Glass wool as geopolymer raw material

Milling process waste with Mil-Tek IC60 screw mill

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Abstract:

Mineral wool waste in construction and demolition is left largely unutilized, with 2.5 million tons landfilled annually in the EU. This material can be used as a raw material for alkali-activated materials, or geopolymers, which could be used in traditional cement applications that have very large CO_2-emissivities. Upcycling waste material to alternative cement is an important part of fighting global warming. In this study, glass wool from Saint Gobain ISOVER process waste was milled using a specialized screw mill built for mineral wool processing. The effectiveness of the mill in producing a geopolymer raw material was evaluated, as well as its overall suitability as a part of the ISOVER manufacturing process. Particle sizes and size-distributions were measured from milled acoustic panels made from glass wool. The material was made into a geopolymer sample and its properties were analyzed using optical microscopy and photographic measuring of the particles. The mill produced material that was fine enough for geopolymerization with the cumulative particle distribution values $d_{50} = 36$ µm and $d_{80} = 65$ µm. Microscopic inspection showed the glass wool fibres having been mostly hydrolyzed within the sample, but compressive testing proved inconclusive. The overall performance of the mill was not optimal, as the process was prone to interference and interruptions. The raw material requirements are very specific, which affects the practicality of the mill as a part of a manufacturing process.

Keywords:	Geopolymer, alkali-activation, mineral wool, glass wool, stone wool, milling, upcycling, Saint-Gobain Finland
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Tiivistelmä:

Rakentamisessa ja purkamisessa syntyvää mineraalivillajätettä päätyy vuosittain kaatopaikalle 2,5 miljoonaa tonnia EU:n alueella. Tämä materiaali soveltuu erinomaisesti geopolymeerien, eli alkaliaktivoitujen materiaalien raaka-aineeksi. Geopolymeerejä voidaan käyttää vaihtoehtona perinteisissä sementtisovelluksissa, joilla on erittäin suuri hiilidioksidijalanjälki. Jätemateriaalien käyttäminen vaihtoehtoisina raaka-aineina, etenkin sementissä, on tärkeä osa ilmaston lämpenemisen hillitsemistä.
Tässä opinnäytetyössä Saint-Gobain ISOVERIN lasivillatehtaan prosessijätettä jauhettiin mineraalivillan käsittelyyn rakennetulla ruuvimyllyllä. Myllyn soveltuvuutta arvioitiin sekä geopolymeerin raaka-aineen tuottamisen suhteen, että laajemmin osana tuotantoprosessia.
Lasivillapohjaisista akustiikkapaneeleista jauhetusta materiaalista mitattiin raekoko ja raejakauma. Materiaalista valmistettu geopolymeerinäyte analysoitiin käyttämällä optista mikroskopiaa ja hiukkasten valokuvamittausta. Myös puristuslujuutta mitattiin.
Myllyn jauhama materiaali oli riittävän hienoa geopolymeerin raaka-aineeksi, kumulatiivisen raejakauman arvot olivat d_{50} = 36 µm ja d_{80} = 65 µm. Mikroskoopilla tarkastellussa näytteessä lasivillakuidut olivat enimmäkseen hydrolysoituneet, osoittaen alkaliaktivaation onnistuneen. Puristuslujuuden tulos jäi selvästi alle odotusten. Myllyn soveltuvuus jäi myös tavoitteista, koska jauhamisprosessi oli altis häiriöille ja keskeytyksille. Soveltuvan raaka-aineen vaatimukset ovat hyvin tarkat, mikä vaikuttaa laitteen käyttökelpoisuuteen tuotantoprosessissa.

Avainsanat:	Geopolymeeri, alkaliaktivointi, mineraalivilla, lasivilla, kivivilla, vaihtoehtoiset raaka-aineet, Saint-Gobain Finland
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FOREWORD

When attending an excursion at Saint-Gobain Finland Oy in the autumn of 2019, it came as a somewhat of a surprise how much the company was working on with reducing carbon emissions of the building materials manufactured by Saint-Gobain Group. These include gypsum boards (Gyproc), industrial mortars (Weber), expanded clay (Leca) and glass wool insulation (ISOVER). There is a terrific potential of renewable resources that come with circular economy models, and that's exactly what the company is pursuing in exploring alternative and low-carbon processes and materials. I have been very interested in sustainability and circular economy both in my studies and in my personal life, so naturally I was very interested in the company. I applied for a summer job and was given the opportunity to write a thesis about the processing and geopolymerization of glass wool waste at the Saint-Gobain ISOVER glass wool plant at Forssa (Later: Forssa plant).

I am currently working as a project worker for the Wool2Loop-project and have been involved with milling mineral wool for the project for the past autumn. I have had a vested interest in learning as much as possible about the processing of glass wool and the manufacturing all the other construction materials produced at Saint-Gobain, and it has greatly increased my knowledge about the possibilities of alternative construction materials. The time I have spent learning about research and development will help me greatly in my future employment at Saint-Gobain within the field of circular economy. As a student of materials processing, I could not have asked for a more relevant thesis topic, or workplace. It has been a challenging three and a half years, but it has been worth it many times over. I am confident that I will look back at this degree as a major turning point in my life.

I'd also like to thank Maija Siiki for her invaluable support during my studies, as well as Anne Kaiser for giving me the opportunity of a lifetime.

ABBREVIATIONS

AAM	Alkali-activated materials
CDW	Construction and demolition waste
EHS	Environmental, health and safety
FIBC	Flexible intermediary bulk container
GGBFS	Groung granulated blast furnace slag
GW	Glass wool
GWW	Glass wool waste
MMMF	Man made mineral fibers
MMVF	Man made vitreous fibers
MW	Mineral wool (glass wool and stone wool)
MWW	Mineral wool waste
OPC	Ordinary Portland cement
W2L	WOOL2LOOP

1 INTRODUCTION

1.1 Background

The Intergovernmental Panel on Climate Change (IPCC) published a report on the impacts of global warming: the objective is to reduce the anthropogenic warming to 1.5 degrees Celsius by 2030 (IPCC, 2019). Along with the global goals, The Finnish government has also pledged to reduce the emissions by the year 2030 in a way to facilitate a carbon neutral Finland by the year 2035.

Buildings and construction are responsible for creating up to 40% of energy related CO_2-emissions annually (Abergel, et al., 2017).

The carbon footprint of buildings includes the whole life cycle: the manufacturing of building materials, transportation, construction site activities, maintenance and renovation, changing of materials, the use of energy and water, as well as demolition of buildings and the end processing of the waste material created. Today, the majority of the carbon footprint of a building is caused by the energy consumption of the building being used. As the energy efficiency of maintaining buildings continues to rise, aided by the growing use of renewable energy, the significance of CO_2-emissions caused by the building materials themselves continues to grow. (Bionova, 2017)

The majority of the emissions from building materials are generated during the manufacturing process of these materials. And when it comes to the construction sector, concrete is responsible for the majority of these emissions. More specifically, the key ingredient of concrete, Ordinary Portland cement or OPC, is responsible for approximately 8% of global CO_2-emissions. Annually, 4 billion tonnes of cement is produced. (Lehne & Preston, 2019)
For the construction industry to reach the goals of carbon neutrality, there is a growing demand of alternative raw materials with a low, or even negative, carbon footprint. Waste materials can be often used to reduce the emissions and the construction industry creates a lot of waste that could be re-used.

Construction and demolition waste (CDW) is one of the biggest waste fractions in the EU, it consists of 25-30% of all waste generated. These include: concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil. A majority of these can be recycled. (European Commission, 2019) Article 11.2 of the Waste Framework Directive (2008/98/EC) stipulates that by the year 2020, a minimum of 70% of the non-hazardous construction and demolition waste is required to be re-used (European Union, 2008).

One of the CDW materials that can be reused is mineral wool waste (MWW), as geopolymer raw material. As a part of the EU Horizons 2020-program, Wool2Loop-project (W2L) aims to utilize the glass- and stone wool waste from construction-, demolition-, as well as manufacturing process waste streams. (WOOL2LOOP, 2019) In the project, the waste material is screened, pre-crushed and finally milled to a powder as fine as 10 μm. As a part of the W2L-project, also process waste from the Forssa plant will be milled and geopolymerized.

After mechanical processing, the material undergoes alkali-activation, or geopolymerization. The main process in activation is dissolution, where the aluminosilicate raw materials undergo hydrolysis and transform into aluminate- and silicate groups and form oligomers that finally form a 3-dimensional network of polymers (Hirvijoki, 2018). The activation reaction occurs in room temperature conditions and therefore, it is vastly superior to the OPC-manufacturing process in terms of energy efficiency.

Although the amount of MWW-based geopolymer could, at best, replace just a fraction of the annual OPC produced, utilizing the waste is nevertheless a step in the right direction. It is good to remember that the amount of MWW generated yearly is 2.5 million tons (Ramaswamy, et al., 2019). All of which could be used as raw-material for other processes.

1.2 Objectives and scope of thesis

The objectives of this thesis are the following:

1. Presenting the background and relevance of the topic of using glass wool waste as a source for geopolymer raw-material with low CO_2-emissivity

2. Presenting methods and results of milling glass wool with a Mil-Tek IC60 screw mill to small enough size for it to react optimally with an alkaline activator

3. Describing the results of geopolymerization by analyzing a sample made from material produced from milled glass wool

4. Based on the experimental results, analysing the IC60 suitability in producing geopolymer raw material, as well as its overall practical performance

The literature review of this thesis deals with the composition of glass wool and its general manufacturing process. The motivation of milling GW material is explained. Geopolymerization and especially GW as geopolymer raw material is examined.
The milling and geopolymerization of GW is described and the results of the experimental part are discussed along with recommendations regarding the findings.

Stone wool, as well as CDW were left out of the scope of the thesis, as the main focus lies in processing specifically ISOVER GW waste material. Due to delays involving both Covid-19-pandemic and contractor scheduling, additional fine milling using an industrial ball mill had to be left out of the scope, as milling could not commence in time. The fine milling would have been important in comparing fine milled geopolymer raw material and the results from the IC60.

2 LITERATURE REVIEW

2.1 Glass wool

Glass wool can be classified as being man-made mineral fiber (MMMF), or man-made vitreous fiber (MMVF). It is fibrous glass, formed in a drawing process where molten glass is poured in a spinning centrifuge with holes along the outer diameter, as seen in Figure 1. The glass is pushed through these holes at 3000 rpm, simultaneously cooling and forming long, thin fibers. (Le Bourhis, 2008) This type of manufacturing process is called “TEL”, named after the laboratory that first developed the technique, “Laboratoire d’Etudes Thermiques” (Saint-Gobain insulation, 2007).

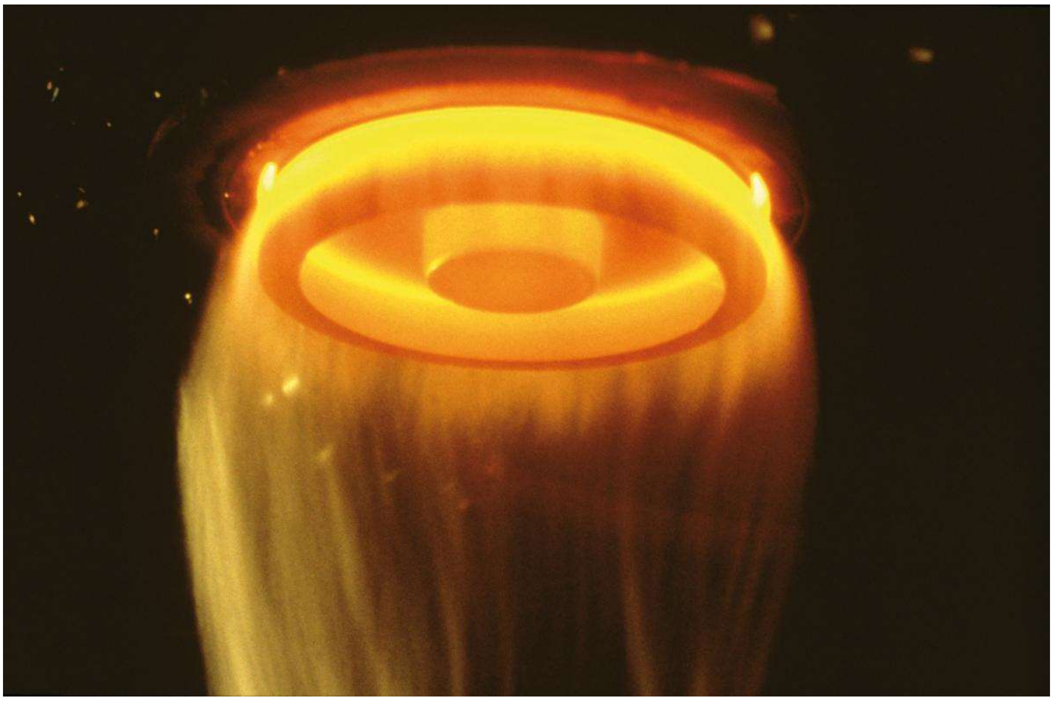

Figure 1 TEL-process: Centrifuge producing glass fiber (Isover Saint-Gobain, 2020)

2.1.1 Composition

Glass wool composition varies according to the different applications, but the main components are: SiO_2 (60–65 wt%), Na_2O (~16 wt%), and CaO (~7 wt%), with a width of approximately 10 µm (Yliniemi, et al., 2020). In the Forssa plant process, 80% of the glass wool raw material consists of recycled glass cullet mainly from glass processing industry. This is mainly soda-lime-silica-glass, with the same main components as mentioned above. Using recycled material reduces the environmental impact of glass wool significantly, as it reduces the energy consumption of the process considerably. (Isover Saint-Gobain, 2020) The main component, SiO_2 is found in nature as quartz, and it is the major constituent of ordinary sand.

2.1.2 Glass wool manufacturing process

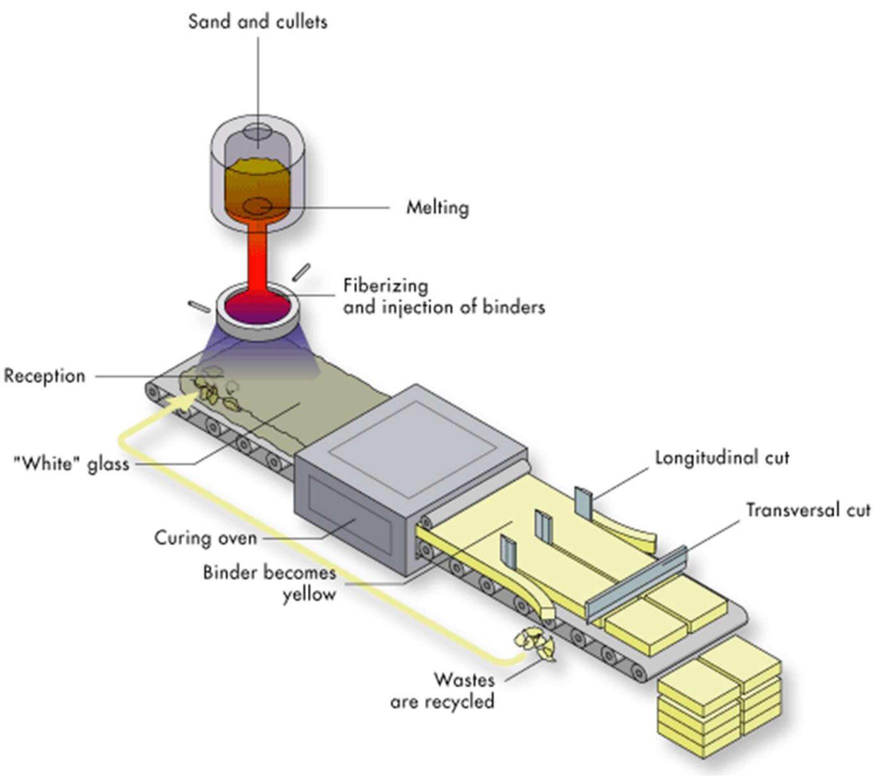

Figure 2 Glass wool manufacturing process (EURIMA, 2018)

In the GW manufacturing process, seen in Figure 2, recycled glass cullet, sand and other raw materials, such as soda-ash and limestone, are mixed and melted at 1400°C in an electric furnace.

The molten glass is then fed to the spinning centrifuge in the TEL-process to produce fibers. As the fibers exit the centrifuge, they are then sprayed with binder resin and propelled downward using air. The coated glass fibers are blown onto a conveyor where a blanket is formed. In the next phase, the material enters the curing oven, the material is usually compressed to suit a variety of product requirements. After the curing oven the

shaped GW is cut into required sizes, and the edge cut-offs are removed. Finally, the product is packed and shipped to storage. (Isover Saint-Gobain, 2020)
Saint-Gobain Forssa plant manufactures both ISOVER glass wool and Ecophon acoustic panels - both brands of Saint-Gobain.

2.1.3 Milling GW

The bulk density of ISOVER GW varies greatly from 15 to 150 kg/m^3 (Isover Saint-Gobain, 2020). Even at 150 kg/m^3, the density is still relatively low, compared to minerals densities usually milled in industrial processes. This causes issues with processing the material, as storing, transporting or other handling is made more difficult because of the low bulk density. The material volume is large compared to the weight, making logistics costlier.

There are many types of machines that can crush mineral wool in a large scale industrial context. The operation is often based on a driving screw, with a rotating disc that crushes the material. One such type of mill is the Hansek Machinenbau HSM 300 seen in Figure 3. The mill is suited for larger quantities, producing 1500kg of milled material in an hour, but the mechanism allows the material to be left too heterogeneous to be used without finer milling. Also the infeed dimensions are quite small, the optimal size being no greater than 5x5 cm^2. The mills for processing mineral wools are often intended to be used in sequence, where one mill crushes the source material to finer sizes, that can then be fed to another mill that handles the finer milling (Hansek Machinenbau GmbH, 2020)

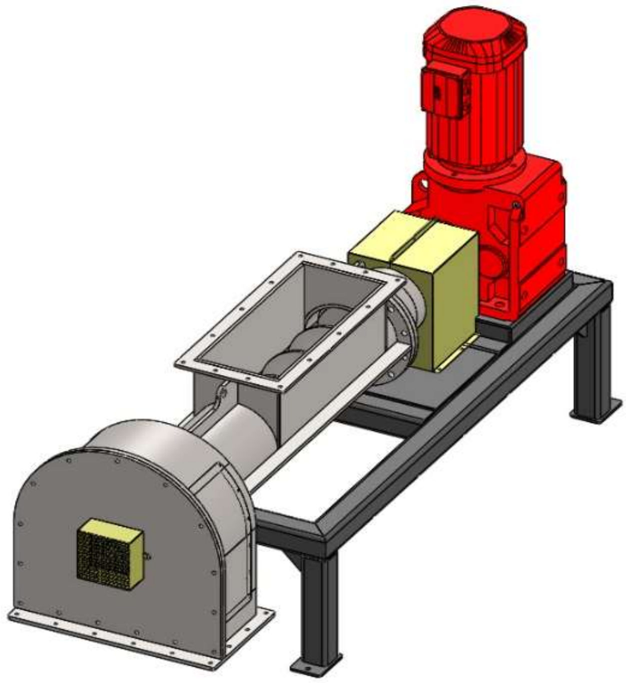

Figure 3 Hansek Machinenbau circular disc mill HSM 300 (Hansek Machinenbau GmbH, 2020)

Industrial crushers are generally meant for increasing the bulk density of the mineral wool material to improve logistics and waste management, and are not necessarily designed for producing micrometer-scale particles.

In the laboratory scale, rotating disc mills or ball mills are often used, both of which operate under the same principle, where material is ground between a moving and a stationary body. In a ball mill steel balls mill material in a cylindrical container that revolves horizontally around its axis. Usually balls with varying diameters are used, because of the centrifugal forces inside the cylinder along with the milled material force the balls on separate levels. This way, the larger, heavier balls are on the bottom milling coarser material, and the smaller, lighter balls are higher milling finer materials This type of milling can produce particles down to single-digit micrometers. (Heikkilä, 2020, p. 26)

Figure 4 shows a horizontal ball mill. Ball mills are very common on the industrial scale, where the milling method is largely the same. The elongated cylinder is only situated horizontally and the material is fed from the end of the cylinder. In a continuous process mill the milled material exits from the opposing end of the cylinder. (Laarmann Group, 2018)

Figure 4 Continuous ball mill for pilot scale milling (Laarmann Group, 2018)

2.2 Geopolymers and alkali-activated materials

Alkali-activated materials (AAM) are also called inorganic polymers or geopolymers. In this thesis, the terms are used interchangeably. Geopolymers are considered to be good alternatives to Ordinary Portland cement (OPC), mainly because of the comparable mechanical properties. The other very topical reason being, the very low CO_2 emissions of geopolymers. Waste streams of existing industrial processes can also be used in the making of geopolymers, such as fly ash, or furnace slag, which makes the process ideal both environmentally as well as economically. (Heikkilä, 2020).

In the alkali-activation process seen in Figure 5, aluminosilicate material and an alkaline activator react, forming a network of molecules consisting of Si-O-Al and Si-O-Si components. As an activator, sodium hydroxide (NaOH), potassium hydroxide (KOH), or sodium silicate (Na_2SiO_3) can be used. In the reaction, the aluminosilicate material hydrolyzes under alkaline conditions into distinct alumina- and silicate groups. The material undergoes gelification and a network begins to build through condensation. The structure re-organizes and forms 3-dimensional structures. A polymer structure is formed and the material begins to dry. (Hirvijoki, 2018)

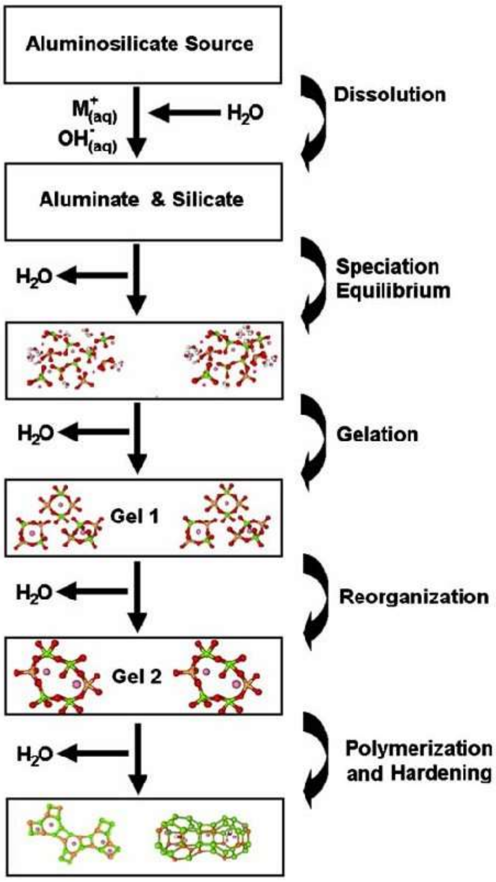

Figure 5 Geopolymerization model (Fernández-Jiménez, et al., 2006)

2.2.1 Geopolymerization of GW

Sodium aluminate solution has proven useful in activating GW, which contains intrinsically small amounts of aluminum. Using sodium silicate has also made GW based geopolymers show high compressive strengths, up to 30 MPa. This result has been obtained without the use of co-binders, the only constituents being GW and sodium silicate solution. Remaining insoluble fibers also contribute to the added strength due to the composite effect of the fibers on the material. The presence of the phenolic-formaldehyde resin in GW has also been shown to increase the mechanical strength. (Yliniemi, et al., 2016)
NH_3-emissions during the alkali-activation have also been registered. The issue is under detailed investigation, as experiments are still ongoing. (Nunes de Sousa, 2020) Good ventilation and the use of PPE is warranted whenever dealing with alkali-activated materials.

2.3 Health and safety

The International Agency for Research on Cancer (IARC) published a study in 1988 describing mineral wool as being potentially carcinogenic to humans. It classified mineral wool to group 2B " The agent is possibly carcinogenic to humans" (IARC, 1988).
In 1997 EU Commission Directive 97/69/EC introduced a "Note Q" to declassify mineral wool fibres, if the substance fulfills at least one criterion listed. These criteria include short-term biopersistence and evidence of the absence of carcinogenicity. (European commission, 1997)
The subsequent evaluation by IARC conducted in 2002 had re-classified mineral wool to group 3 "The agent (mixture or exposure circumstance) is not classifiable as to its carcinogenicity to humans". For reference, tea belongs to the same group. (IARC, 2002). In some EU-countries, MW produced prior to 1997 is still considered to belong to group 2B, which makes recycling of this material difficult, even though there is no evidence of carcinogenic effects on mineral wool (Egnot, et al., 2020).

The exposure to these fibers is at its most hazardous when inhaled, but unlike asbestos for example, MW fibers are bio-soluble. The structure of MW is amorphous and the structure breaks down easily if ingested. Long fibers (> 10 µm) break easily into smaller pieces, and shorter fibers (<10 µm) are cleared by macrophages. (Koch, 2018)

3 MATERIALS AND METHODS

For this thesis, process waste wool from the Forssa plant was milled with a specialized screw mill designed for processing mineral wool (Appendix 2: Mil-Tek IC60 brochure). The particle size, distribution and morphology of the milled material was analysed using a Retsch Camsizer XT-analyser. The efficiency of the IC60 in producing geopolymer raw material was assessed, as well as its overall performance as a part of the Forssa plant production line for the purpose of processing waste GW. The capacity of the mill is limited and therefore it will most likely fall short for any full size industrial application within the manufacturing process. The evaluation of the suitability of the mill focuses mainly on the quality of milled material, based on particle size and morphology analysis, as well as the consistency and reliability of the milling process as a whole.

The milled GW material was processed into geopolymer cement and the compressive strength of a sample was measured. Only one sample was tested, so the results are only directional, especially as the sample piece did conform to any standard. The expectation is that the sample will exhibit high compressive strength. The cross section of the sample was analysed using an optical microscope to determine the quantity of any remaining fibres within the sample surface, that had not been hydrolysed in the geopolymerization process. Moderate amount of remaining glass wool fibres in the geopolymer would result in a composite structure, which in turn could add to the mechanical strength of the geopolymer sample. This effect depends however on the respective strengths of the fibres and formed alumina silicate structure. (Yliniemi, et al., 2016)
Material produced with the IC60 is likely not to be optimal as geopolymer pre-cursor, the hypothesis is that the milled material particle size and distribution of the IC60 will be too heterogeneous to meet the pre-cursor requirements for the alkali-activation process. The particle sizes and –distribution of the resulting material from the Mil-Tek IC60 have not been thoroughly tested prior to this thesis, but the expected IC60 output d_{80}-value (meaning 80% of the produced material) of the resulting material should be no larger than 90 µm and absolutely no larger than 100 µm.

3.1 Mechanical processing of GW

The mechanical processing of the GW was conducted with a Danish Mil-Tek IC60 screw mill (Appendix 2: Mil-Tek IC60 brochure) A number of manufactures had initially been contacted, but Mil-Tek was chosen among the other candidates because of its relatively low cost and simplicity of operation. One key feature was that there was more tolerance in the infeed size requirements of the IC60, which meant that it could handle a wider range of material sizes, the only limiting feature being the infeed chute opening dimensions of 60x70 cm^2. The mill was installed and initially tested at the Forssa plant in August 2020. The expected performance of the mill was estimated at being able to produce 500 kg of milled material in an hour. The promised output d_{80} =90 -100 µm, meaning that at least 80% of produced particles should be absolutely no larger than 100 µm in size.
The material produced by the IC60 was originally meant to be further milled with a specialized ball mill by an outside contractor. This fine milling was deemed necessary in obtaining the maximum surface area for the GW material in order to obtain the best possible results in the alkali-activation process. Due to scheduling delays by the contractor and unforeseen problems in the milling process with the IC60 itself, the fine milling could not take place to be included in this thesis.

3.1.1 Testing plan and EHS considerations

As also CDW material was to be processed as a part of the Wool2Loop –project, environmental permit had to be applied. The State Regional Administrative Agency (Aluehallintovirasto, AVI) also required a testing plan to support the environmental permit needed. The author of this thesis was charged by Saint-Gobain to write the plan and to act as the milling test manager. The plan goes over the main parts and operation of the mill, as well as detailing the testing parameters and analyzing the results (Appendix 1: Testing plan Mil-Tek IC60).
A great deal of emphasis was also given to the risk identification and management, which were done in coordination with the EHS-specialist responsible for ISOVER operations at the Forssa plant. Although environmental emissions or waste were not an issue, there were clear health and safety risks associated with the milling. Regarding health issues, airborne dust and microbiological particles being among the most significant. The plan

also describes occupational safety hazards identified and improvement suggestions on how to counteract those risks. The plan serves both as an operating manual, as well as a checklist for occupational health and safety risks. It is also an important document for anyone not familiar with the mill and its operation.

3.1.2 Milling GW with the Mil-Tek IC60 screw mill

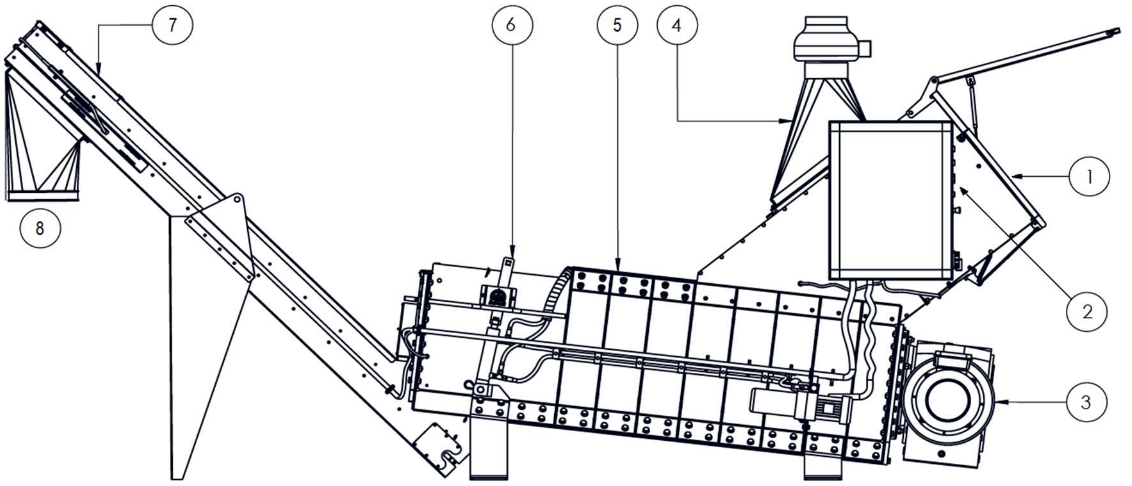

Figure 6: The main components and general operating principle of the mill: Material is fed to the inlet chute (1), milling screw motor (3) is turned on by pressing the power button (2). Dust emissions exit via the dust extraction chimney (4). The screw pushes the material towards the end of the mill, where a hydraulic pressure yoke (6) is restricting the flow of the outgoing material, creating a "plug"from the milled material inside the actual crushing chamber (5). This pressure mills the mineral wool fibers to a fine powder. Resulting material is exited (8) to a flexible intermediate bulk container (FIBC) via a conveyor belt (7) (Mil-Tek Danmark A/S, 2018)

The milling process and the major components of the mill are explained in Figure 6. Operating the mill is very simple, the motor is turned on and the screw starts to push material forward. The only thing the operator needs to do, is to regulate the material feeding speed. This also means that the operator has very little influence on the mill adjustment, as there are few operating controls, most importantly the on/off-button.

Figure 7 Mil-Tek IC60 situated on the ISOVER factory floor (Kohvakka, 2020)

Inside the electrical box there are components that can be adjusted, but these are pre-set by the manufacturer and are not meant for the end user to adjust as such. These include setting the operating range in amperes. As the screw turns, it crushes and pushes any material in the mill, resulting in an increase of power. The power drawn is continually shown in amperes inside the electric box. If the power needed exceeds the upper limit of the amperes, the mill lifts the pressure yoke automatically, reducing the pressure. This could happen, for example, if too much material is fed to the inlet chute too fast.

Figure 8 Mil-Tek IC60 inlet chute and the milling screw (Kohvakka, 2020)

The mill is designed for any type of mineral wool, with the exception of aluminum-, or plastic -coated products. The only limiting factor to the dimensions of the material is the size of the inlet chute.

The material is forwarded inside the mill and pushes the material against itself, essentially breaking the fibers by pressure. This material plug inside the crushing chamber is shown in the testing plan (Appendix 1: Testing plan Mil-Tek IC60). The pressure yoke at the outlet is set at maximum, making the opening as small as possible at the end. This creates the maximum amount of pressure inside the mill, resulting in very small particles. The material exits to the outlet chamber and is transported to a FIBC via the conveyor.

Figure 9 Outlet chamber, showing finely milled GW exiting the mill (Kohvakka, 2020)

Initial milling conducted after installation consisted of acoustic panels with a top coating of a painted fiber glass layer. The density of these panels varied from 55 to 110 kg/m^3 (Saarenko, 2020). Although the mill can easily mill these denser panels, top coating fragments were not completely crushed and they can be seen within the finely milled GW material.

3.2 Geopolymerization of milled GW

The composition of the raw materials meant for alkali activation effect greatly in the choice of activator. GW waste is comprised mainly of SiO_2, Na_2O, and CaO. (Yliniemi, et al., 2020) As the reaction happens between an alkaline activator and an aluminum silicate, Al_2O_3 for example, is needed to create the optimal composition for geopolymerization. Ground granulated blast furnace slag (GGBFS) has 8-10 wt% of Al_2O_3 and works well as a co-binder in GW based geopolymers. It has been shown that for raw materials rich in calcium, sodium silicate (Na_2SO_4) is an effective activator. (Heikkilä, 2020)

GW is well suited for geopolymerization mainly due to its high SiO_2-content. The material may also contain some fibers not completely milled in the processing, which adds to the mechanical strength due to the composite structure of the finished geopolymer cement.

3.2.1 Geopolymer mix design

The mix design used in this thesis was developed for Wool2Loop by the University of Oulu (Yliniemi, 2020). The recipe consists of GW, naturally high in SiO_2 (60–65 wt%), with substantial amounts of Na_2O (~16 wt%), and CaO (~7 wt%). As a co-binder, GGBFS is used, the main constituents being CaO (36-42 wt%), SiO_2 (36-40 wt%) and Al_2O_3 (8-10 wt%) (Finnsementti Oy, 2020). As alkali-activator, Betol 52 T was used (Woellner GmbH & Co., 2008). Betol 52 T is a Sodium Silicate with a high pH (12.5). The composition of Betol 52 is Na_2O (14.7 wt%), SiO_2 (30.3 wt%), H_2O (55 wt%).

3.2.2 GW geopolymerization at Oulu University

Geopolymerization was conducted by the author at the Fibre and Particle Engineering research unit laboratory at the University of Oulu. Based on the research already done at the department, an optimal mix design seen in Table 1 was used in creating a geopolymer sample (Yliniemi, 2020).

Table 1 Geopolymer mix design for Wool2Loop (Yliniemi, 2020)

Geopolymer mix design 25.8.2020		
Composition	**grams**	**wt%**
Milled glass wool	50	28,6
GGBFS	50	28,6
Betol 52 T	75	42,9

Betol 52 was diluted with 10% water. The relatively high content of the activator liquid (42.9 wt%), was to add workability due to the fibrous nature of the GW raw material, which increases the water absorption. The organic resin in the GW material has the same effect. (Yliniemi, 2020)

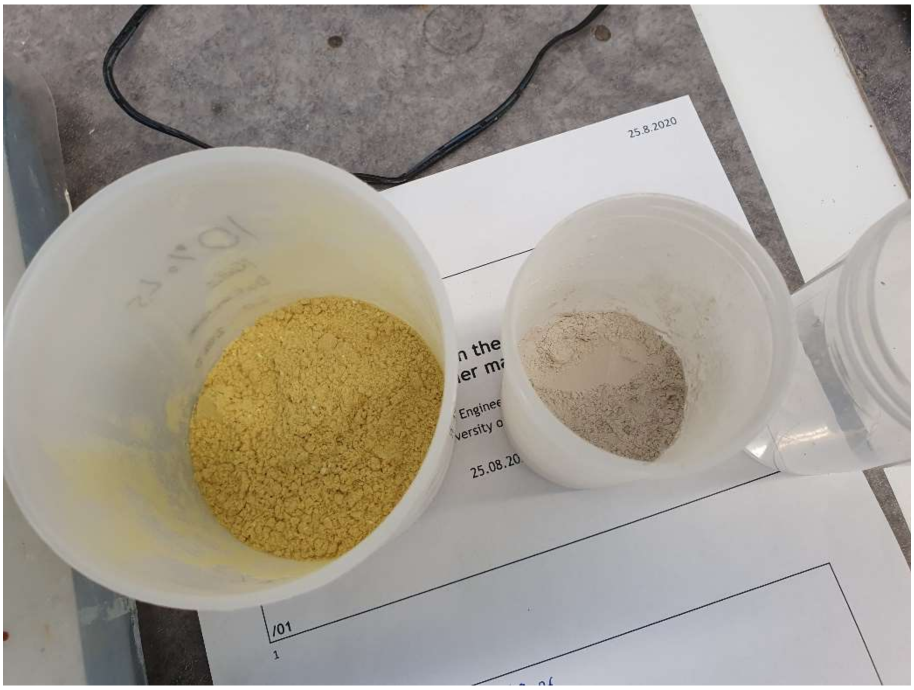

Figure 10 GW and GGBFS weighed before mixing (Kohvakka, 2020)

The dry components shown in Figure 10 were mixed together using an overhead stirrer (Figure 11). Then, the 10 % water diluted Betol 52 was incrementally added in over a 5-minute period. The resulting paste was thoroughly mixed to ensure effective reaction.

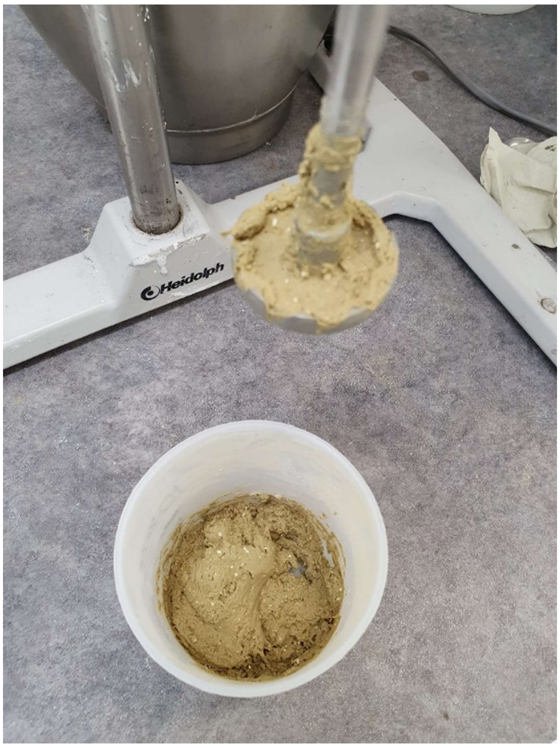

Figure 11 Mixing with an overhead stirrer (Kohvakka, 2020)

Due to the high viscosity of the material, air bubbles were left in the sample. These had to be removed using a jolting table (Figure 12), where the samples were agitated for 15 minutes.

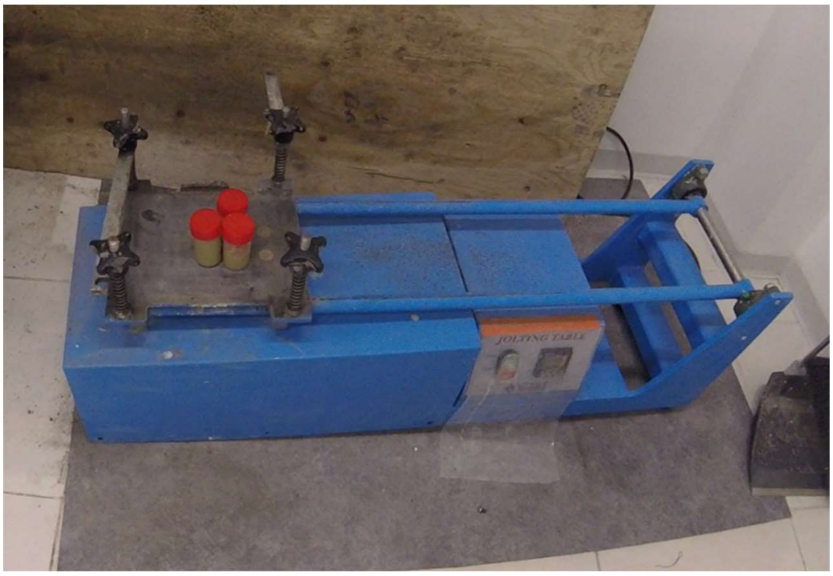

Figure 12 Jolting table for removing air bubbles (Kohvakka, 2020)

The samples were left in the cylindrical containers to cure at room temperature and were completely hardened after 4 hours.

3.3 Analysis equipment

3.3.1 Particle size and morphology analysis with Camsizer XT

The particle analysis was conducted by lab technician Juuso Hukkila with the Retsch Camsizer XT (Figure 13) installed at the Saint-Gobain Weber laboratory at Parainen, Finland. (Later: Weber laboratory)

Figure 13 Retsch Camsizer XT (Retsch Technology GmbH, 2011)

In Figure 14, the operating principle of the Camsizer XT can be seen. Measurement is done by introducing the sample particles in a dispersion of fluid, which passes two pulsating LED lights. The shadows of the particles are then recorder using two cameras. One camera analyzes small particles and the other camera the bigger particles. The optical paths of both cameras intersect, creating a reliable and real-time analysis of the sample sizes, as well as shapes.

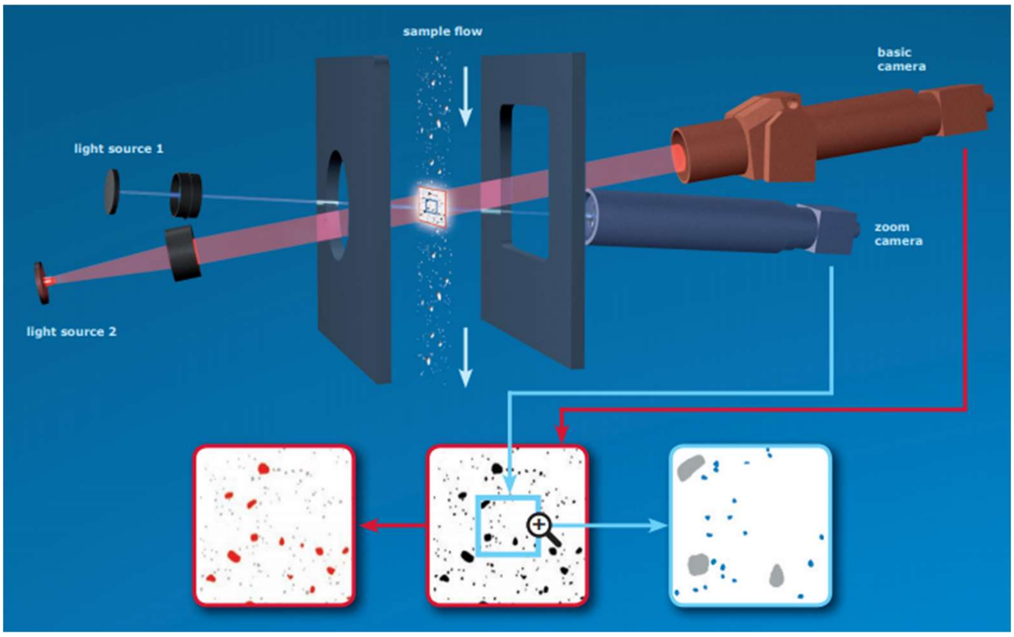

Figure 14 Retsch Camsizer XT measurement principle (Retsch Technology GmbH, 2011)

There are many benefits of analyzing milled GW using the Camsizer technology. The measurement range is wide, from 1 µm to 3mm, which is especially suited for analyzing milled GW material which contains small particles as well as longer fibers. It is also well suited for evaluating the shapes of the particles, showing the aspect ratio and roundness. The measurement time is also a factor, as it takes only minutes to conduct a reliable measurement. Using the wet dispersion module of the Camsizer, agglomeration of the particles is also greatly reduced. (Retsch Technology GmbH, 2011)

3.3.2 Optical microscopy

Two types of optical microscopes were used in analyzing the samples. An UShM-1 optical microscope was used to examine the fibers present in the initial milled sample (Figure 15). The microscope requires an external light source that is reflected to the sample from below via a concave mirror. Samples need to be translucent for analysis. Milled GW sample was deposited between two slides with a drop of water. Photographs were taken using a mobile phone placed on the eyepiece. Magnification 140x was used for the analysis.

Figure 15 UShM-1 Optical microscope (Anatolio, 2019)

Geopolymer sample cut-offs were analyzed with the Zeiss Axio Scope A1 optical microscope (Figure 16) at the chemical laboratory at Arcada UAS.

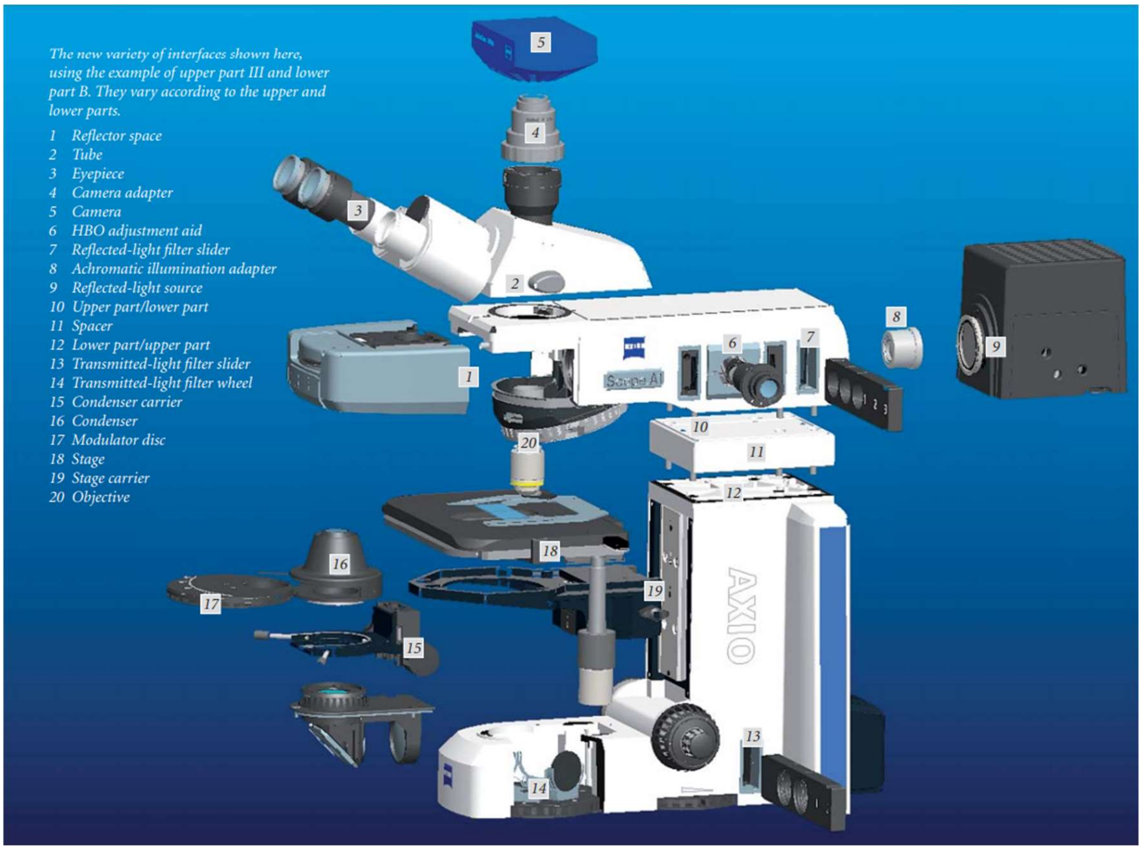

Figure 16 Zeiss Axio A1 optical microscope, main parts. (Carl Zeiss MicroImaging GmbH, 2020)

The surfaces of the cross-sections of both cut pieces were first sanded with grit 240 sand paper, after which the surfaces of the two pieces were ground against each other with water to obtain a smooth surface. The cross-section used in the analysis was left to dry and was not treated in any way. The sample was analyzed with many different magnifications in order to see if any visible GW fibers were left intact after the geopolymerization process (Figure 17). Various magnifications were used, to determine the best way of analyzing the sample. Reflective light source was used at maximum intensity, due to the nature of the sample thickness. Dark field setting was used in the reflector to increase contrast, and all apertures were set to maximum opening.

Figure 17 The geopolymer sample in the Zeiss Axio Scope A1 (Kohvakka, 2020)

3.3.3 Compressive testing

Compressive testing was conducted by Juuso Hukkila at Weber laboratory with a Form+Test Digimaxx C-20 compression testing machine, load range of the machine is 5-200kN (Figure 18).

Figure 18 Form+Test Digimaxx C-20 compressive testing machine (Hukkila, 2020)

4 RESULTS

4.1 Milling results

Milling conducted immediately after installation with acoustic panels produced very fine, dust-like material, not including the top coating fragments, which consisted approximately 12 wt% of the total weight of the three samples gathered. The milled material was separated using a sieve with 1.5 mm diameter holes (Figure 19).

Figure 19 Milled sample before sieving, acoustic panel coating fragments are visible (Kohvakka, 2020)

The fine material was then weighed using a 250 ml beaker, to obtain an estimate on the bulk density, which was calculated to be approximately 750 kg/m^3. The density of the raw material can be calculated as being 80 kg/m^3 on average, which makes the practical compression ratio to 9:1.

Overall, the mill showed that it can, upon visual inspection, produce very fine material. The output capacity was also consistent with the promised output of 500kg/h. However, the actual operation of the mill was inconsistent and milling had to be stopped frequently.

4.1.1 Optical microscopy

Milled material was inspected using the UShM-1 optical microscope. Most of the fibers in the sample were relatively long fibers. For size reference, the approximate diameter of ISOVER glass wool fibers is 10 µm (Saint-Gobain insulation, 2007), where as a human hair diameter is approximately 80 µm, as seen in Figure 20. There were no visible smaller spherical particles present in the sample. Thicker fibers originate most likely from the acoustic panel coating. Phenolic resin used as binder can be also seen as yellow coloration between the fibers.

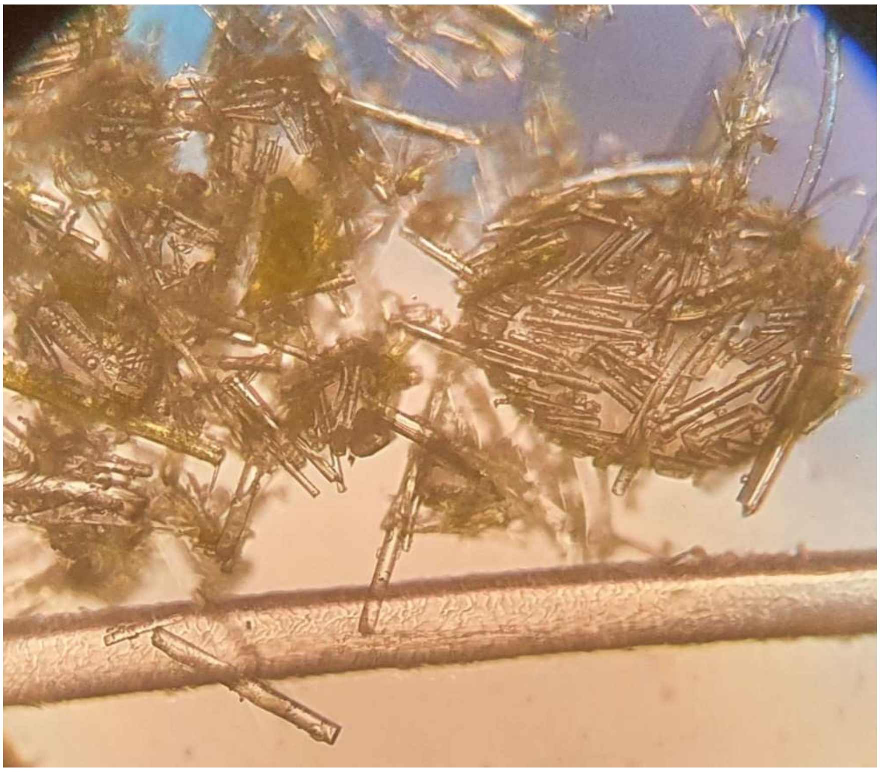

Figure 20 Microscope image of milled GW sample, magnification 140x, human hair as reference (Kohvakka, 2020)

4.1.2 Camsizer XT

A deeper analysis was conducted by Juuso Hukkila with the Camsizer XT particle analysis machine at Weber laboratory. The parameters analysed were the breadth to length ratio (B/L), sphericity (SPHT), particle size distribution and the cumulative distribution of all particles in the tested sample volume. The samples showed clear tendency to elongation, which was expected due to the fibrous nature of the GW.

B/L plot in Figure 21 denotes breadth to length ratio where spherical particles have a value of 1 and elongated particles are closer to 0.

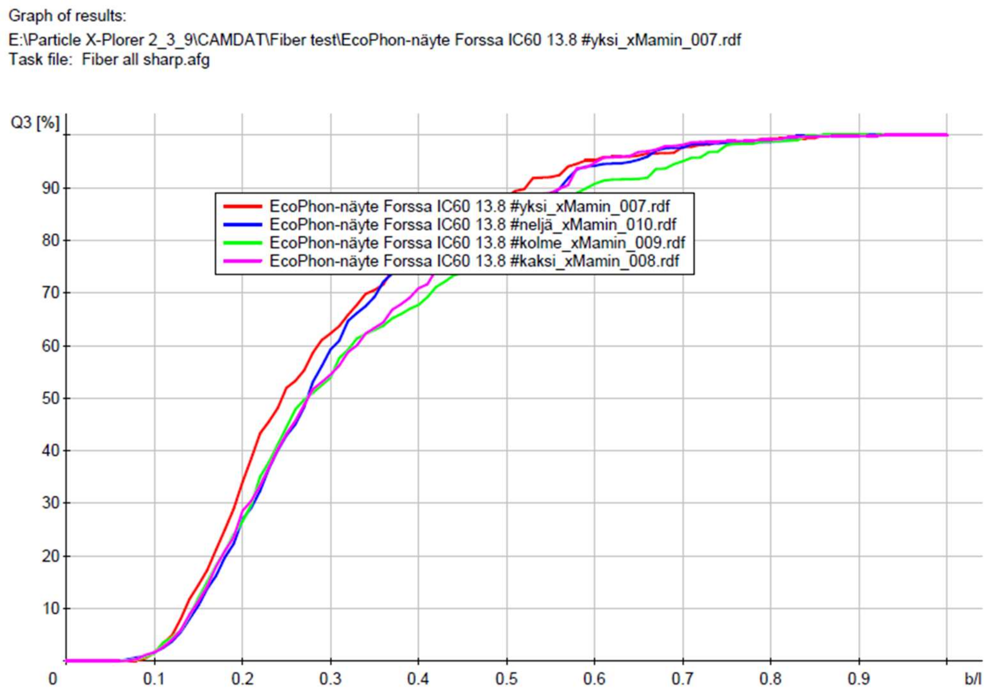

Figure 21 Camsizer XT B/L graph (Saint-Gobain Weber, 2020)

Figure 22 shows the SPHT plot, where spherical particles have a value of 1, here again the values are well under 1, showing the elongation of the particles.

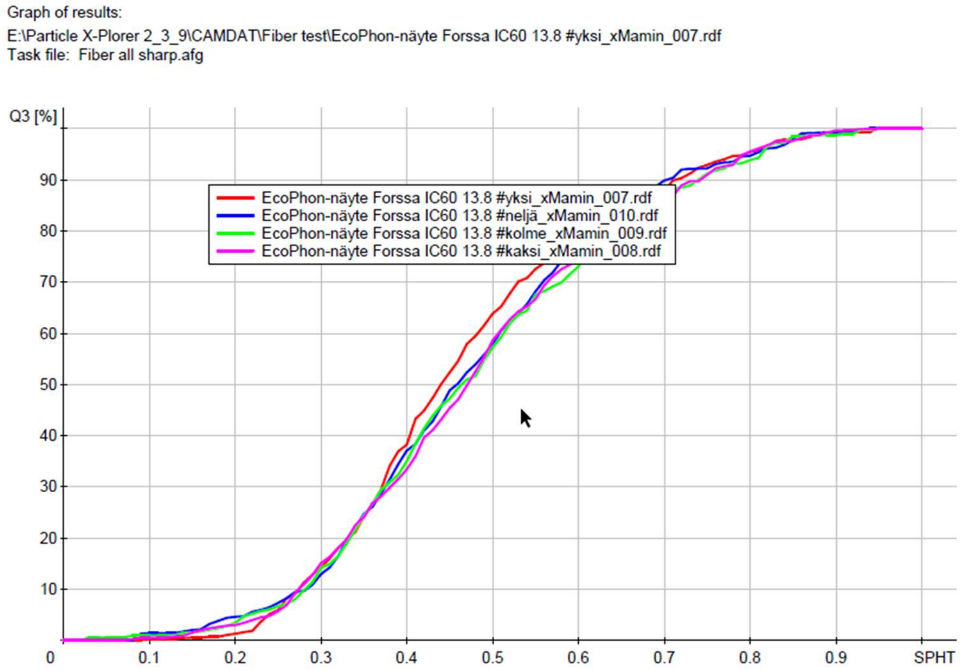

Figure 22 Camsizer XT SPHT graph (Saint-Gobain Weber, 2020)

Particle size distribution in Figure 23 shows the sizes of the particles in millimeters on the x-axis.

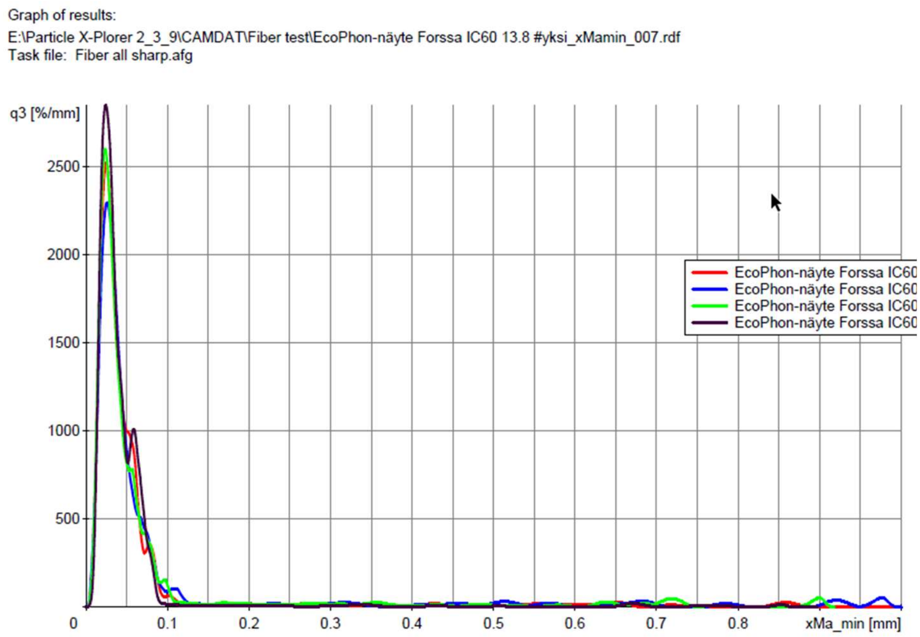

Figure 23 Camsizer XT Cumulative particle distribution graph (Saint-Gobain Weber, 2020)

The main criteria for evaluating the Mil-Tek IC60 mill was the attainable particle sizes. The cumulative particle sizes from Camsizer data is collated in Table 2: average d_{50} = ~35 µm and the d_{80} = ~65 µm. As the particle sizes grow, an aberration can be seen with one sample in Figure 24. If this deviating sample is omitted, the sample data shows the average value for d90 = ~159 µm. With the sample included, d90 = ~137 µm.

Table 2 Camsizer XT cumulative particle distribution (Kohvakka, 2020)

	d50	particle size (mm)	%	d80	particle size (mm)	%
Sample 1		0,035	50,6		0,0633	81,092
Sample 2		0,0367	51,5		0,0733	80,232
Sample 3		0,035	51,4		0,0667	79,975
Sample 4		0,0333	51,4		0,0567	79,081
Avg		**0,035**	**51,23**		**0,065**	**80,10**

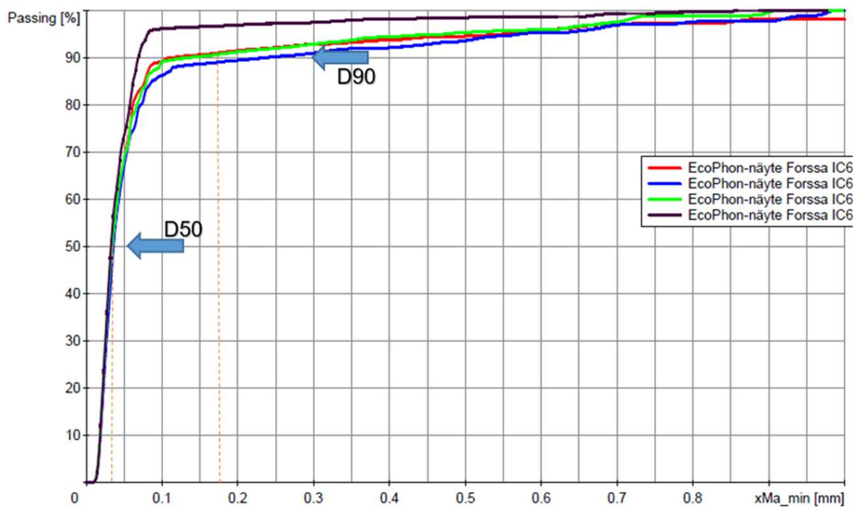

Figure 24 Cumulative distribution of 4 acoustic panel samples (Saint-Gobain Weber, 2020)

Observing the particle distribution graph in Figure 25, it is clear that the majority of the particles are concentrated on the small end of the x-axis, well under 100 µm.

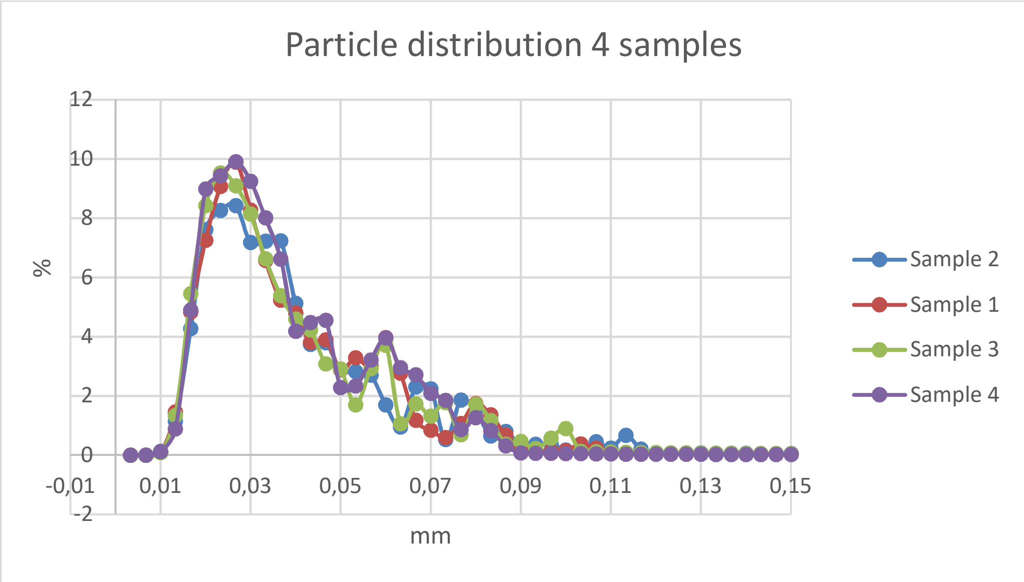

Figure 25 Particle distribution of 4 acoustic panel samples (Kohvakka, 2020)

4.2 Geopolymerization results

4.2.1 Microscopy analysis

Geopolymer sample cylinder was cut in half using a wet tile saw and the cross-section surface was observed through the Zeiss Axio Scope A1 optical microscope.

The picture taken from the sample under the microscope in Figure 26 show white fragments from the acoustic panel coating, yellow fragments of phenolic resin, as well as overall mottled effect on the surface. Some GW fibers can be clearly seen.

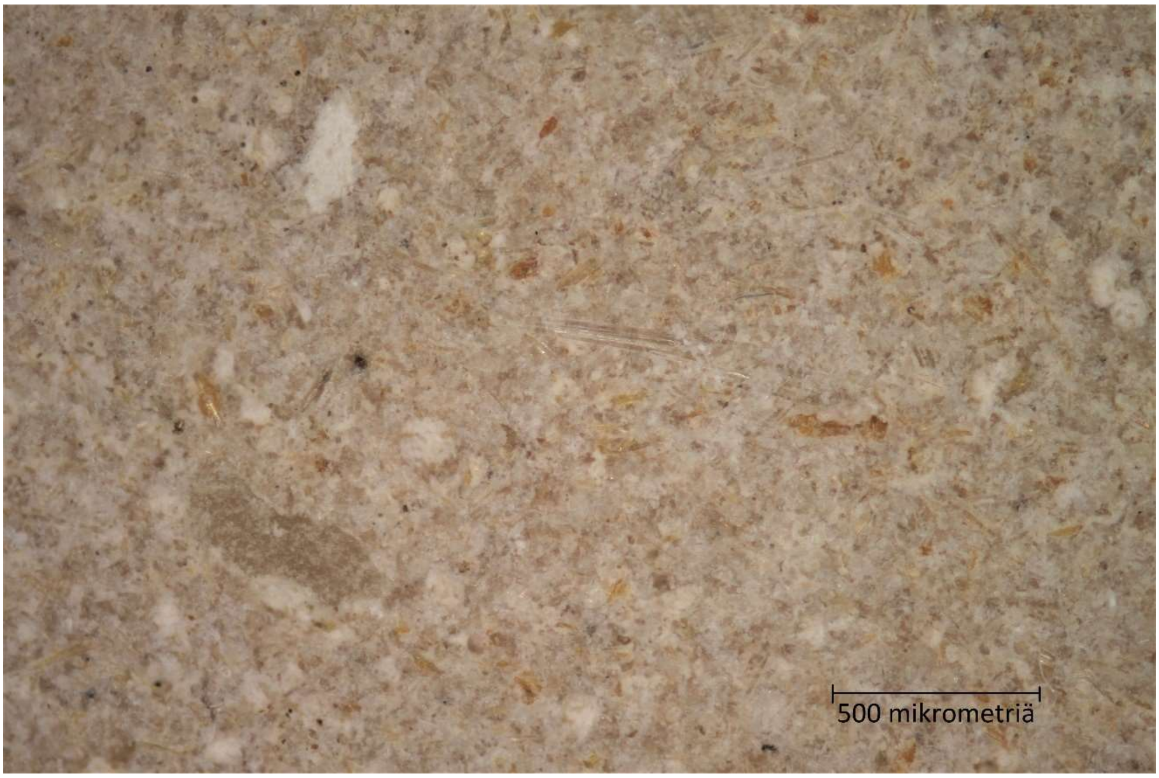

Figure 26 Geopolymer sample, reference bar 500 µm (Kohvakka, 2020)

With a slightly greater magnification, more fibers can be found. In Figure 27, these remaining fibers have been marked with black to better illustrate the lengths and orientation of the fibers. The fibers are randomly oriented and comprise a relatively small portion of the overall surface. The majority of GW fibers have been hydrolyzed in the alkali-activation process.

Figure 27 Remaining fibers after hydrolysis highlighted in black, reference bar 200 µm (Kohvakka, 2020)

4.2.2 Mechanical properties

A cylindrical sample, diameter 32 mm x height 40 mm, mass 55.6 g and with the density of 1728 kg/m^3 was tested by Juuso Hukkila at Weber laboratory. Figure 28 shows the sample in the Form+Test compressive testing device, multiple holes left by air bubbles can be seen. By the time of testing the sample had cured for 84 days. The maximum strength was recorded at 11.86 MPa, with the maximum force of 9.54 kN. The splitting failure mode can be clearly seen in Figure 29 Geopolymer sample with a splitting failure mode Figure 29.

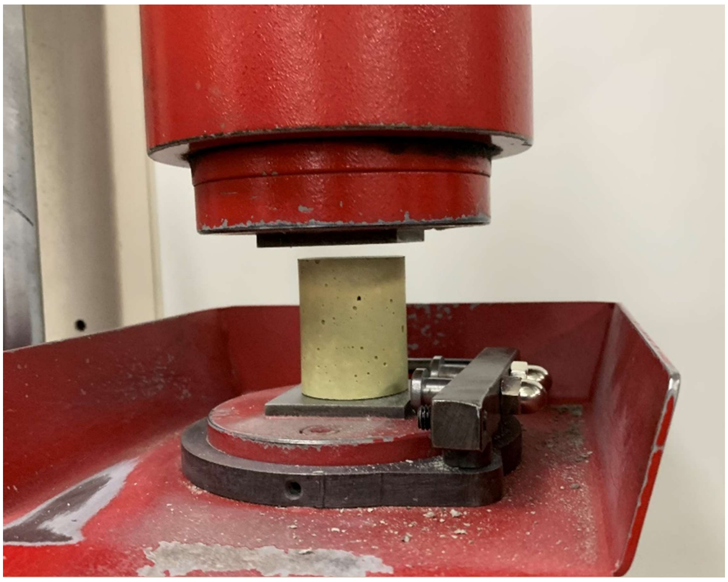

Figure 28 Geopolymer sample 30x40mm weighing 55.6 g (Hukkila, 2020)

Figure 29 Geopolymer sample with a splitting failure mode (Hukkila, 2020)

5 DISCUSSION

5.1 IC60 performance in producing geopolymer raw material

The particle sizes and distribution produced by the IC60 was proven to be well within the required specifications. Camsizer XT data seen in Table 2 shows clearly that the measured d_{80}-value from four samples tested was approximately 65 μm. This result is well below the objective of 90 μm lower limit. The smaller the particle sizes are, the more optimal chemical reactivity is usually obtained, as the surface area for the reaction is increased.

When compared to the particle size distribution of ordinary Portland cement (OPC), the quality of the milled GW material is within the same order. The particle distribution between the two materials is clearly different. For OPC, d_{50} = 18 μm and d_{95} = 67 μm (Yoon, 2015), for the milled GW the d_{50} = 36 μm, double that of OPC and even the d_{90} = 159 μm is not comparable. However, as the Camsizer data in Figure 25 clearly shows, the majority of the milled material is still well under 90 μm, leaving a great deal of reactive material for the alkali-activation process.

Even though the sample material originally contained fragments from the acoustic panel top coating fragments and had to be removed, the remaining material quality showed that the milling process of the IC60 is efficient and exceeds the requirements. Due to the milling method of the IC60, the top coating material was never expected to be completely crushed. As discussed in section 4.1, the compression ratio based on the bulk densities of raw material and the end product was 9:1, as opposed to the manufacturer's claim of 25:1. Having a compression ratio this large, would mean that the average density of the raw material of 80 kg/m^3 would result in dust with the bulk density of 2000 kg/m^3, which is clearly not a realistic capacity for the mill, based on the results of the testing so far.
The geopolymer sample made from the milled material showed that only a small portion of fibers were left in the surface of the sample cross-section. This indicates that either the majority of fibers have been hydrolyzed, or that they are small enough not to be seen with the optical microscope. The fibers that were still visible, were randomly oriented, suggesting that these fibers are most likely distributed equally randomly throughout the bulk

of the material, creating composite properties and thus contributing to the mechanical strength to the geopolymer.

The compression test results were much lower than expected. The lowest required compressive strength value for a Weber floor screed product is 16 MPa, and so the 11.86 MPa for the sample was clearly low, especially as it had been curing for 84 days. The main difference between the two materials is that the floor cement mixture included sand and fine gravel as aggregate and the geopolymer was cast with only binder material. The aggregate plays a large role in strength of any cement products. As the sample dimensions were not according to standard, and the faces of the sample cylinder were not completely level, there is a strong possibility that these factors have affected the results. The holes left from air bubbles may also have played a role in the failure. The geopolymer was cast into a generic sample container, and the sample was not designed for compressive testing as such. The compressive testing results are not conclusive, multiple standardized samples need to be tested to obtain reliable results.

5.2 IC60 operation and suitability for ISOVER and W2L

The initial testing of the IC60 indicated that the mill performed according to expectations, or even exceeding them. The material produced has been shown to meet the criteria set for the particle sizes and distribution. The operation of the mill, however, has proven to be far from optimal. Creating and maintaining the required conditions for the mill to operate within the needed parameters has been difficult, greatly affecting the reliability of the process and making it inconsistent. Somewhat restricted technical support was available only remotely from the manufacturer, due to the Covid-19 pandemic.

After the initial testing following installation, the mill has been tested on five occasions. The material plug needed for the effective milling of GW has been difficult to obtain, maintaining it has been even more difficult. The factors most affecting the plug formation is the quality and density of GW material fed to the mill, as well as the feed rate. If the material is not dense enough, the mill might not be able to pack the material tightly enough to create the plug. If on the other hand, the material is fed to the mill too fast, the screw will push all of the material through too fast, pushing the material plug out too fast.

In Figure 30, the outlet chamber is filled with material after too much material has been pushed through it. The sensor on the chamber wall had to be removed, so that the manual conveyor operation could be turned on. This way the compartment could be cleared without the mill itself running.

Figure 30 The material has been pushed through the machine, dissipating the plug (Kohvakka, 2020)

Acoustic panels have been largely successful in creating the material plug, due most likely to the density and large coating fragments aiding the pressure formation. But even during the feeding of these panels, the plug formed and subsequently dissipated, making it very difficult to evaluate the optimal operation parameters. When the material is packed efficiently by the screw, the pressure often rises beyond the upper limit of operating amperes, resulting in the automatic rising of the pressure yoke, seen in Figure 31, making it easier for the screw to push the material forward. This does not always affect the stability of the material plug, but it may result in its dissipation.

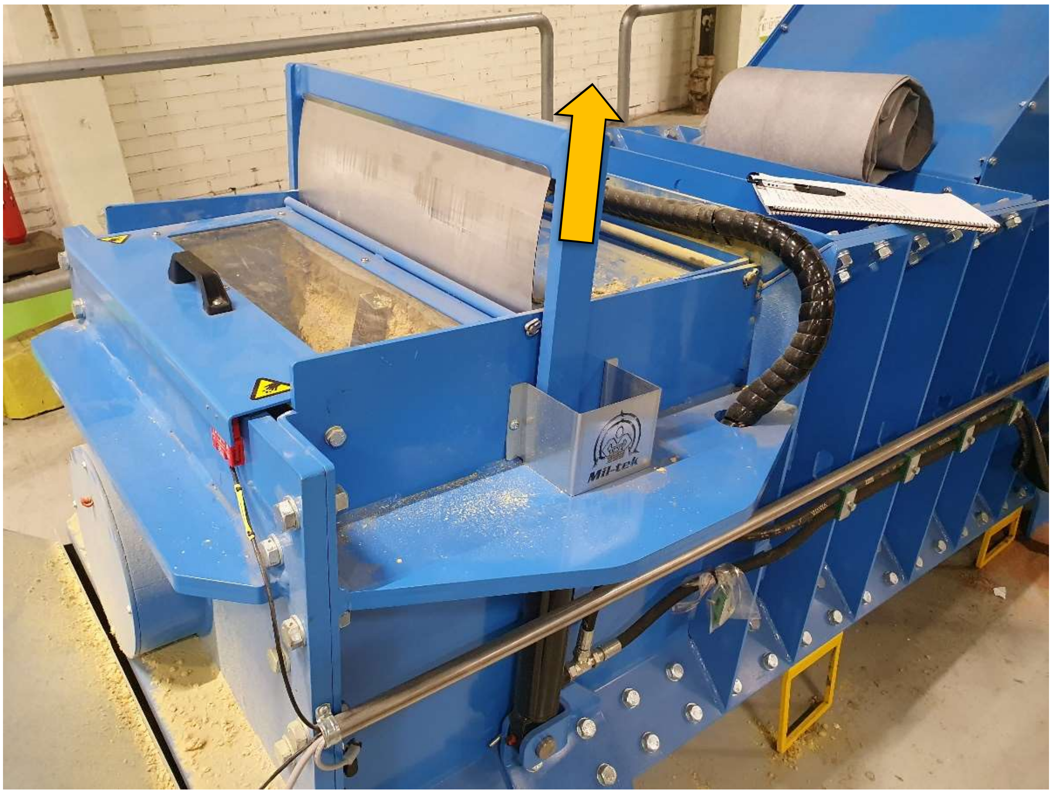

Figure 31 The pressure yoke has lifted, letting material flow through (Kohvakka, 2020)

The suitability of the IC60 in creating finely milled GW material seems questionable. Even if the mill is capable in producing the required particle sizes, the operation is far too delicate and prone to interference to be useful as a part of any industrial process where GW materials with varying densities and quality needs to be milled. Even with the most successful material tested, being the acoustic panels, the plug dissipated during the feeding. This suggests that even the densest of materials fed consistently does not guarantee successful milling. Further testing is naturally needed and will continue with the IC60.

5.3 Health and safety

The IC60 dust extractor at the inlet chute works well upon visual inspection, extracting airborne dust and particles effectively. This can be seen in Figure 32, where dust is being drawn back in the inlet chute. On the other hand, Figure 33 shows the fine dust produced by the mill leaks abundantly from the conveyor housing seams at the end of the process. This seems like an apparent oversight in the design of the mill. The dust emissions created at the end is equally large compared to the dust created at the inlet. The operator stands mostly beside the inlet, being more exposed to the dust emissions caused by feeding the mill and therefore it is of course more warranted to have the dust extractor on the inlet side. The use of personal protection equipment is still very much recommended. Microbiological measurements, as well as airborne dust particle measurements will also be conducted in the future.

Figure 32 Draft from the dust extractor drawing dust back inside the inlet chute (Kohvakka, 2020)

Figure 33 Dust emissions from the conveyor housing (Kohvakka, 2020)

6 CONCLUSION

The process of milling glass wool with the IC60 was an interesting and an eye-opening task. Having been involved in all the steps from raw-material sourcing to preparing and analyzing geopolymer samples, the experience has given much needed insight into the complexities of creating an alternative cement product from a waste stream, and the Wool2Loop project in general. The delays and restrictions of the Covid-19 pandemic caused a need for adaptation, re-thinking and re-scheduling of the thesis process as well. It would have been especially interesting to be able to compare geopolymer samples made from ball milled material with the samples produced with the IC60.

The initial objectives of the thesis were achieved for the most part. It is however clear that to obtain reliable results, sample sizes would have needed to be much larger This includes more variation in raw material type and quality, and more compressive strength measurements of geopolymer samples with varying composition. In the confines of the thesis schedule however, the results were promising and show that geopolymer raw material can be produced.

The IC60 is an effective mill in terms of milling capability. The pressure created inside the mill is enough to crush the GW fibers into a very fine powder, tentatively suitable for geopolymer raw material without additional milling. Although the compression test was inconclusive, the results here do in no way suggest that GW based geopolymer does not perform well in mechanical testing in general, especially as there are good results with similar material already published.

The operation of the mill is delicate. Obtaining a good milling result has proven to be difficult because of the delicate operating conditions. For the mill to be effective, minimum requirement is that different types of MW would have to be suited as raw material without time consuming pre-processing. The process should be at least semi-autonomous, meaning that the operator could just insert material in the mill and collect the milled material without having to selectively control the infeed material and constantly stopping the process due to interference.

6.1 Recommendations

It is clear that some adjustments need to be made to the operating variables of the mill. The infeed material is not subject to change, the waste material being typical mineral wools. It is in any case necessary to continue testing with different types of infeed materials, that have not yet been tested to see if that will make a difference in the results. The only other option is to consider an another type of mill either to replace, or complement the existing mill.

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APPENDICES

Appendix 1: Testing plan Mil-Tek IC60

TESTAUSSUUNNITELMA

MIL-TEK IC 60

TUOMAS KOHVAKKA

SAINT-GOBAIN FINLAND OY

SAINT-GOBAIN

Sisällysluettelo

1. JOHDANTO

Testauksen tarkoituksena on selvittää eri mineraalivillalaatujen ja –tuotteiden jauhettavuutta Mil-Tek IC60 Jauhinmyllyllä. Jauhettava materiaali on eritasoista prosessi- ja purkujätettä. Lisäksi arvioidaan testauksen lopputuotteena syntyvän jauhetun materiaalin soveltuvuutta eri käyttötarkoituksiin ja -tuotteisiin.

Materiaalien ja lopputuotteiden soveltuvuutta mitataan eri kriteereillä, riippuen käyttökohteiden tarpeista.

Testattavan materiaalin lisäksi mitataan prosessin energiankulutusta, kustannuksia, ajankäyttöä, sekä terveys- ja ympäristöhaittoja.

Testaukselle määritetään aina vastuuhenkilö, joka vastaa joko yksittäisen-, tai yleisen tason testauksen suorittamisesta, dokumentoinnista ja raportoimisesta.

Testauksen raaka-aineiden, sekä lopputuotteiden käyttöön liittyvien sidosryhmien kanssa on tarkoituksenmukaista pitää yhteyttä laadun varmistamiseksi, sekä testauksen sujuvuuden turvaamiseksi.

Testausprosessia noudatetaan ohjeiden ja säännösten mukaisesti. Poikkeamista prosessissa sovitaan testauksen laadusta vastaavan henkilön kanssa.

2. TESTAUSPROSESSI

Testauslaitteisto

Mil-Tek IC60 Jauhinmylly

Tekniset tiedot	
Koko K x L x P (mm)	2820 x 1500 x 5300
Teholähde	3x 400 V 35 A
Hydraulinen prässi	150 bar
Moottori	15.0 KW
Hydraulinen pumppu	0.37 KW
Kuljetin	0.12 KW
Paino (kg)	2615

Pääosat

1 – Syöttökuilu

2 – Virtakytkin ja vikatilojen nollaus

3 – Puristinruuvin moottori

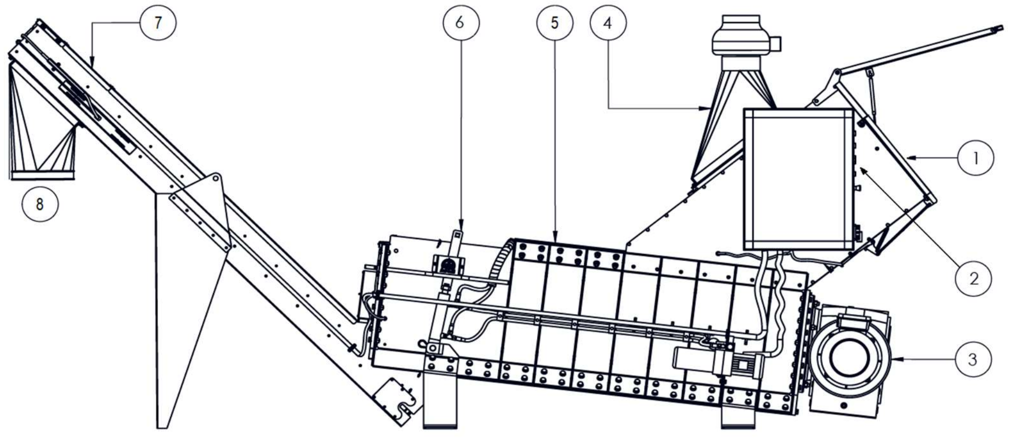
4 – Pölynpoistoputki

5 – Puristinkammio

6 – Hydraulinen supistin

7 – Kuljetin

8 – Poistoputki



Kuva: Mil-Tek IC60 kaaviokuva (Mil-Tek 2020)

Laitteen toiminnan kuvaus: Laite käynnistetään käynnistyspainikkeesta (2). Testattava materiaali syötetään syöttökuiluun (1), irtoava pöly poistuu suodatettuna hormin (4) kautta. Ruuvipuristin pyörii ja työntää materiaalia eteenpäin puristinkammioon (5). Hydraulinen supistin (6) lisää painetta koneen sisälle, murskaten villakuituja. Hieno villajäte poistuu koneesta kuljettimelle (7), joka kuljettaa materiaalin suursäkkiin (8).

Testausparametrit

Syötteet

Testattava materiaali kuvataan asiaankuuluviin taulukoihin: Nimike, tyyppi, alkuperä, valmistus-, tai keräilyaika. Syötteen koodi koostuu materiaalin alkuperästä, nimikkeestä ja juoksevasta järjestysnumerosta. Tällä tavoin voidaan myöhemmin todentaa luotettavasti testatun materiaalin alkuperä. Lisätietoja-kohtaan kuvaus materiaalin laadusta, ja koostumuksesta tms.

Prosessijäte

Prosessijätteen syöteluettelon täyttöesimerkki:

	PROSESSIJÄTE		**ALKUPERÄ**	**NIMIKE**	
			F = Forssa	**RA = Raskas villa**	
	TYYPPI		**H = Hyvinkää**	**KE = Kevyt villa**	
	GW = Lasivilla			**PU = Puhallusvilla**	
				MIX = Sekalainen villajäte	
	Isoverin prosessijäte on oletuksena aina lasivillaa		**Syötekoodi = ALKUPERÄ_NIMIKE_JÄRJESTYSNUMERO**		
			Lisätietoa:	**Koostumus/muu lisätieto**	
Nro.	**Nimike**	**Syötekoodi**	**Alkuperä**	**Valmistusaika**	**Kirjaaja**
1	Raskas villa	F_RA_001	Isover Forssa	10.4.2020	N.N.
	Lisätietoa:	Sideaine tms			
2	Sekalainen villajäte	H_MIX_002	Hyvinkää	05/2020	N.N.
	Lisätietoa:	Arvio koostumuksesta			
3					
	Lisätietoa:				

Leikkuu- ja Purkujäte

Purkujätteen laadun kuvaus: Likainen, kostea, puhdas, mahdolliset kontaminantit, kuten ”roskia”, tms. Merkitään taulukkoon laatu- ja lisätietoa-sarakkeeseen. Märkää purkuvillaa ei voi testata, syöte-erän kosteusprosentti testataan tarvittaessa ennen jauhamista

Leikkuu- ja purkujätteen syöteluettelon täyttöesimerkki:

	LEIKKUU- JA PURKUJÄTE		**ALKUPERÄ**	**NIMIKE**		
			LE = Leikkuujäte	**GW = Lasivilla**		
	TYYPPI		**PU = Purkujäte**	**SW = Kivivilla**		
	GW = lasivilla			**MIX = Sekalainen villajäte**		
	SW = kivivilla					
	MIX = lasi/kivivilla		**Syötekoodi = ALKUPERÄ_NIMIKE_JÄRJESTYSNUMERO**			
					Laatu:	
		Lisätietoa:	**Koostumus/Säilytysolosuhteet/**		**Puhdas/Likainen/**	
			Muu lisätieto		**Kostea/Kontaminantteja**	
Nro.	**Nimike**	**Syötekoodi**	**Alkuperä**	**Keräilypäivämäärä**	**Laatu**	**Kirjaaja**
1	Sekalainen purkujäte	PU_MIX_001	Kiertokaari Oy	1.6.2020	Puhdas	N.N.
	Lisätietoa:	GW 20% / SW 80%, säilytetty ulkona pressun alla				
2						
	Lisätietoa:					
3						
	Lisätietoa:					

Näytteiden kirjaaminen

Testattavat syöte-erät listataan testauslistaan. Lista toimii osaltaan toiminnan käyttöpäiväkirjana.

Testauslistan täyttöesimerkki:

TESTAUSLISTA		**Mil-Tek IC60**			
		Isover Forssa			
	Testausvastaava:				
	Yhteyshenkilö Isover Forssa:				
	Lisätietoa-kohtaan tarvittaessa kuvaus laadusta tms.				
Nro.	**Syötekoodi**	**Testaajan nimi**	**pvm**	**Aika**	**Määrä (kg)**
1	F_RA_001	Tuomas Kohvakka	15.9.2020	8-16	2000
	Lisätietoa:				
2					
	Lisätietoa:				
3					
	Lisätietoa:				

Jauhimen teho

Teho ja jauhinruuvin nopeus on esisäädetty tehtaalla, tähän ei voi loppukäyttäjä vaikuttaa. Partikkelikoko on ilmoitettu olevan minimissä nykyisellä säädöllä. Jauhimen ilmoitettu teho on 15.49 kW. Vuosittainen teoreettinen kokonaisenergiankulutus on täten noin 23.3 MWh (7 tuntia ajoa päivässä, 215 työpäivää/vuosi).

Jauhimen kapasiteetti

Kapasiteetiksi on valmistajan puolesta ilmoitettu 500 kg/tunti. Jauhettavan materiaalin tyyppi tai laatu ei vaikuta merkittävästi kapasiteettiin. Kapasiteettiin vaikuttaa eniten hydraulinen supistinlevy, joka on säädetty suurimpaan mahdolliseen paineeseen. Tämä määrittelee materiaalin läpimenovauhdin.

Testausvastaavan nimeäminen

Testausvastaava vastaa testauksen työturvallisuudesta, sekä raportoinnista. Näytteiden kirjaamisen yhteydessä merkittävä aina testausta suorittavan, sekä testauksesta vastaavan henkilön nimi.

Testauksen organisointi ja tavoitteet

Testausvastaava vastaa testauksen organisoinnista yhdessä tehtaan vastuuhenkilön kanssa.

Testauksen lopputuotteiden vaatimustaso vaihtelee syötteen ja lopullisen käyttökohteen mukaan. Arvioidaan aina tapauskohtaisesti. Mittareina käytetään partikkelikokoa, materiaalin koostumusta ja laatua, tai muuta soveltuvuutta käyttökohteeseen.

Perustason tavoitteena on aloitus- ja lopetuskriteerien täyttyminen sovitussa aikataulussa ja budjetissa, sekä testauksen parametrien yhdenmukaisuus ja toistettavuus luotettavien tulosten saamiseksi.

Aloitus- ja lopetuskriteerit

aloituskriteerit:

- Testauksen ajankohta ja resursointi on hyväksytty yhdessä testauspaikan vastuuhenkilön kanssa

- Testattava materiaali on todettu soveltuvaksi ja hyväksytetty testausvastaavalla
- Testattava materiaali on valmiina ja käytettävissä
- Testausympäristö on valmis ja käytettävissä
- Lopputuotteen varastointi tai kuljetus käyttökohteeseen on sovittu
- Ilmoitus testauksen aloittamisesta on annettu Hämeen ELY:lle ja Forssan kaupungille
- Koetoimintalupa purkujätteen testaamiselle on voimassa

lopetuskriteerit:

- Suoritettu testaus on raportoitu
- Asetetut tavoitteet lopputuotteelle on saavutettu ja mahdolliset poikkeamat raportoitu
- Löydetyt virheet ja muut huomiot testaukseen liittyen on raportoitu
- Ilmoitus testauksen lopettamisesta on annettu Hämeen ELY:lle ja Forssan kaupungille

Testauksen suunnittelu

Testauksen suunnittelu voidaan tehdä vapaamuotoisesti aloituskriteerien mukaisesti. Tärkeimpänä organisointi testauspaikan kanssa liittyen resursointiin ja aikatauluun. Testaussuunnitelma täytetään asiaankuuluvin tiedoin, joka hyväksytetään testausvastaavalla ennen testauksen aloittamista. Samaan dokumenttiin täytetään testauksen tulokset. Dokumentti liitetään osaksi käyttöpäiväkirjaa testauslistan kanssa.

Testaussuunnitelma täyttöesimerkki:

TESTAUSSUUNNITELMA		
Testauspaikka:		Forssa Isover
Testauslaitteisto:		Mil-Tek IC60
Päivämäärä:		25.9.2020
Testattava materiaali:		Sekalainen prosessijäte
Testauskoodi:		F_MIX_001
Määrä (kg)		500
Testausaika:		08-12
Energiankulutus (15,5 kW*h):		62 kWh
Testaajan nimi:		Tuomas Kohvakka
Ilmoitus testauksesta:		
Forssan kaupunki/Hämeen ELY		
Koetoimintalupa voimassa	x	ESAVI/21462/2020
TULOKSET		
Lopputuote:		
Varastointipaikka:		Isover Forssa
Asiakas/käyttökohde:		Leca
Kuljetuspvm:		10.10.2020
Näytetiedot:		
Laboratorio:		Weber Parainen
Näyte lähetetty:		26.9.2020
Näyte analysoitu:		1.10.2020
Laite:		Camsizer XT
Analysoija:		N.N.
Näytteen tunnus		F_MIX_001
Hyväksyntä:		Allekirjoitus:
Testausvastaava	x	
Isover Forssa vastuuhenkilö	x	

Testauksen suorittaminen

Testaus suoritetaan yhteistyössä testauspaikan kanssa aloituskriteerien mukaisesti. Testauksesta tulee ilmoittaa testauspaikan vastuuhenkilölle ja testausvastaavalle, sekä tarpeen mukaan muille asianomaisille (esimerkiksi lopputuotteen vastaanottajalle).

Työturvallisuus

Noudatetaan perustasona testauspaikan työturvallisuussäädöksiä (ISOVER Forssa). Testausvastaava voi määritellä lisäyksiä työturvallisuuteen jauhettavasta materiaalista riippuen (esimerkiksi purkujäte). Perusvaatimuksena testaushenkilöstölle on henkilökohtainen suojavarustus (suojalasit, hengityssuojain, kuulonsuojaimet, sekä suojavaatteet).

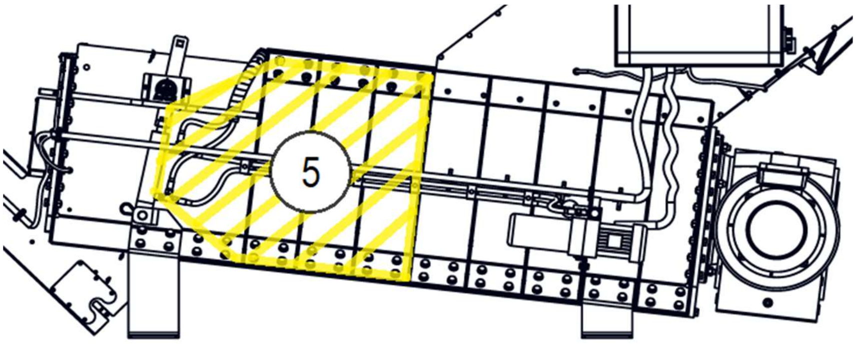
3. TESTAUKSEN TULOKSET

Näytteet

Näytteeotto

Näytteet testatusta materiaalista otetaan jauhamisen lopussa, mutta aikaisintaan 30 minuutin päästä jauhamisen aloittamisesta. Näin varmistutaan siitä, että näyte sisältää mahdollisimman paljon testattavan erän materiaalia. Jauhimen puristinkammioon (5) saattaa jäädä aina jonkin verran materiaalia, joka saattaa vaikuttaa testaustulokseen.

Tasalaatuisen lopputuloksen varmistamiseksi koneen syöttökuilua ei tule koskaan ajaa tyhjäksi. Jos materiaalin syötössä tulee katkoksia, paine puristinkammiossa olevassa materiaalissa häiriintyy. Seurauksena on epätäydellinen jauhamistulos. Tällöin uutta materiaalia tulee jauhaa niin kauan, että epätäydellisesti jauhautunut materiaali poistuu puristinkammiosta kokonaan. Materiaalin laatu varmistetaan silmämääräisesti.



Kuva: Mil-Tek IC 60 Puristinkammio (Mil-Tek, 2020)

Läpimenoaika voidaan myös varmistaa lisäämällä jauhamisen alussa materiaalin sekaan indikaattoriainetta, mikä on helppo havainnoida koneen poistopäässä jauhetun materiaalin poistuessa. Indikaattorina voidaan käyttää esimerkiksi värillistä paperia (tai muuta vastaavaa), joka on helppo erottaa jauhetun materiaalin seasta, eikä aiheuta haitallista kontaminaatioita itse näytteessä.

Kuva: Akustiikkalevyn pinnoitteen palasia jauhetun villan seassa noin 30 min jauhamisen aloittamisesta (Kohvakka, 2020)

Näyteastia

Näytteet otetaan vähintään kahteen 1 l. HDPE pakastuspulloon (esim. Plastex pakastuspullo 1L LV HDPE). Minigrip-pusseja voidaan myös käyttää, mutta mikäli näytteitä tarvitsee lähettää testattavaksi, on kierrekorkillinen pullo varmempi.

Näytteiden lukumäärä

Jauhettavasta erästä otetaan vähintään kaksi näytettä. Yksi näyte varastoidaan mahdollista myöhempää laadunvarmistusta varten ja toinen näyte voidaan lähettää esimerkiksi testattavaksi. Molempiin näyteastioihin merkitään syötteen koodi (esim. F_RA_001). Varastoitavassa astiassa tulee lukea: ”Varastonäyte/Säilytettävä” Näytteet varastoidaan sovittuun paikkaan joko testauspaikassa tai testausvastaavan määrittelemään paikkaan.

Näytteiden analysointi

Näytteet analysoidaan soveltuvalla laitteella, riippuen analysoitavasta ominaisuudesta.

Partikkelikoko, -jakauma, sekä muoto analysoidaan Camsizer XT-laitteella Weberin laboratoriossa Paraisilla. Muut analyysit sovitaan tapaus- ja tavoitekohtaisesti testausvastaavan kanssa.

Hyväksymiskriteerit

Hyväksymiskriteerit vaihtelevat käyttökohteen mukaisesti. Testausvastaava määrittelee yhdessä loppukäyttäjän kanssa tarvittavan laatutason testattavalle materiaalille.

Jauhetun materiaalin käyttökohteet

Wool2Loop – geopolymerisointi

Leca – LWA-rakeen täyteaine

ISOVER prosessin sisäinen käyttö (ei vielä käytössä)

Pölynpoistoaine

Riippuen käyttökohteesta, tulee jauhettava materiaali käsitellä pölynpoistoaineella. Pölynpoistoaineen tyyppi ja annostelu tarkistetaan tapauskohtaisesti testausvastaavan kanssa.

Testauksen seuranta ja raportointi

Seuranta

Testaussuunnitelma toimii yhdessä testauslistan kanssa toiminnan käyttöpäiväkirjana, dokumenteista ilmenevät kaikki olennaiset tiedot testauksen suorittamisesta.

Raportointi

Testausvastaava vastaa raportoinnista, käytetään lomaketta ”Testaussuunnitelma”.

Jokaisesta testauserästä tulee tehdä testaussuunnitelma, jossa on ilmoitettu näytteenottoaika tulosten analysointia varten. Näytteen tulokset merkitään syötteen koodilla ja arkistoidaan testausvastaavan toimesta

4. TESTAUKSEN RISKIT JA NIIDEN HALLINTA

Ympäristö- ja turvallisuusriskien arviointi

Testauksen riskiarviointilomakkeet liitteissä 5-7.

5. LIITTEET

Liite 1. Testauslista

Liite 2. Testaussuunnitelmapohja

Liite 3. Leikkuu- ja purkujäte syöteluettelo

Liite 4. Prosessijäte syöteluettelo

Liite 5. Riskiarviointi_Kaikki perusosion lomakkeet

Liite 6. Riskiarviointi_Koneet ja käsityövälineet_Mil-Tek IC60

Liite 7. Riskiarviointi_Ympäristöasiat

Liite 8. Koetoimintalupa

Liite 9. Suursäkki BPNLA 115C tekniset tiedot

Liite 10. Pölynpoistoaine käyttöturvatiedote

Appendix 2: Mil-Tek IC60 brochure

IC60

HEALTH AND SAFETY

Minimize your risk

Perfect for

Recycling

Construction companies

Demolition work

Minimize your waste of time, space and money

- Compression ratio: 25: 1
- Less waste space compared to a container
- Easy to use – front-loaded at working height
- Low maintenance costs - filter and oil only
- Can be mobilized for easy transport

The IC60 Rockwool Press shreds and compresses waste Rockwool and glass wool.

Waste material can easily be loaded into the inlet funnel, and large sacks can be attached to the outlet to minimize dust expulsion. The machine compresses Rockwool at a rate of 25:1.
The compressed material can be more easily transported and recycled, with transport savings of up to 90%, which overrides the deposit fee.

The IC60 can be mounted on a trailer or onto a loading container to mobilize it, making it easy to transport or move around a site.

For further information, please contact Mil-tek Danmark A/S

Specifications

Machine size H x W x D (mm)	2820 x 1500 x 5300
Power supply	3x 400 V 35 A
Hydraulic press	150 bar
Motor	15,0 KW
Hydraulic pump	0,37 KW
Forwarder	0,12 KW
Weight (kg)	2615

Don't waste your time - **Book a Free Site Survey**
or contact mil-tek Denmark A/S for more information

Mil-tek
Minimize your waste

Appendix 3: Images from microscopy

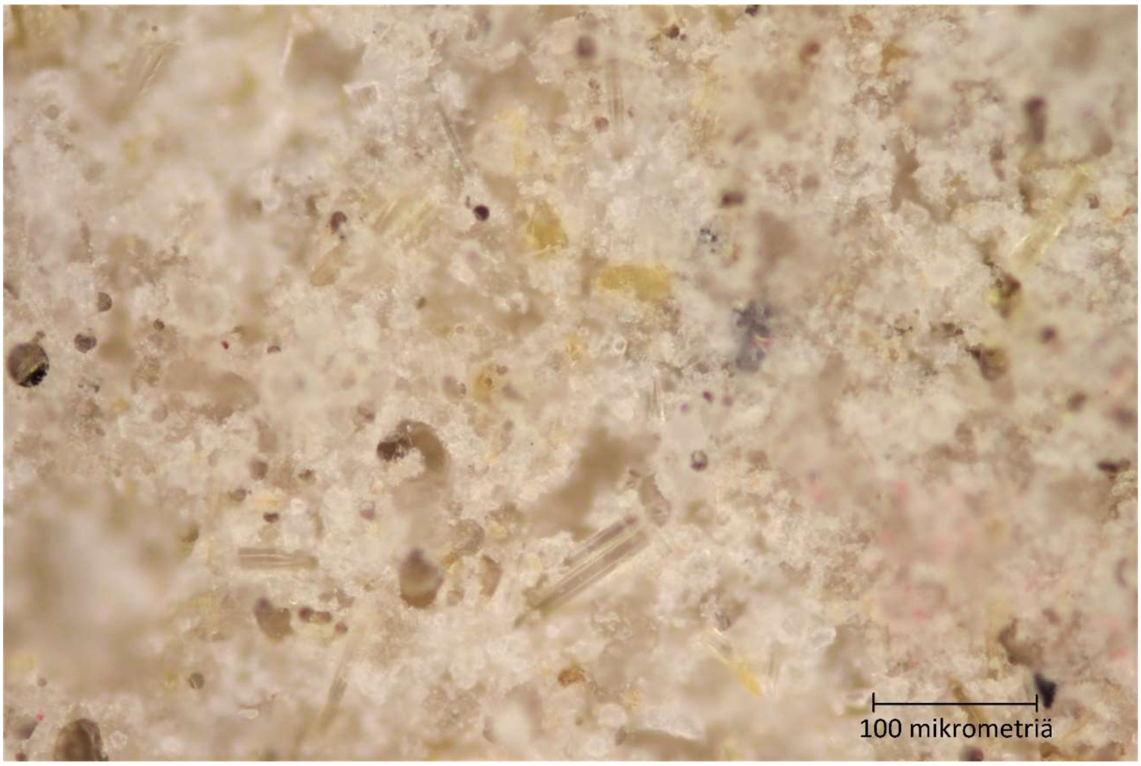


Figure 34 Geopolymer sample, scale bar 100 micrometers (Kohvakka, 2020)

Figure 35 Geopolymer sample, scale bar 500 micrometers (Kohvakka, 2020)

Figure 36 Geopolymer sample, holes left by air bubbles (Kohvakka, 2020)