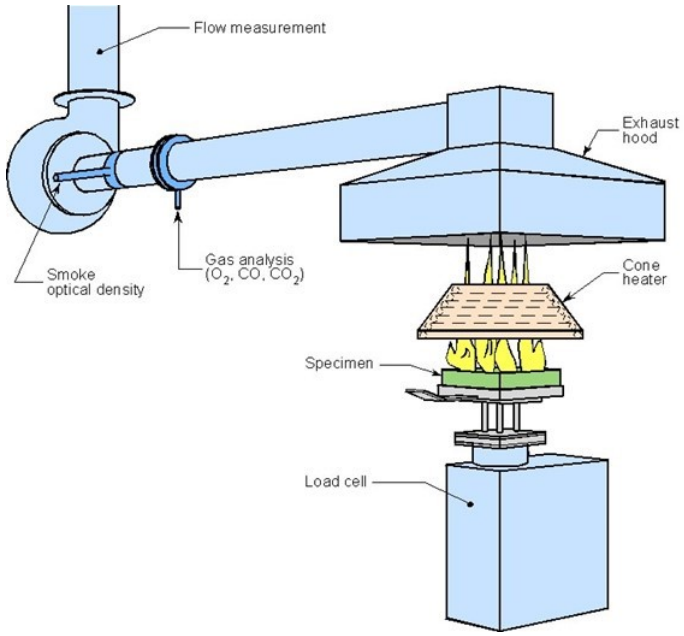


Figure 4.1: schematic view of the cone calorimete [10]

4.1.2 Three-point flexural test

The bending test that is performed on the specimens, is conducted in an universal testing machine. The universal testing machine is used to characterise the mechanical properties of the material, such

as tensile strength and compressive strength.

The flexural properties of the material is determined by subjecting the specimen to an external load perpendicular to the sample. The sample is put on two supporting blocks with a set distance, called the bending span, see figure 4.2. For each prototype 2 flexural bend-

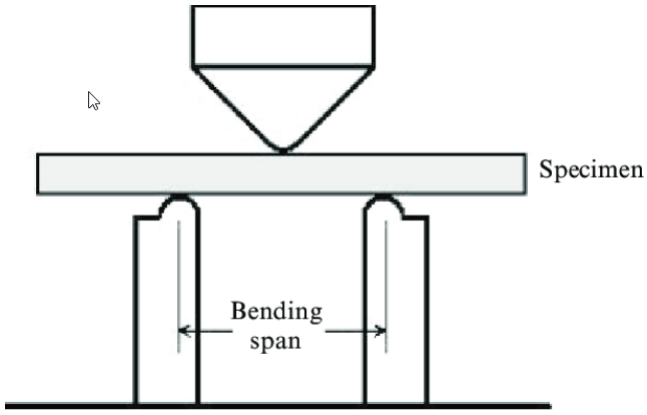


Figure 4.2: Three point bending test. An external load being applied in the middle of the specimen [37].

ing tests are done. Ideally more tests should be conducted to get a more precise result, but this is not possible due to the limited amount of test material. The flexural properties can vary depending on the thickness of the sample, the testing environment, as well as deflection rate. During evaluation all of these parameters need to stay consistent for all of the samples in order to get comparable values. The outcome of the test is presented as stress-strain curves. A stress strain curve shows how much the material deforms under the applied force. Equation 4.1 demonstrates how the stress is calculated for a three point flexural test.

$$\sigma = \frac{3 * F * L}{2 * W * d^2} \tag{4.1}$$

F= The applied force
L= Length of the bending span

W= width of the specimen
d= Thickness of the specimen

Calculating the strain for bending is a little bit more complicated and it will not be covered in this thesis. Note that both the stress and the strain is given directly by the program. The values given from the test will only be an indication of which binder that can show the best mechanical properties.
Following test conditions where used for this test:

- Bending span, 10cm
- Deflection rate, 10 mm/min
- sample dimension 4x15x2.5cm

4.1.3 Air Flow Resistance (AFR)

The acoustic properties of the samples will be evaluated using an Air flow meter. The basic concept of an Air flow meter is to measure the pressure drop that occurs between the two surfaces of the sample while it's being subjected to an airflow [17]. Because the pressure drop is measured it is important to have the correct size of the sample so it fits perfectly into the specimen holder. If the sample is smaller than the measurement cell, the air will flow past the sample on the edges giving an incorrect result.
The samples for the AFR measurements will have a circular form with a diameter of 10cm.

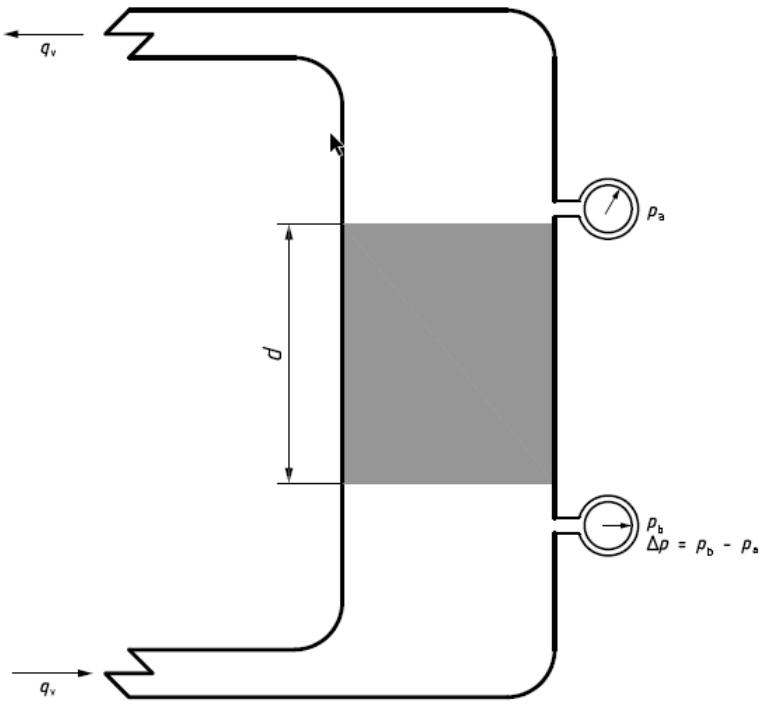


Figure 4.3: The figure shows the basic principle on how the AFR value is calculated [17]

4.1.4 Thermal analysis

Thermal analysis (TA) is the method used to evaluate the properties and physical changes that occur when a substance is heated or cooled in a specified atmosphere [9]. There are several different TA-tools but for this thesis the focus will lay on, differential scanning calorimetry (DSC), as well as thermogravimetric analysis (TGA).

4.1.4.1 Differential scanning calormietri

The DSC measures the heat energy uptake of the sample during temperature changes, this makes it possible to detect endothermic or

exothermic peaks, determine specific heat capacity's, evaluate transition and reaction enthalpies. Some common properties to evaluate with the DSC are, melting points, the glass transition temperature, and crystallization behaviour [9].

A differential scanning calorimeter includes a sample cell which contains the sample of interest, and a reference cell, see figure 4.4. During heating or cooling, both of the cells have identical temperature, and any energy difference in the input energy would be caused by energy absorbed or released by the sample. This is then utilized to create DSC-curves where the desired information can be obtained. [9].

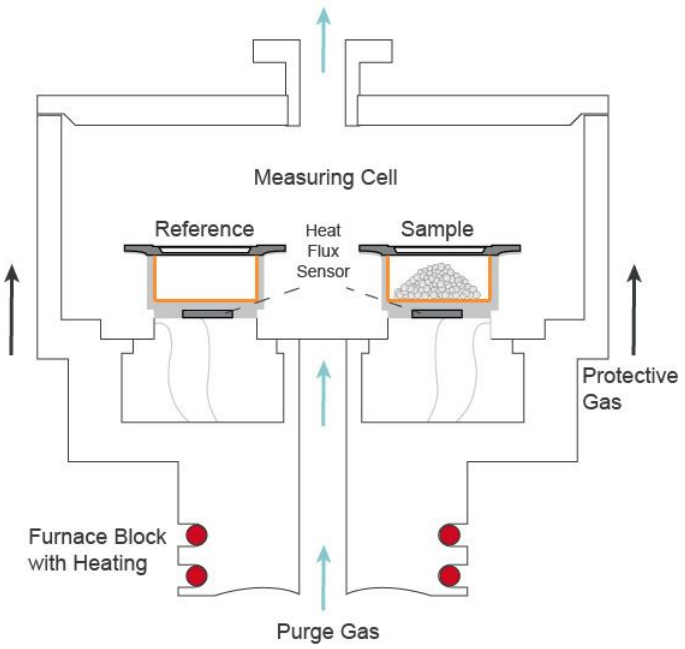


Figure 4.4: Principle of a differential scanning calorimetry[26]

The DSC is used in order to evaluate the binders, more specifically the melting points as well as the melting enthalpy of the bicomponent fibers.
The sample size can vary between 5-20mg. It is also important

not to overfill the crucible, because there is a possibility that the material expands and overflows which could ruin the sensors.

Following program was used for the DSC-measurements

- Environment; Nitrogen gas, N_2 50ml/min
- Heating cycle 1; $25 - 300°C$, with a temperature ramp of $10°C$/min
- Cooling cycle; $300-25°C$, with a temperature ramp of $-10°C$/min
- Heating cycle 2; Same as first heating cycle

The sample is heated, cooled and then reheated again, this is to eliminate any thermal history of the polymer as well as any residual solvents.

4.1.4.2 Thermogravimetric analysis TGA

A thermogravimetric analyzer is used to determine the thermal stability of a sample. The thermal stability is defined as the materials resistance to decompose under heat. The weight of the sample is measured continuously as the temperature is increased or held isothermally. The result is present in a TGA-curve where the mass change is plotted as a function of either time or temperature. The first derivative of the curve can also be used to show the rate of the mass change. This is called the DTG curve. The thermal decomposition temperature will also determine the upper limit of the temperature during any type of processing of the polymer[9].

Following heat program was used to evaluate the thermal stability of the binders;

- Environment; Nitrogen gas, N_2 50ml/min
- $25 - 750°C$, with a heating rate of $10°C$/min.

The sample size varies between 5-20mg.

Chapter 5

Material and tools

In this section the material and tools used for this project will be presented.

5.1 Shredded glass wool

The shredded glass wool originated from worn out acoustic tiles.The acoustic tiles all had both paint and a surface layer before they were shredded. The wool was minced at the loop factory in Varberg and delivered to the lab in Hyllinge. The shredded wool (see figure 5.1) came in different sizes and it was also separated between shredded wool with a plant based binder and phenolic binder. The idea was to test each type of wool and then stick to one type for the binder evaluation.

Figure 5.1: Shredded wool with different sizes.
1.Shredded and hammer milled wool with plant based binder from TLF. 2.shredded wool with plant based binder from TLF. 3.shredded wool with plant based binder but much bigger pieces (source unknown). 4. shredded and hammer milled wool with phenolic binder. 5.Shredded wool with phenolic binder 6. very fine minced wool with phenol binder from external company.

During a study visit at The Loop Factory in varberg, the process in which the wool was shredded and hammer milled was shown, see figure 5.2-5.3

Figure 5.2: Acoustic tiles in shredder, at TLF varberg

Figure 5.3: Shredded wool put on a moving band into the hammer mill.

5.2 Binders

The following binders were chosen and evaluated

5.2.1 Acrylic binders

Five different acrylic binders were supplied by BASF. The binders are water based and used to replace the traditional formaldehyde containing binders used for glass fiber nonwovens. The finished product is supposed to emit low amount of VOCs making it an indoor friendly product. The acrylic binders are thermosets and are expected to give the tiles good strength and flexibility as well as providing high thermal resistance [6]

- **Acrodur DS 3530**-Is a polymer solution of a modified polycarboxylic acid and a polyol as the crosslinking component. Crosslinks to form a thermoset material by heating, relatively low viscosity, dedicated to be used as "glass wool" binder. Crosslinks at a temperature between 160-180 °C. pH≈2.5-4 [16].
- **Acrodur Plus 2580**-Is a polymer solution based in carboxylic acid monomer, combined with a crosslinker component. Crosslinkning occours by proper heat treatment. similar low viscosity as Acrodur DS 3530 if compared at same concentration / dilution, also usable as "glass wool" binder. Crosslinks at a temperature between 170-210 °C. pH≈4 [16].
- **Acrodur DS 3515**-Is a polymer dispersion based on on styrene and acrylic ester monomers, chemically linked with a modified copolymer based on carboxylic acid monomers combined with a crosslinker component. Crosslinking by heating, not (yet) used as "glass wool" binder but usually used as binder for heat-moldable fiber boards made from natural wood fibers.Crosslinks at a temperature between 170-210 °C. pH≈3.5 [16].
- **Acrodur power 2580**- Is a polymer dispersion based on polyacrylate, it is not crosslinkable by heating. It is used as a thermoplastic binder for composite applications and it is not (yet) used as "glass wool" binder but usually used as binder for heat-moldable, "thermoplastic" fiber boards made from wood fibers. Prior to using this product it is recommended that the substrate is heated with contact heat to a temperature between 150 – 175 °C to ensure best mechanical properties. pH≈3.5 [16].

- **Acronal A 969**-Is a polymer dispersion based on acrylic esters and methaacrylic esters as main monomers,containing carboxylated side monomers. It is not crosslinkble by heating, not (yet) used as "glass wool binder, but usually used as "stiff" coating binder for acoustic ceiling tiles made from mineral fibers by wet-laid processing. After drying/curing a further heat treatment is recommended, temperatures between 140-160 °C. pH≈7.5 [16].

5.2.2 Bi-component fibers

The bi-component fibers used for this thesis were delivered by different suppliers such as Trevira GmbH, Fiberpartner, and Fibervision.

Notation; Decitex (dtex) is a metric unit which is defined as the mass in grams per 10 000m, this unit is commonly used for fibers

- **Fiberpartner**

  These fibers are thermoplastics with low melting points, they also show self-adhesive properties when blended with regular wool or other fibers. The first bi-component fiber on the list below is a biodegradable fiber. The fiber is designed and optimized with a sugar that makes it easier for microbes to digest the fiber. [14]

  - *PrimaLoft Bio*: modified Polyester sheath /Polyethylene terephthalate core(PET) with melting points T_m1=120 °C, T_m2=252 °C, cut length of fiber 51mm, dtex 4.5
  - *PSF BICO LM-white*: Polyester sheath/PET core with melting points T_m1=110 °C, T_m2=252 °C, cut length of fiber 51mm, dtex 5
  - *PSF BICO LM-Brown*: Polyester sheath/PET core with melting points T_m1=110 °C, T_m2=252 °C, cut length of fiber 64mm, dtex 5

- **Fibervision**

  - *Intraloc 12mm*: Polyethylene sheath/polypropylene core T_m1=130 °C, T_m2=160 °C, cut length of fiber 12mm, dtex 1.7

- *Intraloc 6mm*: Polyethylene sheath/polypropylene core T_m1=130 °C, T_m2=160 °C, cut length of fiber 6mm, dtex 1.7

- **Trevira**
  - *T755*: Copolyolefin sheath/PET core T_m1=130 °C, T_m2=256 °C, cut length of fiber 6mm, dtex 1.79
  - *T453*: Polybutylene succinate (PBS) sheath/ Polylactic Acid (PLA) core, T_m1=116 °C, T_m2=160 °C, cut length of fiber 6mm, dtex 2.20.
  - *T255*: Copolyolefin sheath/PET core T_m1=140 °C, T_m2=256 °C, cut length of fiber 6mm, dtex 1.79
  - *T276*: Copolyolefin sheath(PE+PE modifier)/PET core T_m1=140 °C, T_m2=256 °C, cut length of fiber 6mm, dtex 2.2

5.2.3 Sodium-silicate glue (SS)

- **Sodium silicate**
  - Adhesive in powder form

5.3 Tools

- **customized mixer**
  In order to achieve a homogeneous mixture with sufficient fluff, a custom made mixer was used. The mixer was built from an empty oil barrel with an inlet for pressurised air and an outlet for the air to leave, see figure 5.4

Figure 5.4: Mixer

- **Molds**
  The prototypes were formed in 30x30cm metal molds with lids, made at the maintenance department at Ecophon, see figure 5.5. The molds were covered with Teflon sheet to protect the mold as well as to get the sample out easily.

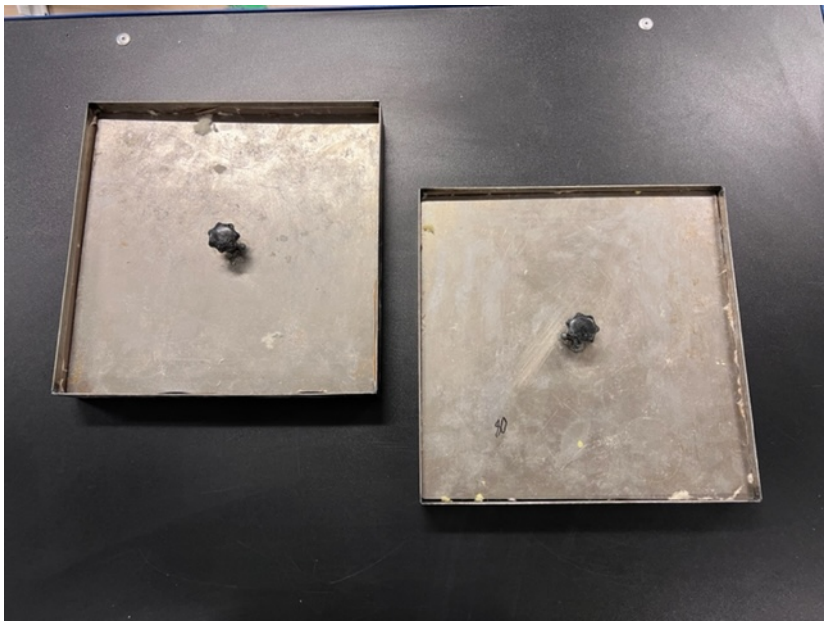


Figure 5.5: 30x30cm metal molds with lids

- **Oven**
  The wool and binder mixtures were cured in an oven between 100-200°C, depending on the binder used.
- **Weight scale**
  Laboratory scales were used to weigh the binders as well as the glass wool.

Chapter 6

Prototypes

This section will include information about the method for creating the prototypes as well as the issues that occurred during the first trials. It will also include some general evaluation of the binders

The first step of the practical part of this project was to create prototypes using the chosen binders. The prototypes were made in an internal lab at Ecophon.
The initial step was to develop an optimized process for the prototype making, using the tools that were available at Ecophon, in addition to creating a process that is as similar as possible to the pilot line that is in development by TLF. Different methods were tested and excluded when creating the prototypes.

The process that was eventually chosen for the prototypes included:

1. Weighing the correct amount of shredded wool and the chosen binder to get the desired density and binder amount.
2. For the bico-fibers: The fibers were put in the mixer to fluff them up before adding the glass wool.
   For the liquid binders: The binders were diluted to the desired concentration, and sprayed on the wool.
3. For the bico-fibers: The shredded wool was added to the fluffed fibers and then mixed together.

For the liquid binders: The wool with sprayed binder was added to the mixer to fluff the fibers up before putting them in a mold.

4. For the Bico-fibers: For some of the mixtures with bico-fiber, the mixture was sprayed with some water to get a damp mixture and some powdered silicate was sieved onto the damp mixture,

5. The mixtures were put in a metal mold and the lid was put on top of it to achieve the desired thickness of the tile (2.5cm). The molds were then put in the oven to let the binders cure.

6.1 First prototype issues

The aim was to get prototypes with approximately the same thickness of 2.5cm and density of, 80 kg/m^3 and 110kg/m^3. There were however some issues with the preparation of the first few prototypes. The first issue arose from the fact that the shredded wool was not homogeneous. This means that the size distribution of the wool was very wide, ranging from fine powder like wool to bigger chunks, see figure 5.1.
This meant that the mixture was very uneven which resulted in difficulties getting the same dimension and density of all the boards. The first type of mixer that was used was a concrete mixer, but the issue with this was that the fibers did not open up enough but also that, the density difference between the binder and the fiber caused a big portion of the binder to end up at the top of the mixture subsequent to the concrete mixer. A proposed solution to this issue was to fluff the fibers using air during the mixing with the binder.

Initially a hydraulic press was used to press down the mixture in the mold. This resulted in very high density boards which was not desired. The acoustic properties is affected by the density, a dense board does not absorb sound as well as a lighter board does. The hydraulic press was therefor not used from there on.

At the beginning wood molds were used. This became an issue because the heat transfer between the mold and the mixture was very low, which resulted in very long curing time. This with the

combination of that the mixture consists of a minimum of 80 wt% glass wool, made it hard to achieve the desired core temperature. The easiest solution to this was to create new metal molds which reduced the curing time.

6.2 Sample cutting

The finished 30x30cm prototypes were cut in the shape and dimensions. according to figure 6.1 From each protype, two samples were taken for the mechanical testing (4x15cm) and two samples for the fire classification test (10x10), see figure 6.3. These samples were cut at the design department at Ecophon, see figure 6.2.

For the acoustic test two circular samples were cut with a diameter of 10cm (see figure 6.4). These were cut externally using a water jet cutter, see figure. This was to ensure that the samples had the exact desired dimension.

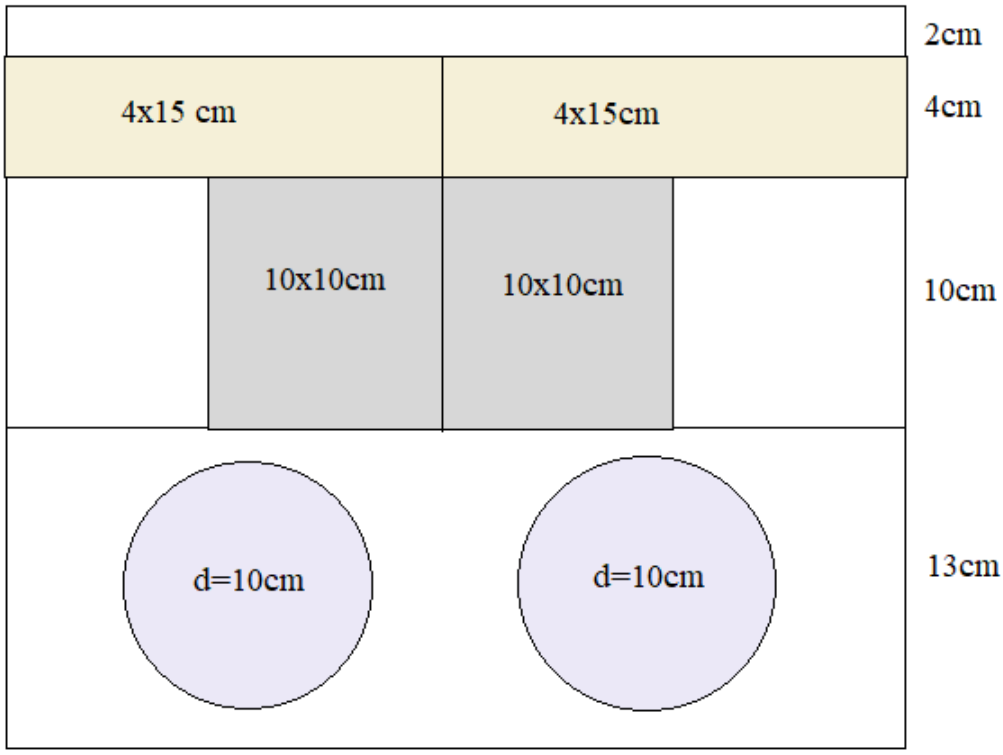


Figure 6.1: Schematic overview of how the prototypes were cut for the different analysis

Figure 6.2: Cutting tool at the design department in Ecophon.

Figure 6.3: Cut samples for fire, mechanical and acoustic tests.

Figure 6.4: Cut samples for AFR measurements.

6.3 Experimental plan

An experimental plan was set for the prototype making. The aim was to make prototypes of two different densities, 80kg/m^3 and 110kg/m^3 for each type of binder. The parameters that were altered includes, the binder amount which varied between 5-20%, the temperature of the oven which depends on the specific binder that was used, as well as the curing time of each tile. In table A.1 the different trials for the prototypes are shown. In this table the performance of the tiles are graded as "Approved" which indicates that the tiles had enough mechanical strength to be removed from the mold and held at one corner of the end without the tile falling apart,

and "not approved" which means the tiles broke/crumbled before any more analysis could be made.

Before any further experiments were conducted, the different shredded glass wool were evaluated (see figure 6.5). Prototypes with 20% binder (bico-fiber) were made and the wool that showed best mechanical strength were chosen. Wool number 1, and 3 (see figure 5.1) were chosen to be used for the following experiments (see table A.1). This choice was based on the fact that the plant based binder wool performed better than the phenolic binder based wool. The prototypes made from phenolic based wool crumbled more easily and the mechanical strength was not as high as for the prototypes made from green binder wool. This quick evaluation was however only based on how the tiles felt in the hand and not on any analysis method. What was also discovered during this quick evaluation was that, wool that is minced into finer pieces such as number 6 in figure 5.1, fell apart/crumbled more easily. In order to avoid this higher pressure needed to be applied which in turn resulted in higher density tiles (see figure 6.6) which was not desired. This type of wool was therefor avoided.

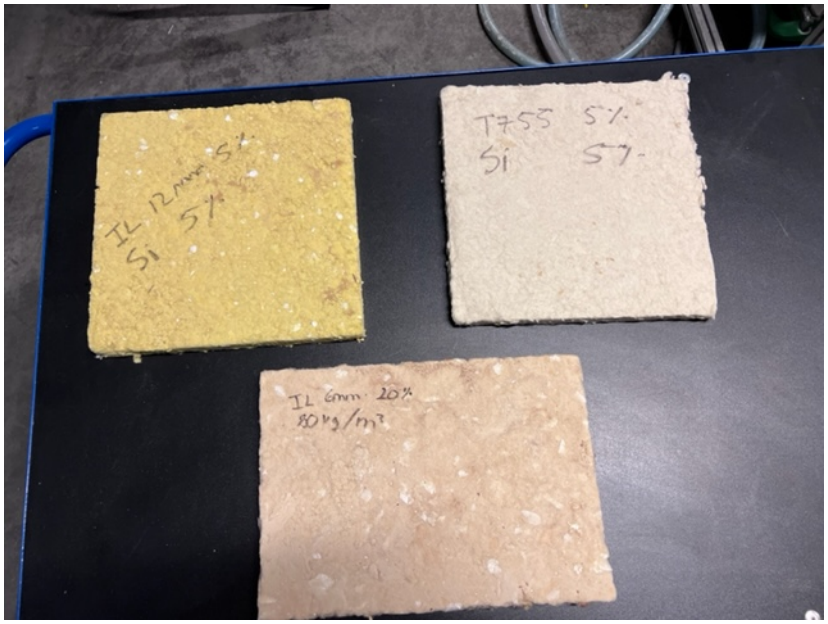


Figure 6.5: Prototypes made of different types of shredded wool

Figure 6.6: Prototype with high density made from fine shredded wool with phenolic binder

Table A.1 in Appendix A, shows the trials made with only one type of binder. In table A.2 different combination of binders were tested, mostly with sodium silicate and bico-fibers. The density was set to 110kg/m^3 for all the tests mentioned in table A.2. The mixtures where sodium silicate was used were lightly sprayed with water in order to activate the binder (<50g of water).

Figure 6.7 shows some of the prototypes made from the tables in

appendix A.

Figure 6.7: Collection of some of the made prototypes

6.4 Evaluation of prototypes

6.4.1 Acrylic binders

As can be seen in table A.1 the acrylic binders which were applied by spray application, did not have the desired mechanical properties, see figure 6.8. There were several trials made with the acrylic binders were parameters such as the temperature, density, concentration and the binder amount was varied in order to get the best possible prototype. The first issue seemed to be the fact that the core temperature of the tiles did not reach high enough temperature in order for the binder to crosslink. This issue was resolved by increasing the temperature of the oven as well as the curing time.

Despite the temperature and time increase the binder did not give the desired properties and the tiles crumbled once they were taken out of the mold. The next attempted to solve this issue was to increase the density as well as the binder amount, however this did not work. Other attempts were made by diluting the binders to different degrees, this would lead to a wetter mixture which in turn added to the curing time, and with no significant change of the mechanical properties.
Different type of wool was also tested with the acrylic binder, but the issue persisted. Lastly a combination of bico-fibers and the acrylic binders were tested (see table A.2). This solution worked for one of the binders, Acrodur plus 2580.

There can be different reasons to why the acrylic binders did not work out as expected. First and foremost the application technique with the combination of the shredded wool made it very difficult to cover each fiber with binder, leading to a very fragile tile. In contrast to how the boards are made at Isover, the binder is sprayed on each individual fiber when it comes out of the nozzle of the spinner. Another reason might be that the cross linking reaction could not be fully completed. The binders contain a modified polycarboxylic acid as a crosslinking component which means that the acidic dispersion could be neutralised if there were any non-volatile bases in the mixture. The shredded wool comes from worn out tiles, which means that both binder and paint with basic nature is incorporated in the wool mixture.

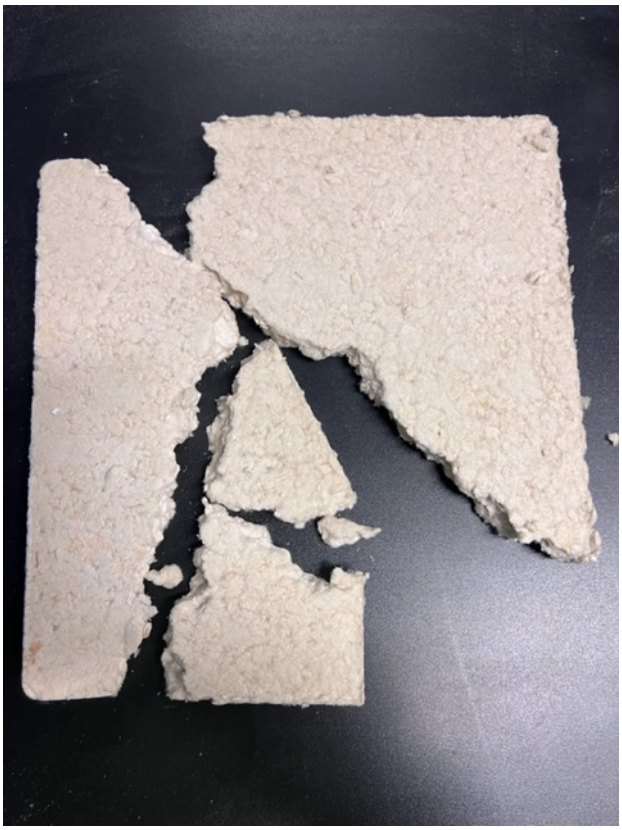


Figure 6.8: Prototype made from liquid binder

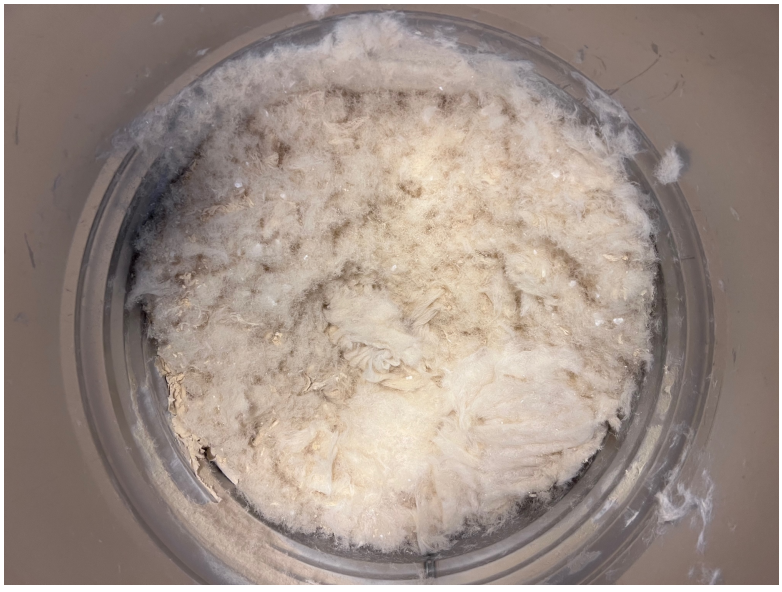
6.4.2 Bi-component fibers

In general the bi-component fibers were the easiest to use among the binders, they also gave the most stable prototypes which could be used for further analysis. however there were some issues with a few of the bico-fibers:

- Prototypes made from T453 (PBS sheath/PLA core) were very soft and could not be used for further analysis.
- Bico-fibers with fiber length 51-64mm (from FiberPartner) did not work as well as the rest of the fibers. This was due to the long length of the fibers which made it hard to get an even

mix. The long bico-fibers got tangled up very easily and did not distribute evenly between the glass wool, see figure 6.9

(a) 51mm bico-fibers mixed with shredded wool



(b) 12mm bico-fibers mixed with shredded wool

Figure 6.9: Comparison of the distribution of bico-fibers with different fiber length.

6.4.3 Sodium silicate

Prototypes made with only sodium silicate as a binder did not have enough stability and could not be used for further analysis. Sodium silicate was however used in combination with bico-fibers to increase the mechanical strength of the boards. This made it possible to decrease the amount of bico-fibers to 5 wt% and still be able to handle the board for further analysis.

6.4.4 Final prototypes

Ultimately 53 different prototypes were adequate for further analysis (see table 6.1) Samples taken from these prototypes were used for the fire test, three point bending test as well as for the acoustic measurements.

Table 6.1: Final prototypes

Product-nr	Binder	Density	Binder amount [wt %]	Temperature [°C]	Time [min]
1	IL 12mm/SS	110	5/15	145	60
2	IL 12mm/SS	110	15/30	145	60
3	IL 12mm/SS	110	10/30	145	60
4	IL 12mm/SS	110	10/20	145	60
5	IL 12mm/SS	110	10/15	145	60
6	IL 12mm/SS	110	5/20	145	60
7	IL 6mm/SS	110	5/15	145	60
8	IL 6mm/SS	110	5/2.5	145	60
9	T255/SS	110	5/5	145	60
10	T755/SS	110	5/5	145	60
11	IL 6mm/SS	110	5/5	145	60
12	IL 12mm/SS	110	5/5	145	60
13	IL 6mm/SS	110	10/10	145	60
14	IL 12mm/SS	110	5/2.5	145	60
15	IL 12mm/SS	110	10/10	145	60
16	FP Bio/SS	110	5/5	145	60
17	IL 6mm/SS	110	5/20	145	60
18	FP Bio/IL 6mm	110	5/5	145	60
19	T276/SS	110	5/5	145	60
20	T225	80	20	180	60
21	T225	110	20	180	60
22	T225	80	15	180	60
23	T225	110	15	180	60
24	FP Bio/plus 2580	110	10/10	145	60
26	FP-Bio	110	15	180	60
27	FP-Bio	80	15	180	60
28	plus 2580/IL 6mm	110	5/5	145	60
29	IL 12MM	110	5	145	60
30	IL 12MM	110	10	145	60

Product-nr	Binder	Density	Binder amount [wt %]	Temperature [°C]	Time [min]
31	IL 12MM	110	15	145	60
32	IL 12MM	80	15	145	45
33	IL 12MM	80	20	145	45
34	IL 12MM	110	20	145	60
35	IL 12MM	80	10	145	45
36	IL 6MM	80	10	145	45
37	IL 6MM	110	10	145	60
38	IL 6MM	110	15	145	60
39	IL 6MM	80	15	145	45
40	IL 6MM	110	20	145	60
41	IL 6MM	80	20	145	45
42	T276	110	20	180	60
43	T276	80	20	180	60
44	T276	80	15	180	60
45	T276	110	15	180	60
46	T276	110	10	180	60
47	T276	80	10	180	60
48	T755	110	20	145	60
49	T755	80	20	145	45
50	T755	110	15	145	60
51	T755	80	15	145	45
52	T755	110	10	145	60
53	T755	80	10	145	45

Chapter 7

Result and Discussion

7.1 Thermal analysis

In this subsection, the result from the TGA and DSC will be provided. TGA and DSC is done to gain thermal information about the binders.

7.1.1 TGA

The TGA and DTG curve for IL 6mm and IL 12m can be seen in figure 7.1-7.2. The curves look very similar and there is no major difference between the IL 6mm and 12mm. This is however expected because the fibers have the same composition, the only thing that differs is the length of the fibers. The bico-fibers from fiber vision (IL) showed an onset around 440 degree Celsius, which indicates that the binders are stable under this temperature. Above 440 °C thermal degradation of the binder would begin. The peak temperature of the DTG curves are around 465-470 °C, this shows that the highest rate of mass loss occurs at this temperature interval. In figure 7.2 some smaller peaks are also visible before the main peak. This could be due to any additives that is combined with the polymers.

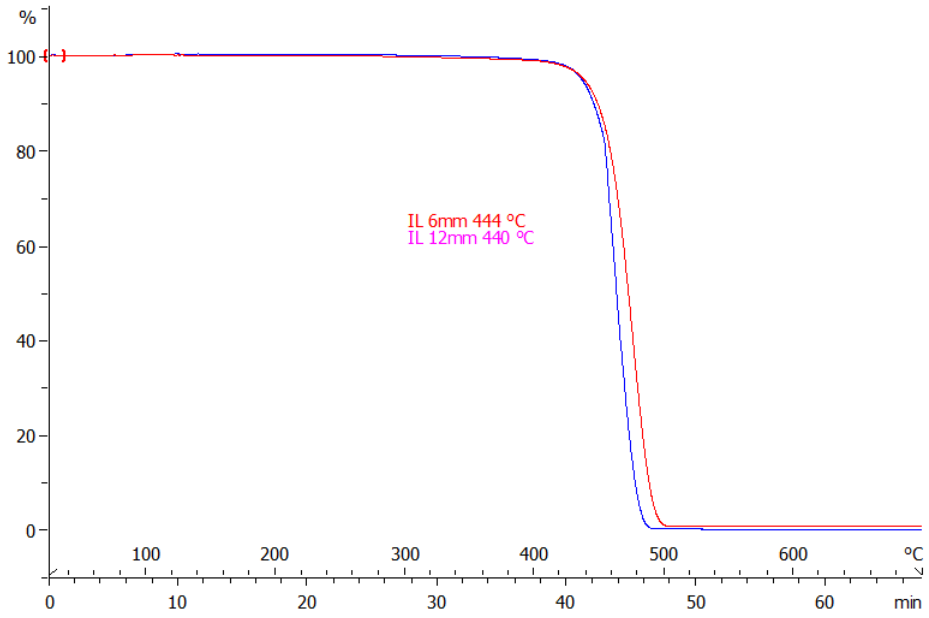


Figure 7.1: TGA curves: Intraloc

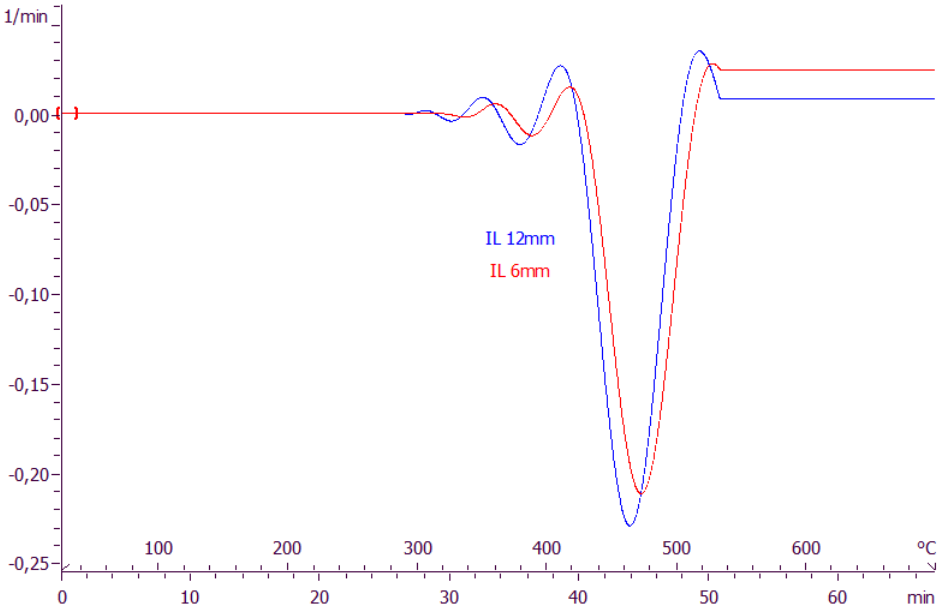


Figure 7.2: The first derivative (DTG) of the TGA curve for Intraloc

In figure 7.3 and 7.4, the TGA and DTG curve for bico-fibers from Trevira can be seen. The onset for T453 which consist of a PBS sheath and PLA core is around 330 °C. This is much lower than for T276, T255 and T755 which consist of a copolyolefin sheath and a PET core. The onset for these binders are around 410-415 °C. A comparison of the DTG curves also show that T453 has a higher mass loss rate, and the peak temperature is at 360 °C.
The peak temperature for the rest is, 420 °C for T276, 440 °C for T755 and 460 °C for T255.

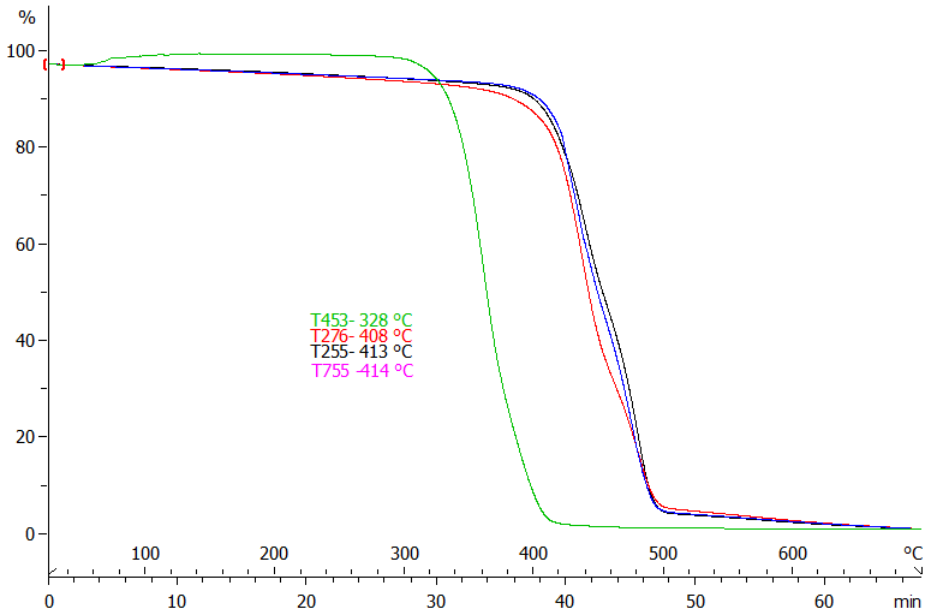


Figure 7.3: TGA curves: Trevira

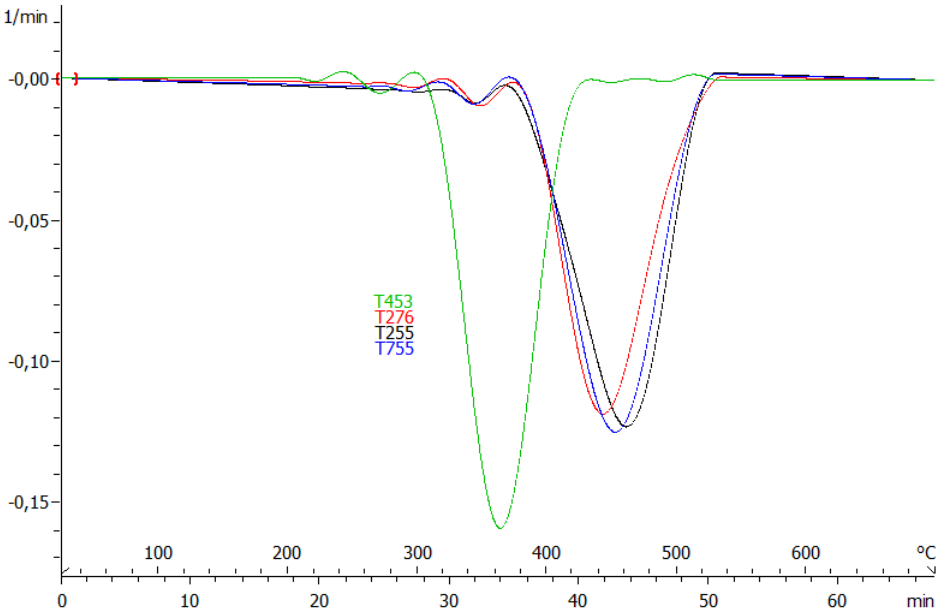


Figure 7.4: The first derivative (DTG) of the TGA curve for Trevira binders

In figure 7.5 and 7.6, the TGA and DTG curve for bico-fibers from Fiber partner as well as one of the acrylic binders from BASF (plus 2580) can be seen. The onset for FP bio and FP-brown is, 402 °C and 410 °C. Both of these fibers consists of a modified polyester sheath and a PET core, so the behaviour is very similar. The onset for, Plus 2580 is at 215 °C, this is a bit lower than for the bico-fibers in general, but the decomposition is also much slower, which can be confirmed in figure 7.6.

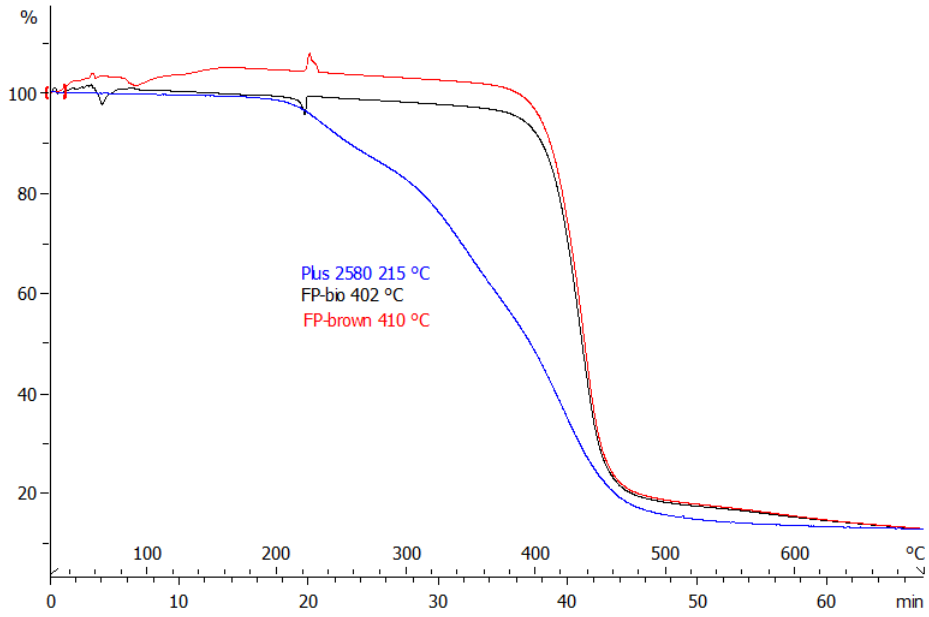


Figure 7.5: TGA curves: Fiber partner and BASF

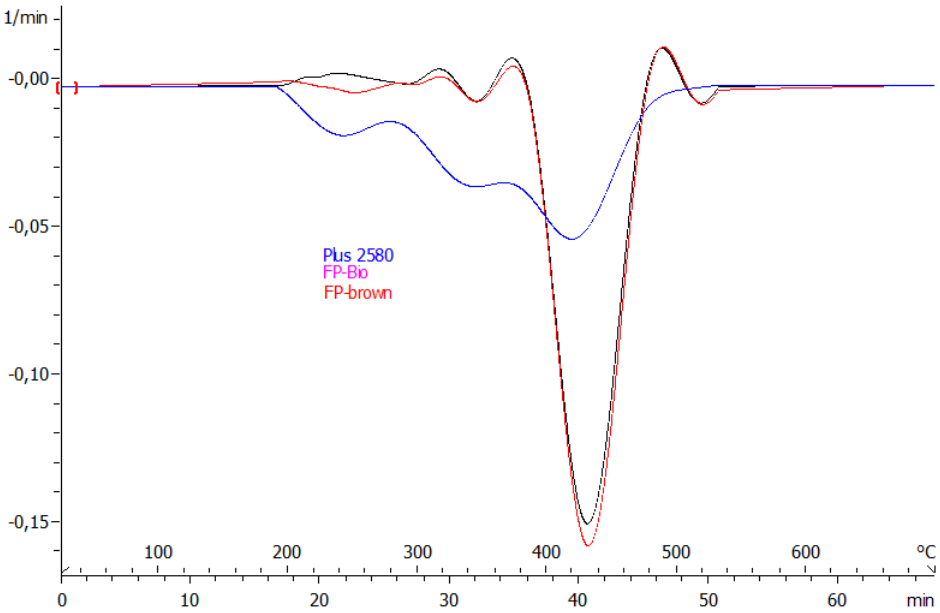


Figure 7.6: The first derivative (DTG) of the TGA curve for FP and BASF

Note that:

-T453 and FP brown was not used for further analysis.
-The thermal stability is not directly linked to the flammability of the product

7.1.2 DSC

Figure 7.7 shows the DSC curve for T755. The curve shows 2 heating cycles and one cooling cycle in between. In the graph below the energy is plotted against the temperature and time of the experiment. In the figure, the melting peaks can be distinguished. First melting peak correspond to the polyethylene sheath and the second melting peak correspond to the melting of the PET core. As mentioned earlier, most polymers have a semi-crystalline arrangement, and the sharp melting peaks come from the crystalline part of the polymer. The amorphous part of the polymer exhibits a glass transition temperature. For PE T_g is -120 °C, which is not in the temperature range of the experiment. For PET, T_g is 75 °C, however this is not visible in the graph neither in the first nor the second heating cycle. This can be due to different reasons, such as that the heating rate is to fast or to slow, or the amorphous part of the polymer might be very small making it hard to detect the T_g. During manufacturing of the bico-fibers the polymers are deformed in one direction when passing through the extruder which could align the polymers, increasing the degree of crystallinity. In the figure, 2 crystallization peaks can be identified, corresponding to the different polymers

DSC was done on T255, T276, T755, IL 12mm and IL 6mm as well as for FP Bio. The DSC was performed on the bico fibers in order to ensure that the correct fibers were being used as well as to get a better understanding of the thermal properties of the fibers. All of the curves showed the expected behaviour and the curves can be found in appendix B.

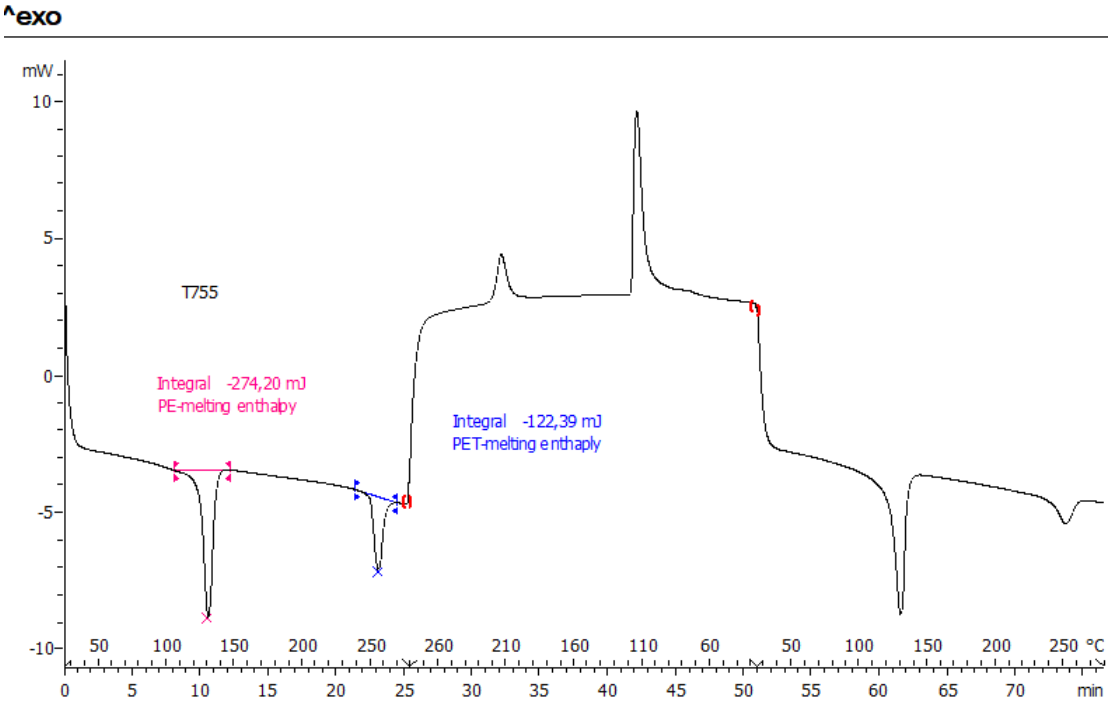


Figure 7.7: DSC curve for T755

7.2 Fire test

The fire tests were conducted in a cone calorimeter. The samples were cut in a 10x10cm dimension to fit the sample holder, see figure 7.8. The samples were wrapped in aluminum foil before putting it on the sample holder. Two 10x10 samples were tested from a total of 32 prototypes. Only 32 prototypes were tested due to the high cost and the limited time of the project. The samples were conditioned in a climate chamber prior to testing, this is to ensure that the samples all had the same humidity and temperate.

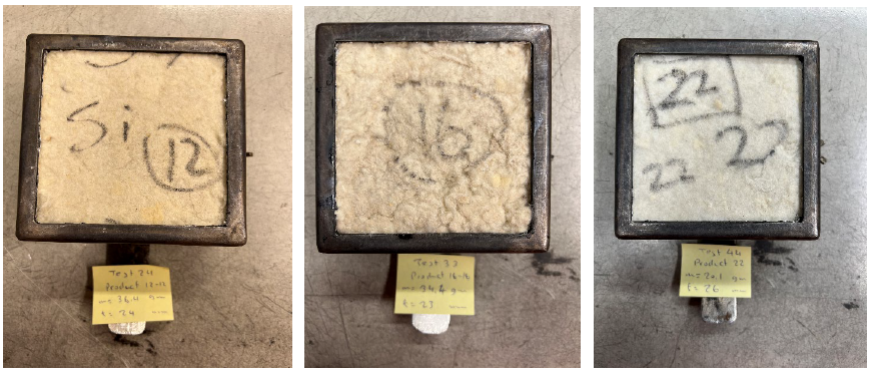


Figure 7.8: Three samples placed in the fire test sample holder before the fire test

The same samples seen in figure 7.8 can be seen in figure 7.9 after the fire tests have been conducted

Figure 7.9: The same samples after the fire test

The results from the fire test can be seen in table 7.1. The product-nr corresponds to the same numbers used in table 6.1.

- Abbreviations used in table 7.1.
  - Euroclass= Fire rating
  - THR_{600}= Total Released Heat during the first 600 seconds
  - TTI= Time to ignition

Table 7.1: Results from cone calorimeter tests. Each product was tested twice, first test labelled with product number and second test labelled product number – product number. "-" N̄o ignition

Product nr	TTI[s]	THR_{600} [MJ]	Predicted Euroclass.
1	1	2.2	D
1-1	5	2.1	C
2	8	3.3	D
2-2	7	3.2	D
3	7	1.9	A2/B
3-3	-	-	A2/B
4	6	3.2	D
4-4	6	2.7	D
5	6	3.3	D
5-5	6	2.6	D
6	5	2.1	C
6-6	6	3.1	A2/B
7	5	1.8	C
7-7	6	2	C
8	3	2.5	D
8-8	5	2.4	C
9	-	-	A2/B
9-9	6	1.9	A2/B
10	5	2.2	A2/B
10-10	17	1.9	A2/B
11	2	2.4	C
11-11	6	2.1	C
12	6	2.2	C
12-12	7	2.2	C
13	7	N/A	operator error
13-13	5	4.7	D
14	8	2,4	C
14-14	5	2.2	D
15	6	3.4	D
15-15	6	3	D
16	-	-	A2/B
16-16	-	-	A2/B
17	13	1.8	A2/B
17-17	8	1.8	C
18	6	3.4	D
18-18	6	3.2	D

Product nr	TTI[s]	THR_{600} [MJ]	Predicted Euroclass.
19	11	2	A2/B
19-19	-	-	A2/B
20	4	4.8	D
20-20	5	3.9	D
21	4	5.9	D
21-21	3	6.3	D
22	5	3.4	D
22-22	3	3.9	D
23	3	4.4	D
23-23	4	4.4	D
24	53	2.4	A2/B
24-24	25	3	A2/B
26	5	2.2	C
26-26	9	3.1	C
27	8	2.7	C
27-27	8	2.9	C
28	4	2.4	D
28-28	5	2.3	C
30	3	6	E or worse
30-30	4	6.3	E or worse
31	3	3.7	D
31-31	4	4.2	D
32	3	5.8	E or worse
32-32	4	5.9	E or worse.

From the fire test, following samples showed an A2/B class;

- IL 12mm + SS (10%/30%)
- IL 12mm + SS (5%/20%)
- T255 + SS (5%/5%)
- T755 + SS (5%/5%)
- T276 + SS (5%/5%)
- FP Bio + SS (5%/5%)
- IL 6mm + SS (5%/20%)
- FP Bio + Plus 2580 (10%/10%)

From these results it can be concluded that the bico-fiber from fibervision, IL had the worst fire class rating. This can be seen in sample 1,2,4,5,8,13,14,30,31 and 32. In almost all of these samples the binder amount did not exceed 10 wt%, however the fireclass ended up being D or E. On the other hand, IL mixed with sodium silicate showed a higher fire class, this seem to be valid as long as the binder amount does not exceed 10 wt% and at least 20 wt% of sodium silicate is used.

All the binders from Trevira mixed with sodium silicate also showed a high fire class, only 5% of sodium silicate was used in most of the cases and this was enough to reach A2/B. Samples 8, 11 and 12 consisted of IL 5% mixed with sodium silicate 5%, and these did not show a higher class than C.

Bico-fiber from fiber partner, FP Bio did also show a high fire class. This fiber worked with both sodium silicate and the acrylic binder. Sample 24 consisted of 10% of acrylic binder and 10% FP Bio, and despite the high binder amount this prototype had the highest TTI.

The fire test concludes that, FP Bio showed the highest fire class, followed by the bico-fibers from Trevira.

7.3 three point bending test

The stress-strain curves obtained from the three point bending test can be seen in figure 7.10-7.19. The noisy curves are due to individual fibers breaking during the test.

In figure 7.10 the stress strain curve for the reference material can be seen. The reference material had a density of $\rho = 80kg/m^3$ and a thickness of 20mm. The reference material did also have a surface layer on both sides. The maximum stress can be seen at 100 KPa.

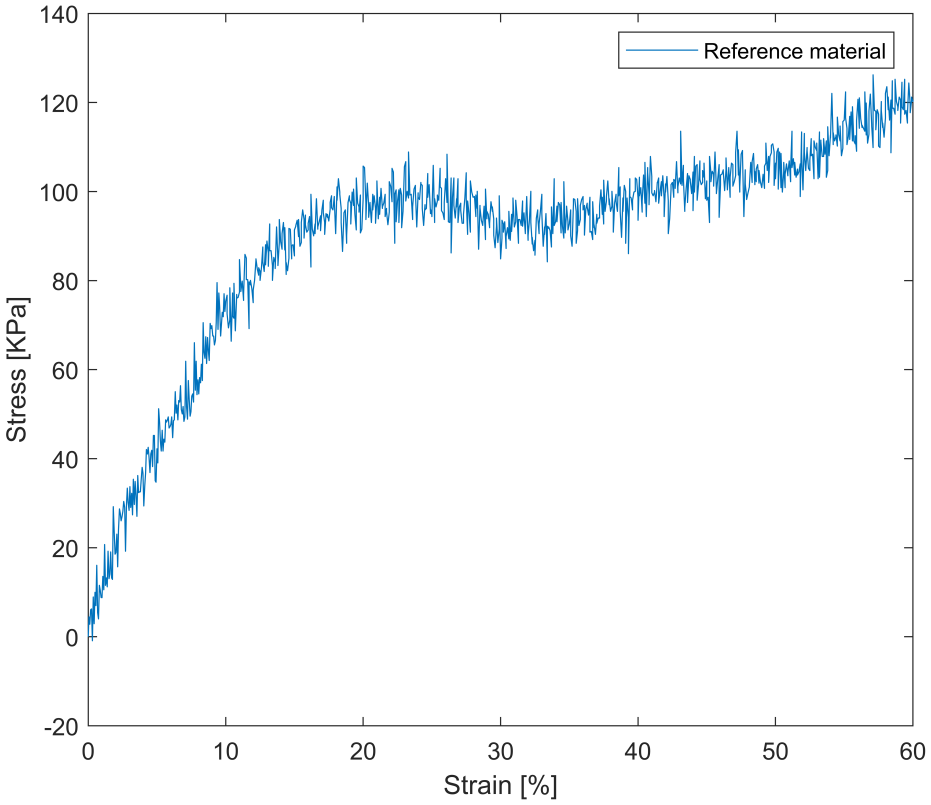


Figure 7.10: Stress-strain curve for reference material

In figure 7.11 the stress strain curves for prototypes with IL 12mm binder can be seen. From the results it can be seen that IL 12mm 15 wt% showed the highest strength, with the maximum stress of around 70 KPa. The lowest strength was shown by the prototype with 5 wt% binder, which only reached a maximum stress of 20 KPa.

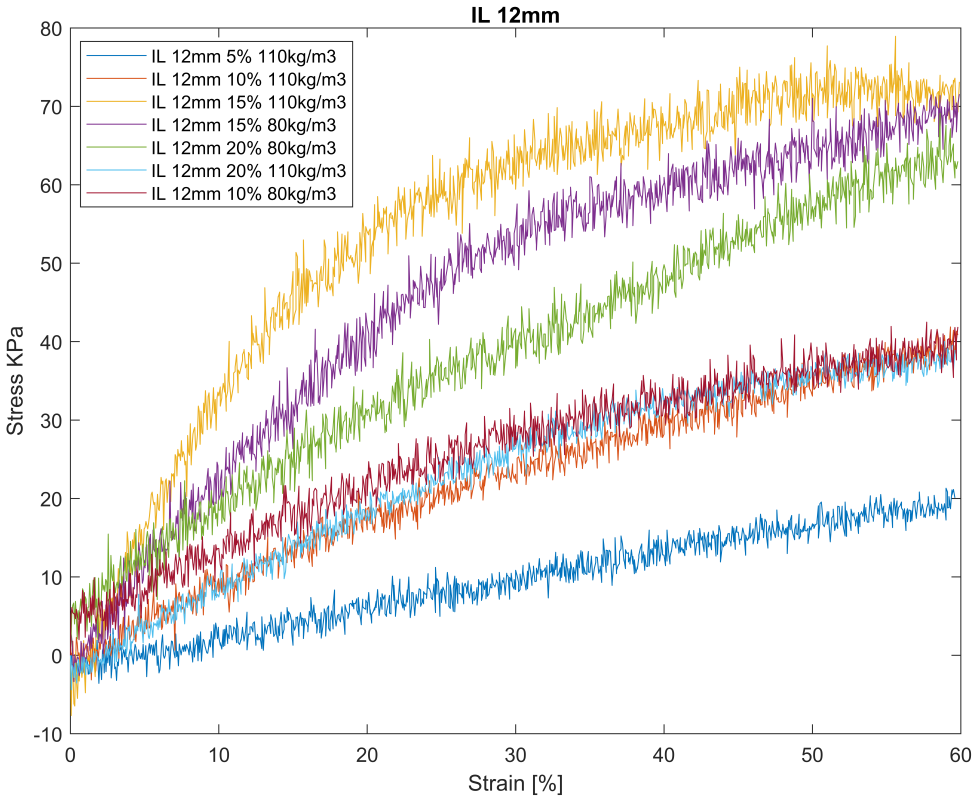


Figure 7.11: Stress-strain curve for prototypes with IL 12mm binder

Figure 7.12 displays the stress strain curves for prototypes with IL 6mm binder. It can be seen that IL 6mm 20 wt% showed the highest strength, with a maximum stress of 85KPa. Prototypes with 10 wt % reached the lowest stress. IL 6mm showed a higher strength in general if compared to IL 12mm.

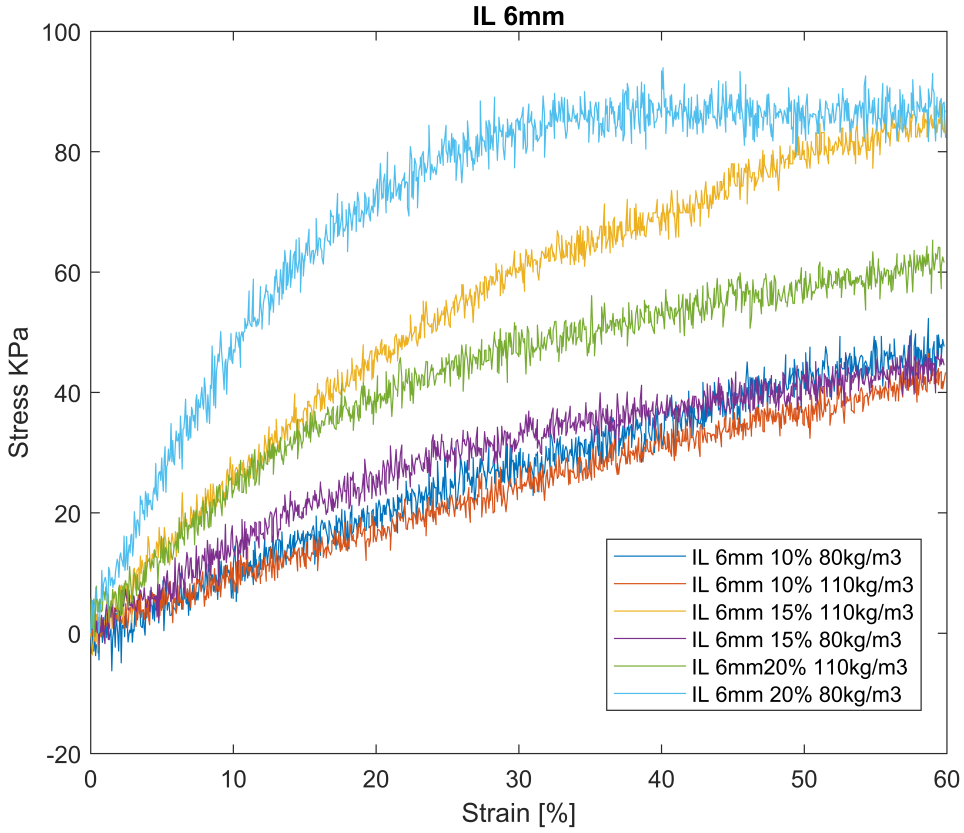


Figure 7.12: Stress-strain curve for prototypes with IL 6mm binder

The stress strain curves for prototypes with T255 can be seen in figure 7.13. The highest strength for these tiles was achieved from 20 wt % binder and $\rho = 110kg/m^3$. For these prototypes, the boards with $\rho = 110kg/m^3$ showed a higher strength than boards with $\rho = 80kg/m^3$ with the same amount of binder. Prototypes with T255 appeared to have less strength than boards with IL 6mm and IL 12mm binder.

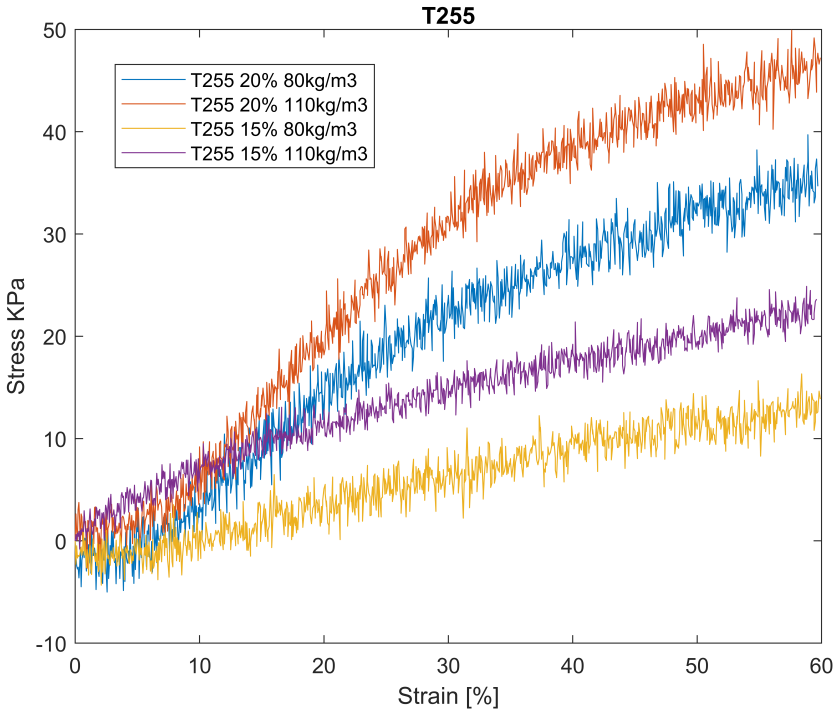


Figure 7.13: Stress-strain curve for prototypes with T255 binder

Most of the prototypes with binder T276 did not show a high strength (see figure 7.14. The highest strength was achieved by adding 20 wt% binder and $\rho = 110 kg/m^3$. This was still not as high as for the IL 6mm and 12mm.

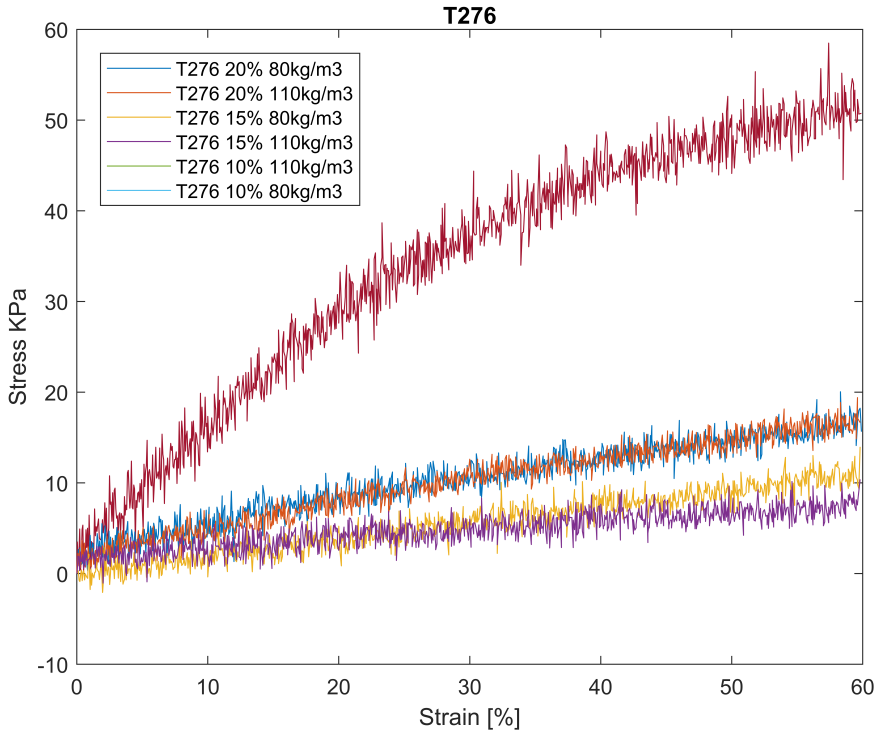


Figure 7.14: Stress-strain curve for prototypes with T276 binder

Prototypes with T755 showed similar mechanical properties as for the boards with T255. In figure 7.15 it can be seen that there were not much of a difference between prototypes with 15 wt% and 20 wt %, which could withstand a stress of around 30KPa. The weakest prototype had 10 wt% of binder and could only withstand 10-15 KPa.

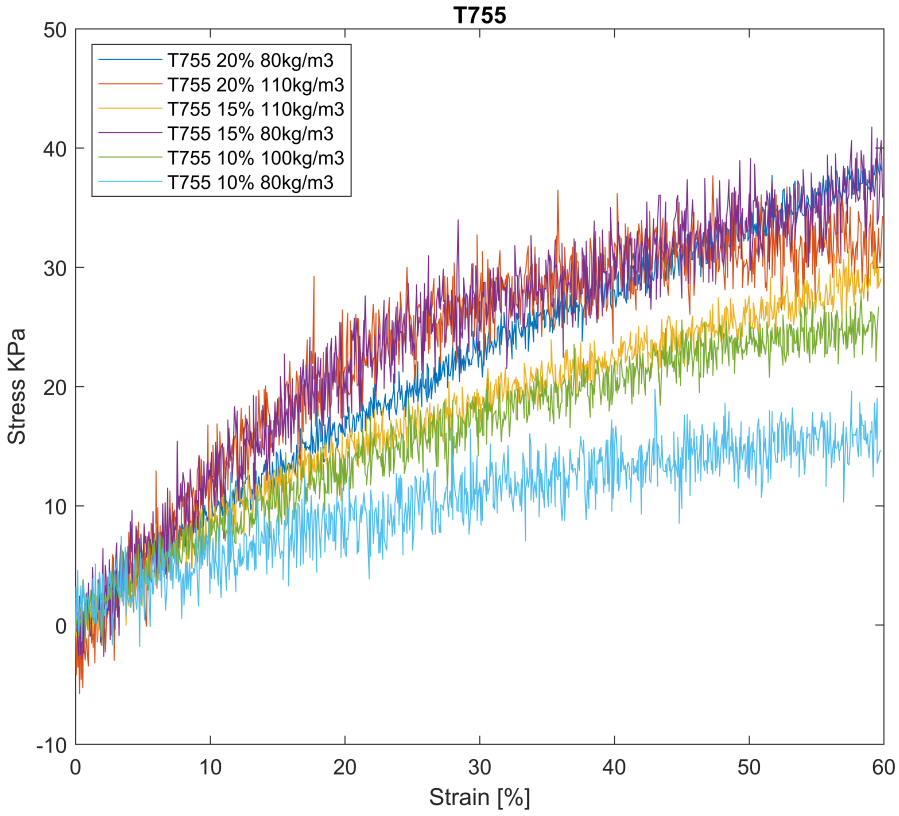


Figure 7.15: Stress-strain curve for prototypes with T755 binder

In figure 7.16 the stress strain curves for IL 12mm mixed with sodium silicate can be seen. Based on the result from the curves it can be seen that adding sodium silicate did add to the mechanical properties of the boards. IL 12mm 15 wt% + SS 30 wt% did show the highest strength, with around 80 Kpa. This is slightly higher than for boards with only IL 12mm, see figure 7.11. Adding SS to the mixture did give most of the boards a higher strength however it was also noticed that some of the boards with SS was a bit fragile. As mentioned earlier, if the bonds for sodium silicate do not form completely the outcome can be a more brittle material. This could be the case for sample, IL 12mm 10 wt% + SS 15 wt %.

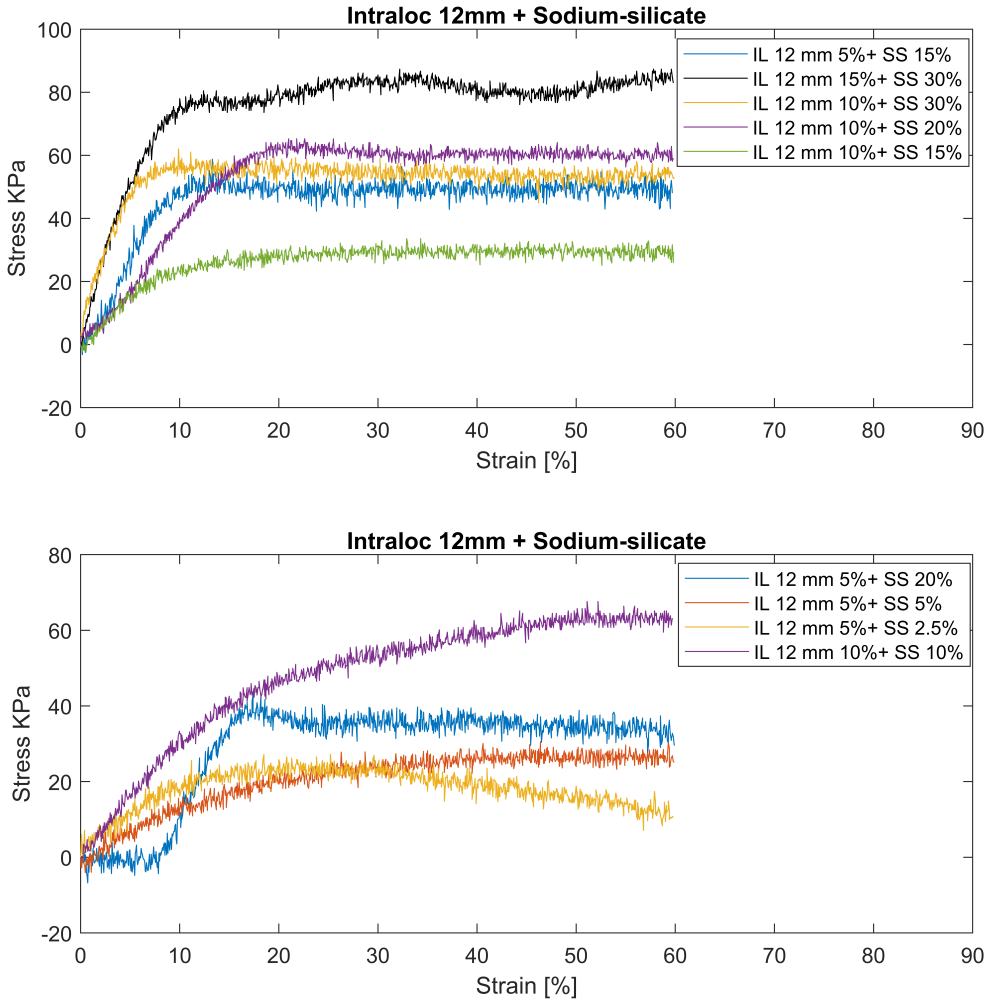


Figure 7.16: Stress-strain curve for prototypes with IL 12mm + SS binder

Sodium silicate was added to IL 6mm, and the stress strain curve can be seen in figure 7.17. IL 6mm with only 5 wt % binder without any added SS was not sufficient to keep the prototype together, but once SS was added to the mixture the strength of the board increased. This can be observed in the figure. Highest strength was for the board with 5 wt% IL 6mm + 15 wt% SS. Prototypes were less than

5 wt% SS was used showed the weakest properties. Although the SS added to the mechanical strength of the boards, it also made them more brittle. Visible cracks appeared during the bending test which did not occur for the rest of the samples.

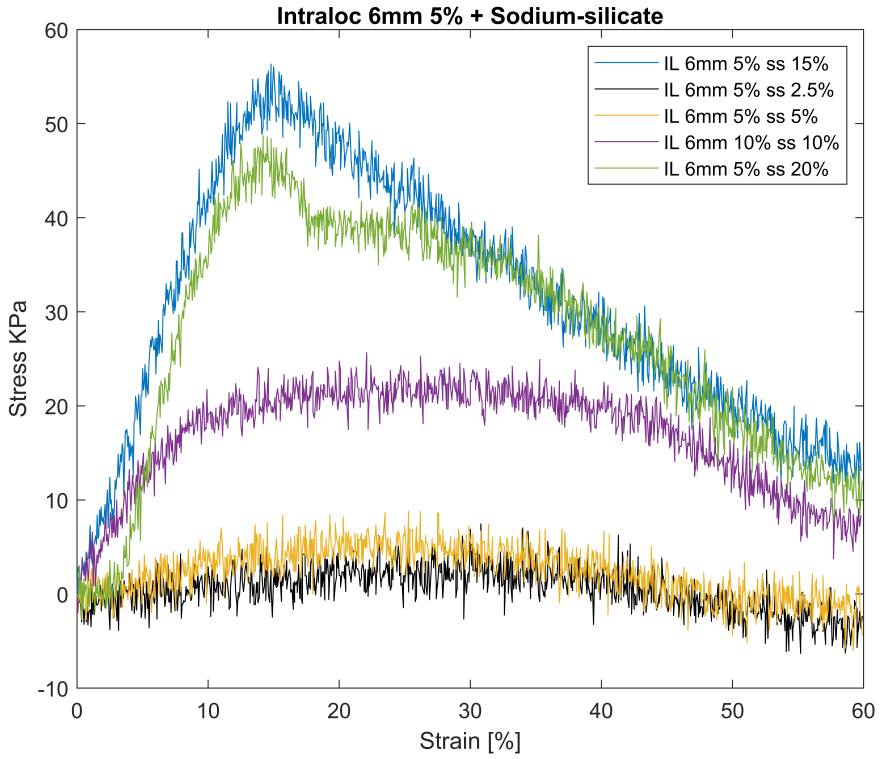


Figure 7.17: Stress-strain curve for prototypes with IL 6mm + SS binder

In figure 7.18 below, the stress strain curves, for all the bico-fibers combined with SS (5/5 wt %). From the figure it can be seen that IL 12mm showed the highest strength meanwhile FP Bio and IL 6mm showed the weakest properties. From the Trevira binders, T255 had the highest strength and T276 was the weakest.

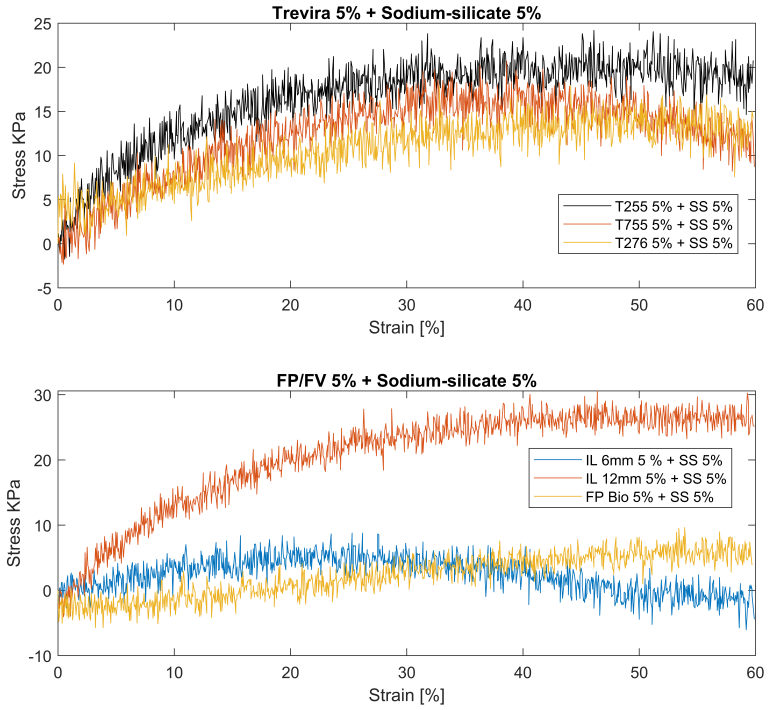


Figure 7.18: Stress-strain curve for prototypes with Trevira + SS binder, IL+SS, and FP Bio +SS

Figure 7.19 shows the stress strain curves for different binder combination. What stood out the most in this figure is the fact that adding an acrylic binder, plus 2580 to FP Bio, increased the strength of the sample.

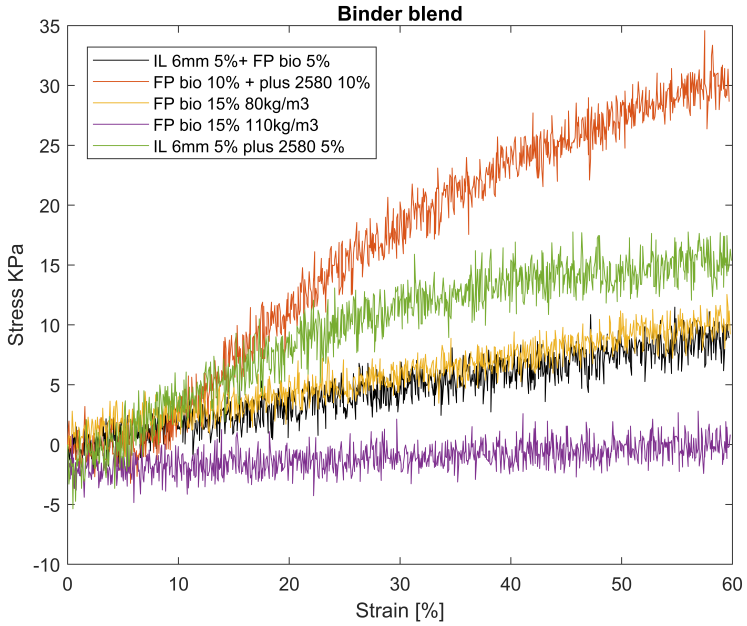


Figure 7.19: Stress-strain curve for prototypes with different binder combination

In conclusion for the three point bending test, it can be said that none of the prototypes, no matter of density, binder type, or binder amount achieved the same mechanical strength as a virgin board. On the other hand the prototypes were not covered with any surface layer unlike the reference material. This could also increase the strength of the board to a certain degree. In most cases, increasing the binder amount also increased the strength of the prototype, one deviation from this statement would be for IL 12mm, which showed the highest strength with only 15 wt%. But as previously mentioned, the prototypes are not homogeneous, and only two samples from each prototype were tested, which means it could be a deviation from the trend. To be more certain more testing needs to be done.

The binders from Fiber vision, IL 12mm and IL 6mm (dtex=1.7)had the best mechanical properties. Secondly comes the binders from Trevira, more specifically T255 (dtex=1.7) and T755(dtex=1.79, followed by T276 (dtex=2.2). Lastly the binder from Fiber Partner, FP Bio (dtex=5) had the weakest mechanical properties. From this

result a trend can be seen that fibers that weigh less (smaller dtex) showed the highest mechanical properties. This can be due to the fact that less weight means more individual fibers, which leads to more junction points.
The issue to the weak properties of FP Bio binder, could be due to the long fibers. Another step to improve the strength could be to try shorter, as well as lighter fibers.

7.4 Air flow resistance

Two samples from each prototype were used for the AFR measurements. The samples were covered with a thin film around the edges(see figure 7.20) in order to ensure that there were no room in between the sample and the sample holder.

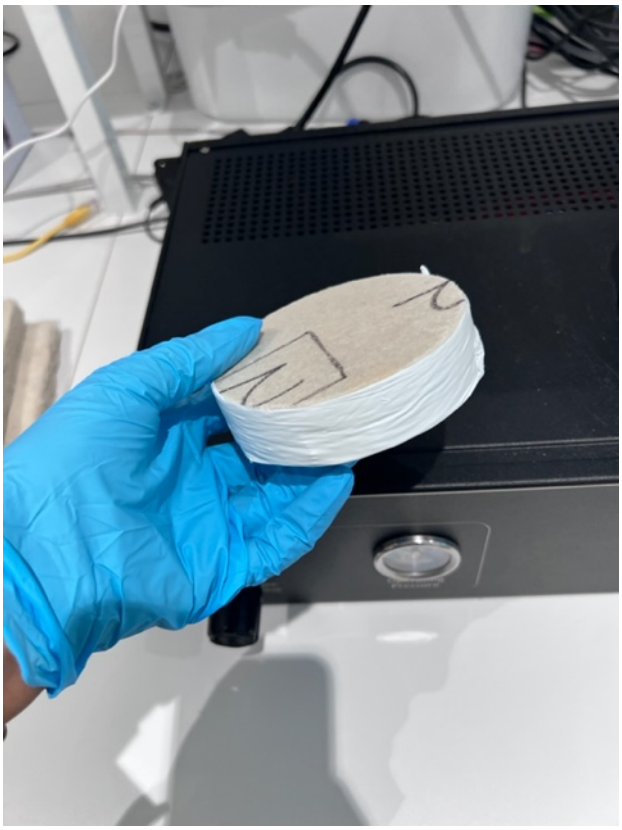


Figure 7.20: AFR sample with thin plastic foil around the edges

The results from the AFR measurements can be seen in table 7.2. Note that there are some slight variation in the density, meaning some of the densities deviates from the desired density of 80 or 110kg/m^3. This again is due to the inhomogeneity of the tiles. In the table the difference from the recommended values are also presented. These values are calculated by taking the difference between the measured AFR value and the closest limit to the recommended values;

$$Difference = Recommended_{value} - AFR_{value} \tag{7.1}$$

Table 7.2: Results from AFR measurements. "-" N̄o sample

Product nr	Density [kg/m^3]	AFR [Pa*s/m^2]	Difference from recommended value
1	115	71555	445
2	119	82140	0
3	113	80720	0
4	119	85270	0
5	115	65755	6245
6	120	73785	0
7	123	67145	4855
8	125	62210	9790
9	115	77450	0
10	120	68970	3030
11	120	73070	0
12	117	57280	14720
13	123	78940	0
14	115	74070	0
15	121	65540	6460
16	110	46155	5845
17	122	82160	0
18	109	52670	0
19	120	72965	0
20	87	34050	7950
21	110	61550	0
22	90	36990	15010
23	108	48845	3155
24	111	65690	0
25	-	-	-
26	109	39875	12125
27	108	39090	12910
28	120	69920	2080
29	107	60320	0
30	96	42860	9140
31	85	39280	2720
32	83	36575	5425
33	82	34295	7705
34	81	34345	7655

Product nr	Density [kg/m^3]	AFR [Pa*s/m^2]	Difference from recommended value
35	83	33610	8390
36	90	34770	17230
37	100	39350	12650
38	102	43160	8840
39	81	30300	11700
40	110	55745	0
41	110	48550	3450
42	107	51885	115
43	81	43015	0
44	93	29860	22140
45	99	36960	15040
46	92	32510	19490
47	91	34750	17250
48	97	49900	2100
49	95	44650	7350
50	102	48890	3110
51	93	42815	9185
52	102	45915	6085
53	83	37425	4575

As mentioned previously the air flow resistivity should be in the range, 42 000- 62 000 Pa*s/m^2 for boards with density 75-85 kg/m^3, 52 000- 75 000 Pa*s/m^2, for boards with density between 90-110 kg/m^3, 72 000-95 000 Pa*s/m^2, for boards with density between 100-120 kg/m^3.

Sample 1-19 had sodium silicate included in the mixture. These samples were more dense and they also showed a higher AFR value. Sample 20-53 did not have sodium silicate included in the mixture and the AFR values actually dropped a bit.Having a high AFR values indicates that the tile is closely packed and the space inside of the tile is limited. A low AFR value on the other hand indicates that the tile is more open and has more space for the air to flow through. This will ofcours affect the sound absorbing properties of the board. If the tile is to closely packed the sound will not be absorbed by the tile and will instead reflect. If the tile is more open, the sound will be transmitted through the tile. Note that the AFR values for sample 1-19 were a bit less than the recommended value, but this is necessarily not a bad thing. These values are still fine to work with because, some kind of surface layer will be added to the

tiles when they are being processed into acoustic tiles. This makes it possible to add different types of surface layers without exceeding the recommended AFR values.

sample 20-23 shows the AFR values for prototypes with binder T255.
sample 24-27 shows the AFR values for prototypes with binder FP Bio.
sample 29-35 shows the AFR values for prototypes with binder IL 12mm.
sample 36-41 shows the AFR values for prototypes with binder IL 6mm.
Sample 42-47 shows the AFR values for prototypes with binder T276.
sample 48-53 shows the AFR values for prototypes with binder T755.

If the different binders are compared, samples with T755 had the least deviation from the recommended values, followed by samples with IL 12mm binder, T255, FP Bio, IL 6mm and lastly T276.

Comparing the different AFR values for the prototypes that achieved A2/B class in the fire test; Sample 3, 6,9 10, 16, 17,19,24 showed A2/B class in the fire test. All of these samples except sample 16 and 17 was in the right range.

7.5 Environmental impact

In this section the environmental impact will be estimated and compared to virgin products.

7.5.1 Environmental product declaration of existing products

In this thesis the re-fiber product will be compared with products made at Isover. The reason for this is to compare it to base board that has not undergone any cutting, painting etc.
In the EPD the numbers are presented in kg CO_2 /m^2 of product.

In the A1-A3 product stage (see figure 7.21), the packaging for the transportation is also included, but the contribution is assumed to be very small compared to the manufacturing process.

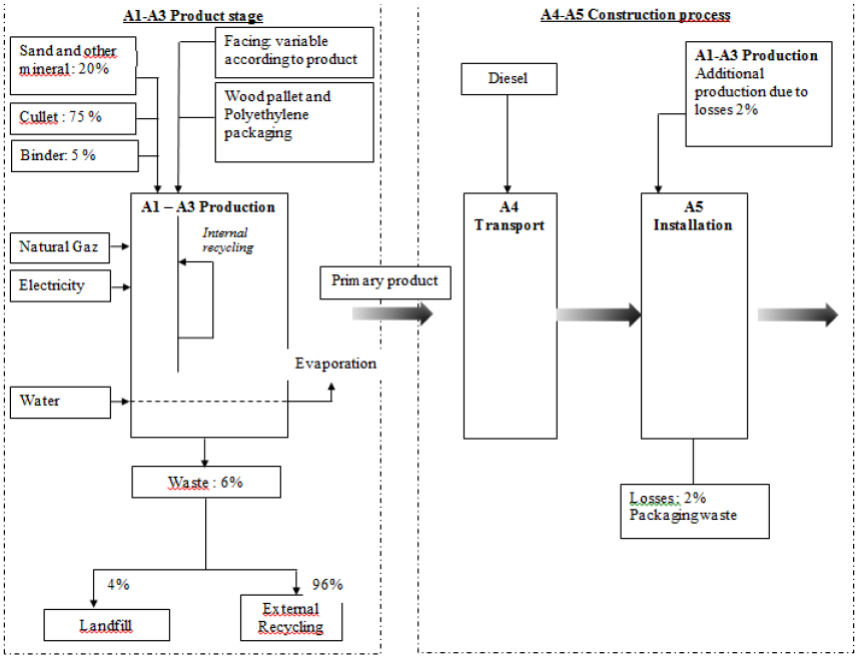


Figure 7.21: Parts of the LCA for one of the products at Isover

The value presented in the EPD for the stages A1-A3 is, 0.637 kg CO_2/m^2 product and the weight of the product is 0.57kg/m^2. Based on the assumption that a linear approach can be used on these values, following calculation can be made to estimate the equivalence for baseboards with a density of 80 and 110kg/m^3 made in the same production. Recall that the thickness of the prototype is $\approx$ 25mm.

$$\rho_1 = 80kg/m^3 \tag{7.2}$$

$$\rho_1 * 0.025 = 2kg/m^2 \tag{7.3}$$

$$\frac{2 * 0.637}{0.57} = 2.24 kgCO_2/m^2 \tag{7.4}$$

Repeating this type of calculation for ρ_2=110 kg/m^3, gives following value (see table 7.3).

Abbreviation used in table 7.3

- GWP- Global warming potential.

Table 7.3: calculated CO_2 emission from values in EPD.

Density [kg/m^3]	mass [kg/m^2]	GWP [kg CO_2/m^2]
Reference	0.57	0.637
80	2	2.24
110	2.75	3.07

7.5.2 CO_2 estimation of the prototypes

A CO_2 estimation was done on the prototypes. The numbers presented in table 7.4 are taken from the LCA database, GaBi. As mentioned earlier, in these calculation only step A1-A3 of the process will be taken into consideration. In order to complete the calculations some approximations has been done, these include:

- The composition of the binders are roughly estimated. E.g. the ratio of each polymer for the bico-fibers are estimated to be 50/50 wt %
- The exact source and extraction method of the raw material for the binders. The calculations are based on that the raw material is taken from Europe.
- The acoustic tiles used for the shredded material, is initially going to come from production waste. For this reason the transportation of material is not included in the calculations.
- The environmental impact during manufacturing is neglected (usually very low number compared to the raw material). The

manufacturing step would account for the heat needed for the oven. The oven is however run by electricity from hydro-power which doesn't have a big impact. The emission is estimated to be 0.003768 kg CO_2/kWh.

- Bico-fibers with co-polyolefins as sheath material is estimated to have the same impact as polyethylene.

To get more exact numbers, more detailed specifications about the binder need to be forwarded from the supplier (such as the exact composition, where the raw material comes from etc), alternatively the EPD for the material needs to be accessible.

Table 7.4: Values that will be used for the CO_2 estimation.

Component	Modelized as	GWP(kg CO_2/kg component
Shredded glass wool	No impact from the wool, only impact from the shredding	0.000866
Polyethylene PE	polyethylene production, low density, granulate	1.92
Polyethylene terephthalate (PET)	polyethylene terephthalate production, granulate, amorphous	2.86
Polypropylene PP	polypropylene production, granulate	1.83
LM polyester	Polyester fiber production	4.1
Acrylic binder	acrylic binder production, product in 34% solution state	1.34
Sodium silicate powder	Market for sodium silicate, solid	0.727

7.5.3 Calculations

The calculations are based on 1kg of baseboard, and the result is presented in table 7.5.
CO_2 amount per baseboard = wt % binder * CO_2/kg for binder + wt % shredded wool * CO_2/kg for shredded wool.

Example of calculation:

20 wt % Intraloc

$$0.2(0.5*1.92+0.5*1.83)+0.8*0.000866 \approx 0.376 kgCO_2/Kgbaseboard \quad (7.5)$$

The numbers should be presented with the unit kg CO_2 /m^2. To get this unit, multiply with the density and the thickness. E.g. for baseboards with $\rho = 80kg/m^3$:

$$0.376kgCO_2/Kgbaseboard * 80kg/m^3 * 0.025m = 0.752kgCO_2/m^2 \tag{7.6}$$

See table 7.5-7.6 for calculated values.

Table 7.5: Calculated values of kg CO_2 / m^2 for boards with $\rho = 80kg/m^3$.

Binder type	Binder amount [wt %]	kg CO_2/kg baseboard	$\rho_1 = 80kg/m^3$, kg CO_2/m^2
IL 6mm and IL 12mm	20	0.376	0.752
IL 6mm and IL 12mm	15	0.282	0.564
IL 6mm and IL 12mm	10	0.188	0.376
T255	20	0.479	0.958
T255	15	0.360	0.720
T255	10	0.240	0.48
T755	20	0.479	0.958
T755	15	0.360	0.720
T755	10	0.240	0.480
T276	20	0.479	0.958
T276	15	0.360	0.720
T276	10	0.240	0.480
FP Bio	20	0.697	1.394
FP Bio	15	0.522	1.044
FP Bio	10	0.348	0.696
Acrodur plus 2580	20	0.269	0.538
Acrodur plus 2580	15	0.202	0.404
Acrodur plus 2580	10	0.135	0.270
IL 6mm and IL 12mm + SS	10/10	0.261	0.522
IL 6mm and IL 12mm + SS	5/5	0.131	0.262
T255 + SS	10/10	0.313	0.626
T255 + SS	5/5	0.157	0.314
T755 + SS	10/10	0.313	0.626
T755 + SS	5/5	0.157	0.314
T276 + SS	10/10	0.313	0.626
T276 + SS	5/5	0.157	0.314
FP Bio + SS	10/10	0.421	0.842
FP Bio + SS	5/5	0.210	0.420
FP Bio + Acrodur plus 2580	10/10	0.482	0.964

Table 7.6: Calculated values of kg CO_2 / m^2 for boards with $\rho = 110kg/m^3$..

Binder type	Binder amount [wt %]	kg CO_2/kg baseboard	$\rho_1 = 110kg/m^3$, kg CO_2/m^2
IL 6mm and IL 12mm	20	0.376	1.034
IL 6mm and IL 12mm	15	0.282	0.775
IL 6mm and IL 12mm	10	0.188	0.517
T255	20	0.479	1.318
T255	15	0.360	0.990
T255	10	0.240	0.660
T755	20	0.479	1.318
T755	15	0.360	0.990
T755	10	0.240	0.660
T276	20	0.479	1.317
T276	15	0.360	0.990
T276	10	0.240	0.660
FP Bio	20	0.697	1.920
FP Bio	15	0.522	1.435
FP Bio	10	0.348	0.957
Acrodur plus 2580	20	0.269	0.740
Acrodur plus 2580	15	0.202	0.555
Acrodur plus 2580	10	0.135	0.371
IL 6mm and IL 12mm + SS	10/10	0.261	0.718
IL 6mm and IL 12mm + SS	5/5	0.131	0.360
T255 + SS	10/10	0.313	0.860
T255 + SS	5/5	0.157	0.432
T755 + SS	10/10	0.313	0.861
T755 + SS	5/5	0.157	0.432
T276 + SS	10/10	0.313	0.861
T276 + SS	5/5	0.157	0.432
FP Bio + SS	10/10	0.421	1.160
FP Bio + SS	5/5	0.210	0.578
FP Bio + Acrodur plus 2580	10/10	0.482	1.326

7.5.4 comparison

The estimated CO_2 values for virgin baseboard can be seen in table 7.3. The estimated values for refiber boards with density 80 and 110 kg/m^3 can be seen in table 7.5 and 7.6. There were several approximations done in order to achieve the numbers in table 7.5 and 7.6, however there were still distinct difference between the GWP for virgin and refiber boards. The lowest values for the GWP

was given by the binder from Fibervision (IL) which gave a GWP of 0.752 kg CO/m^2 for 20 wt% binder and 80kg/m^3 boards. Note that the acrylic binder, Acrodur plus 2580 did have a lower GWP, but as mentioned earlier this binder did not give enough mechanical properties by itself and the numbers presented are only for the curious reader. The highest GWP came from the binder from Fiber Partner. the binder consisted of a polyester sheath with a PET core and both of these polymers do have a high GWP during production. The same binder from fiber partner did also show a high fire class, so the binder is considered a strong candidate.

By mixing sodium silicate with the bico-fibers it was possible to lower the GWP. As previously stated, sodium silicate do not contribute to the flammability of the product, which is a huge advantage.

With the aim to lower the GWP as much as possible, next step would be to use bico-fibers with recycled components, such as recycled PET.

Chapter 8

conclusion and future work

8.1 conclusion

In order to compile all the results and get a better overview of the best candidates for the refiber project, following ranking will be done;

- Thermal stability- ranking between 0.5x(1-6). Although the thermal stability is an important parameter, it was not a huge difference between the thermal stability for the different binders, hence 0.5 X ranking point
- Fire properties- ranking points 2x(1-6). The fire property is a central part of the project, hence twice the ranking points.
- Mechanical properties - ranking points 1-6
- Acoustic properties - ranking points 1-6
- Global warming potential- ranking points 1-3

The sum of the ranking points will show which candidates are the most fitting for this project, see table 8.1.

Table 8.1: Ranking of the different binder candidates

Binder type	Thermal stability	Fire	Mechanical	Acoustic	GWP	Sum
IL 12mm	0.5x5	2x1	6	5	3	18.5
IL 6mm	0.5x6	2x1	5	2	3	15
T255	0.5x3	2x4	4	4	2	19.5
T276	0.5x2	2x5	2	1	2	16
T755	0.5x3	2x3	3	6	2	18.5
FP Bio	0.5x1	2x6	1	3	1	17.5

Best overall performance was achieved by using binder T255. This binder is a strong candidate for the re-fiber project. T755 and IL 12mm are placed secondly. IL 12mm performed well in all categories except for the fire testing which drew down the scores. FP bio had the best result in the fire testing which is a huge advantage, however the mechanical properties were not as good as for the rest. The GWP was also the highest for the FP Bio binder. FP Bio still has potential to be used as a binder for the refiber project however, there need to be some modifications. The fiber length needs to be shorter, 6-12mm is desirable. The dtex also needs to reduced, 1.7 or less could be good. Lastly, if the raw material of the binder comes from recycled PET, the GWP could be reduced making it more desirable.

Recycling worn out acoustic tiles is a possible process. The binder amount and binder type can be optimized to reach the standard that is needed for the product. Comparing the GWP for a refiber board to a virgin board also shows that there is an advantage to use recycled boards as a starting material.

8.2 Future work

Due to the lack of time, many different tests and experiment has been left to future work. The bio-based binder lignin was not tested in this thesis due to the lack of time. This is however still a binder that should be tested and evaluated.If the binder for the refiber project can be covered by a bio-based binder the GWP could decrease even further, making the product even more sustainable.

Another important parameter that needs to be improved is the mechanical properties of the tiles. All of the prototypes that were made had a lower mechanical strength than the reference material. One suggestion to improve the mechanical properties is to use bicofibers with a low dtex, this would mean that more individual fibers are added to the mixture leading to more junction points. This could also lead to less fibers being used in the product which would increase the fire properties. However, this is only an assumption and it still needs to be tested.
Additionally the emission that is released from the tiles should be evaluated to get a complete overview of the binders.

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Appendix A

Appendix

A.1 Prototypes

Table A.1: List of tested prototypes, Performance, A=approved, NA=Not approved

Binder	Density [kg/m^3]	Binder amount [wt %]	Temperature [°C]	Time [min]	Performance
IL 6MM	80	20, 15, 10	145	45	A
IL 6MM	110	20, 15, 10	145	60	A
IL 12MM	80	20, 15, 10	145	45	A
IL 12MM	110	20, 15, 10,5	145	60	A
T755	80	20, 15, 10	145	45	A
T755	110	20, 15, 10	145	60	A
T453	80	20	145	60	NA
T453	110	20	145	60	NA
T225	80	20,15	180	60	A
T225	80	10	180	60	NA
T225	110	20,15	180	60	A
T225	110	10	180	60	NA
T276	80	20,15,10	180	60	A
T276	110	20,15,10	180	60	A
FP-Brown	110	20,15,10	180	60	NA
FP-Brown	80	20,15,10	180	60	NA
FP-white	110	20,15,10	180	60	NA
FP-Bio	80	20,10	180	60	NA
FP-Bio	110	20,10	180	60	NA
FP-Bio	80	15	180	60	A
FP-Bio	110	15	180	60	A
DS 3530	80	20	180	60	NA
DS 3530	80	20 125	190	90	NA
DS 3530	110	20	190	90	NA
DS 3530	150	20	190	90	NA
DS 3530	150	40	190	90	NA
DS 3530	110	20 (diluted)	190	140	NA
DS 3530	110	20(diluted)	190	140	NA
DS 3530	110	20(diluted)	190	140	NA
Plus 2580	80	20	200	90	NA

Table A.2: List of tested prototypes with different binder combination. SS=sodium silicate

Binder	Binder amount [wt %]	Temperature [°C]	Time [min]	Performance
IL 12mm/SS	15/30	145	60	A
IL 12mm/SS	10/30	145	60	A
IL 12mm/SS	10/20	145	60	A
IL 12mm/SS	10/15	145	60	A
IL 12mm/SS	10/10	145	60	A
IL 12mm/SS	5/20	145	60	A
IL 12mm/SS	5/15	145	60	A
IL 12mm/SS	5/15	145	60	A
IL 12mm/SS	5/5	145	60	A
IL 12mm/SS	5/2.5	145	60	A
IL 6mm/SS	10/10	145	60	A
IL 6mm/SS	5/20	145	60	A
IL 6mm/SS	5/15	145	60	A
IL 6mm/SS	5/5	145	60	A
IL 6mm/SS	5/2.5	145	60	A
T255/SS	5/5	145	60	A
T755/SS	5/5	145	60	A
T276/SS	5/5	145	60	A
FP Bio/SS	5/5	145	60	A
IL 6mm/FP Bio	5/5	145	60	A
FP Bio/Plus 2580	10/10	145	60	A
IL 6mm/Plus 2580	5/5	145	60	A

A.2 DSC curves

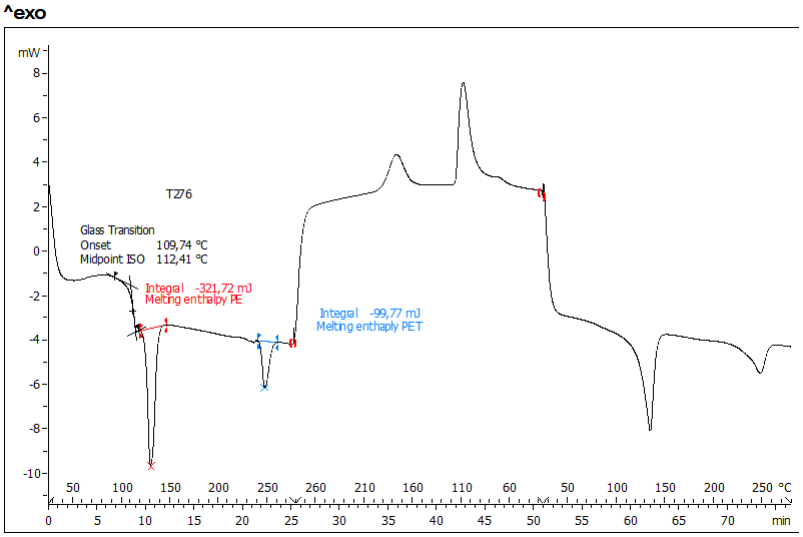

Figure A.1: DSC curve for T276

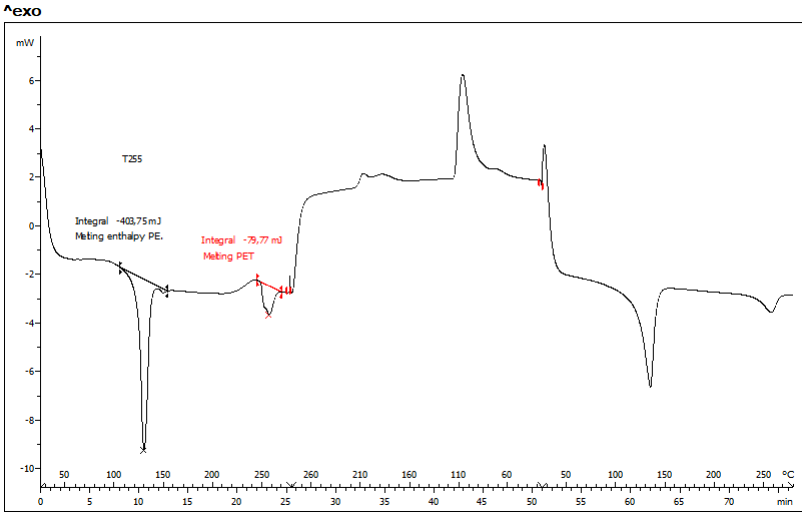

Figure A.2: DSC curve for T255

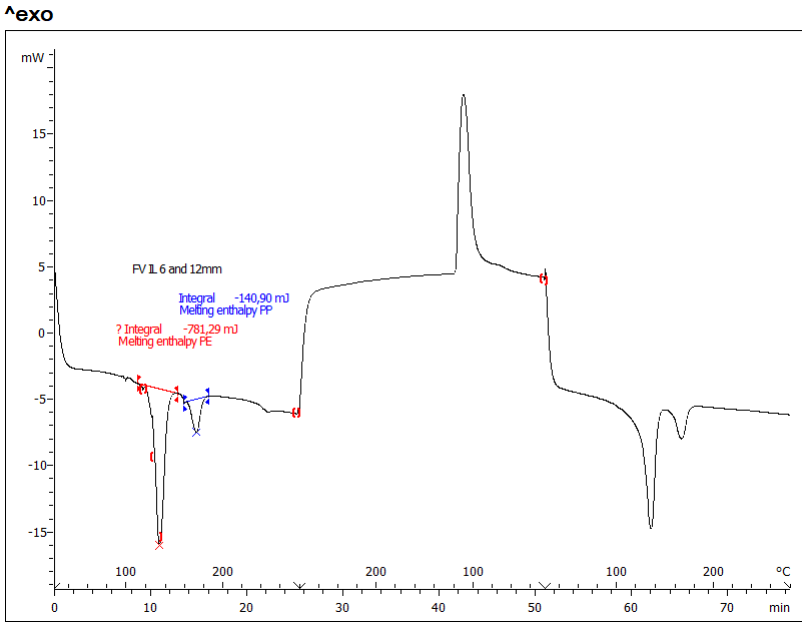

Figure A.3: DSC curve for IL 6mm andIL 12mm

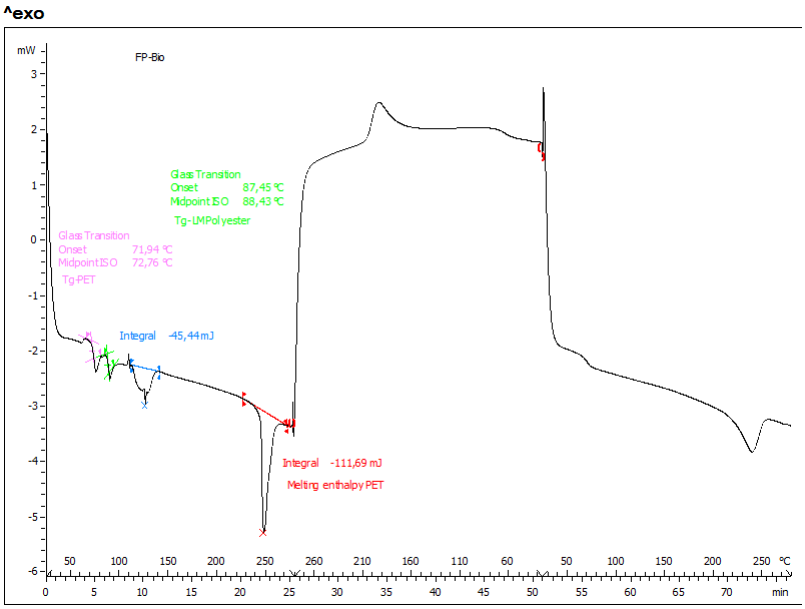

Figure A.4: DSC curve for FP Bio

Appendix B

Risk assessment

B.1 Binder

B.1.1 Acrodur plus 2580

- **Handling**-No special measures necessary provided product is used correctly. Handle in accordance with good industrial hygiene and safety practice. Further information on storage conditions: Store protected against freezing. Containers should be stored tightly sealed in a dry place and protected from direct sunlight
- **Personal protection**-Hand protection: Suitable chemical resistant safety gloves.
  Eye protection: Safety glasses with side-shields.
  General safety and hygiene measures: Wash skin after handling the product. Avoid contact with skin and eyes.
- **Decontamination and waste**-According to Saint-Gobain Ecophon AB's routine for waste.
- **First aid**-Remove contaminated clothing.
  If inhaled: Remove to fresh air, seek medical attention. On skin contact: Wash thoroughly with soap and water. Eye contact: Immediately wash eyes for at least 15 min under running water, consult an eye specialist.

On ingestion: Immediately rinse mouth and then drink 200-300 ml of water, seek medical attention

- **Fire**-Suitable extinguishing media: water spray, dry powder, foam, carbon dioxide.
- **Overall**- Low risk product

B.1.2 Acrodur DS 3530

- **Handling**-No special measures necessary provided product is used correctly. Handle in accordance with good industrial hygiene and safety practice. Further information on storage conditions: Store protected against freezing. Containers should be stored tightly sealed in a dry place and protected from direct sunlight
- **Personal protection**-Hand protection: Suitable chemical resistant safety gloves.
  Eye protection: Safety glasses with side-shields.
  General safety and hygiene measures: Wash skin after handling the product. Avoid contact with skin and eyes.
- **Decontamination and waste**-According to Saint-Gobain Ecophon AB's routine for waste.
- **First aid**-Remove contaminated clothing.
  If inhaled: Remove to fresh air, seek medical attention. On skin contact: Wash thoroughly with soap and water. Eye contact: Immediately wash eyes for at least 15 min under running water, consult an eye specialist.
  On ingestion: Immediately rinse mouth and then drink 200-300 ml of water, seek medical attention
- **Fire**-Suitable extinguishing media: water spray, dry powder, foam, carbon dioxide.
- **Overall**- Low risk product

B.1.3 Acrodur DS 3515

- **Handling**-No special measures necessary provided product is used correctly. Handle in accordance with good industrial hygiene and safety practice. Further information on storage conditions: Store protected against freezing. Containers should be stored tightly sealed in a dry place and protected from direct sunlight
- **Personal protection**-Hand protection: Suitable chemical resistant safety gloves.
  Eye protection: Safety glasses with side-shields.
  General safety and hygiene measures: Wash skin after handling the product. Avoid contact with skin and eyes.
- **Decontamination and waste**-According to Saint-Gobain Ecophon AB's routine for waste.
- **First aid**-Remove contaminated clothing.
  If inhaled: Remove to fresh air, seek medical attention. On skin contact: Wash thoroughly with soap and water. Eye contact: Immediately wash eyes for at least 15 min under running water, consult an eye specialist.
  On ingestion: Immediately rinse mouth and then drink 200-300 ml of water, seek medical attention
- **Fire**-Suitable extinguishing media: water spray, dry powder, foam, carbon dioxide.
- **Overall**- Low risk product

B.1.4 Acrodur power 2850

- **Handling**-No special measures necessary provided product is used correctly. Handle in accordance with good industrial hygiene and safety practice. Further information on storage conditions: Store protected against freezing.Protect from temperatures below: 5 °C Protect from temperatures above: 60 °C. Containers should be stored tightly sealed in a dry place and protected from direct sunlight

- **Personal protection**-Hand protection: Suitable chemical resistant safety gloves.
  Eye protection: Safety glasses with side-shields.
  General safety and hygiene measures: Wash skin after handling the product. Avoid contact with skin and eyes.
- **Decontamination and waste**-According to Saint-Gobain Ecophon AB's routine for waste.
- **First aid**-Remove contaminated clothing.
  If inhaled: Remove to fresh air, seek medical attention. On skin contact: Wash thoroughly with soap and water. Eye contact: Immediately wash eyes for at least 15 min under running water, consult an eye specialist.
  On ingestion: Immediately rinse mouth and then drink 200-300 ml of water, seek medical attention. Do not induce vomiting.
- **Fire**-Suitable extinguishing media: water spray, dry powder, foam, carbon dioxide.
- **Overall**- Low risk product

B.1.5 Acronal A 969

- **Health**- May cause an allergic skin reaction
- **Handling**-No special measures necessary provided product is used correctly. Handle in accordance with good industrial hygiene and safety practice. Further information on storage conditions: Store protected against freezing.Protect from temperatures below: 5 °C Protect from temperatures above: 60 °C. Containers should be stored tightly sealed in a dry place and protected from direct sunlight
- **Personal protection**-Hand protection: Suitable chemical resistant safety gloves.
  Eye protection: Safety glasses with side-shields.
  General safety and hygiene measures: Wash skin after handling the product. Avoid contact with skin and eyes.

- **Decontamination and waste**-According to Saint-Gobain Ecophon AB's routine for waste.
- **First aid**-Remove contaminated clothing.
  If inhaled: Remove to fresh air, seek medical attention. On skin contact: Wash thoroughly with soap and water. Eye contact: Immediately wash eyes for at least 15 min under running water, consult an eye specialist.
  On ingestion: Immediately rinse mouth and then drink 200-300 ml of water, seek medical attention. Do not induce vomiting.
- **Fire**-Suitable extinguishing media: water spray, dry powder, foam, carbon dioxide.
- **Overall**- Low risk product

B.1.6 Bico-fibers

- **Health**- fibers may cause irritations to the eyes and the respiratory system. Fiber dust may be a fire hazard at sufficient concentrations in presence of an ignition source.
- **Handling**- Avoid formation of dust an fiber fly. Accumulation of fiber dust may be a fire hazard at sufficient concentration. Remove ignition sources. Beware of electrostatic charges.

  Storage: Protect against dust, moisture, direct sunlight. electrostatic charges and ignition sources.
- **Personal protection**- Eye protection- Safety glasses with side shield. Hand, skin, and body protection; Wear protective gloves. Inhalation protection: Wear protective mask. Use a fume suction hood.

  Work place hygiene: Continuously clean the working area by wet or vacuum cleaning in order to avoid accumulation of fibber dust.
- **waste**- According to Saint Gobain Ecophon's waste handling routine.

- **first aid**- inhalation: Inahlation of fiber dusy should be avoided. Use good fume hood suction and air ventilation system. In case of irritated airways seek fresh air.

  Eye contact: wash eyes with water.

  Ingestion: Do not induce vomiting.

- **Fire**- All extingushing media can be used.
- **Overall**- Low risk product.

B.2 Tools

B.2.1 Oven

- **Burn hazards**- Be aware of hot surfaces when loading and unloading items.
- **Fire hazard**- Make sure to not use material that can ignite at the temperature that is used. This could cause a fire.
- **Health Hazard**-Fumes and other volatile substances can be released, make sure to use a fume extractor.

B.2.2 Mixer

- For the mixer compressed air is used. If not correctly used over pressure can cause the mixer to burst.