Development of Miscanthus Based Biocrete Against Fire.

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1. Introduction

This research is a joint effort between Centre of Expertise Biobased Economy (CoEBBE) and Vibers, which is being continued from the results of the past research done by researchers before me. Firstly, CoEBBE is a partnership between Avans University of Applied Sciences and HZ University of Applied Sciences. This partnership was set up by the Ministry of Education, Culture and Science to allow for a more rapid and smoother path for Higher Educations to interact and work with research problems such as obtaining a biobased economy. CoEBBE main purpose is being able to ensure a greener future through molding excellently trained professionals who are able to support the world through gathering information for new and sustainable materials and methods which are able to put it to practice too. With the help of all its experts within the organization and with some funding from investors such as the government and/or external companies such as Vibers and De Hoop, CoEBBE is able to ensure the future is green and sustainable. (Centre of Expertise Biobased Economy, 2022)

Vibers is a company that started up in 2010 by Jan-Govert van Gilst when he witnessed a worldwide problem firsthand. He realized the large impact humanity had on the world with mass deforestation and large amounts of litter of nonrecyclable materials that was everywhere. Which gave him an idea, which was initially to grow bamboo on building sites, for co-firing in coal plants. This won the Zuid-Holland Prize and reached the finals of the TEDxAmsterdam Award (2011 and 2013). However, bamboo was not the answer and with the help of Wageningen University, Mr. van Gilst has been pointed into the direction of Elephant grass. This grass is able to grow in almost any weather condition unluck Bamboo. Elephant grass, which are the dried Miscanthus fibers that are being supplied for this research were given in two different sizes, 0mm-4mm and 4mm-10mm. (Oddessey Solutions, 2022) For this part of the research the larger fibers are being used.

The project started with research on the pre-treatment type and method done by HZ student, Dammy Adebiyi, in February 2021. The research concluded that pre-treatment is needed on the natural fibers to ensure solid bonds are formed between particles with in the mixture while the cement hardens. The best pre-treatment method was found to be a cement pre-treatment, with this information the project has moved forward with further tests on Elephant grass being added to the mixture to create bio-crete.

From there the research objective was to test the smaller sized fibers 0mm - 4mm, in all types of tests. The tests and results where documented and recorded by a different student, Andrea Kiss, in February 2022. During this research part of the project is to increase the amount of fibers for each mixture which is tested while it is still wet and workable, as well as in the form of hardened cubes. The tests are done to determine the physical and mechanical properties of the bio-crete with the small fibers. The results of those tests determined that fibers are a good way to add volume to a mixture as well as improve some of the properties, as well as decrease others. The main conclusion drawn from the second phase of the research was that the smaller fibers increase insolation properties, but at the same time decreases the strength of the concrete.

From the results of the second phase of the research it was decided that for the third phase of the research the larger fibers of 4mm – 10mm will be used. The main objective stays similar to the ones of the previous phases where a biocrete with a high percent of fibers is wanted with good properties compared to conventional concrete. Tests will be done to find out if the biocrete is strong enough for it be used in a structural form such as supporting/load bearing walls. However, if the strength is low and the other properties are increased such as the insolation then the product could be used for insulation to create dividing/inner walls. One of the main tests this report focuses on is the fire test, along with all the other tests that have been done in previous phases as well. This is because it is a new test that will be run on the material. The results will show how fast the heat from a fire will transfer through the material as well as have a understanding of how the extreme heat would effect the material in a structural and physical way.

1.1 Background

Concrete is one of the most frequently used building materials worldwide. The first main users of concrete were the Egyptians in approximately 2,500BC and the Romans from 300BC (AZoNetwork, 2002). Concrete consists of four main ingredients: cement, fine aggregate, large aggregate, and water. The first ingredient, cement, is the binder and is the part that adds the strength and keeps everything attached to one another. The finer aggregate, being sand with a grain size of average 0-4mm and is used to fill the volumes left between the large aggregates. Which is our third ingredient and is often gravel with a grain size of 4-16mm, creating most of the volume of the concrete and contribute to the strength. Lastly water is added to start the chemical reaction of binders and to attach the aggregates to form an homogeneous mixture that can be molded and set to harden.

The Romans went on to realize that concrete could be adjusted to fulfill different needs. Such as by using lightweight aggregates to construct the roof of the Pantheon and by adding bronze bars to reinforce the concrete. (AZoNetwork, 2002) These were only the first few steps made and since then they were optimized and other ingredients where tested and found to do better in some characteristics of concrete, as well as decrease other characteristics at the same time. Inventions such as plasticizers were added to concrete mixtures to decrease the amount of water needed, as well as increases the workability of the mixture. The main disadvantage is that the slump loss is greater, and the plasticizers add some extra costs to the process. (Constructionor.com, 2015)

Seeing as concrete is so widely and often used in construction, it would be assumed that the process of making concrete would have been perfected just as the material that is being made. However, this is not the case as the process of making concrete accounts for around 5% of the global carbon dioxide emissions. The industry emits 900kg of CO_2 for every 1000kg of concrete produced, which is a large amount of greenhouse gasses being added to the atmosphere and to global warming. (Mahasenan, Smith, & Humphreys, 2003) For this reason as well as the incentive from the government to be carbon neutral by the year 2050, steps are being taken to decrease CO_2 levels during the process of making concrete.

One of the first steps taken to reduce the carbon dioxide levels within the process of making concrete. Is by replacing some of the common aggregates, being sand and gravel, with more natural products, like synthetic fibers or another natural material. The reason behind the change is because the more common aggregates are beginning to become harder to find, resulting in it needed to be transported in from further away, again adding to the CO_2 levels. One means of decreasing the use of the common aggregates and in turn decreasing the carbon dioxide levels is by replacing the sand or gravel aggregates with sustainable materials, such as the Elephant grass (Miscanthus x giganteus) which is dried and used as a fine aggregate replacement. (Prakash, Subramanian, Raman, & Divyah, 2022)

However, adding different ingredients does not improve all properties of concrete. More often than not the compressive and tensile strengths are decreased, which is the main property for the reason concrete is so widely used. However, other properties could be increased and that is why as many tests will be done on the mixtures as possible. For this reason, it is important that other sustainable materials are research and looked into other than Elephant grass. The other sustainable and natural materials looked into were Bamboo and seashells which were tested and researched before by other researchers. The costs of the sustainable mixture is increased as well, because the natural materials often undergo a pretreatment which needs extra materials and time. The natural materials are also more expensive, however as the common aggregates become more scares, they will become more expensive as well. (Rahman, 2020) The new test, fire test, was decided on as well, since very little is known about the material, all possible test to be done need to be done. This ensures everything possible characteristic to know about the material is know for once it is sold and used in the world.

1.2 Problem Statement

The process of making concrete produces a lot of greenhouse gasses which is released into the environment. Not only is the process of making concrete a problem, but the act of obtaining and transporting the ingredients to the site to start mixing adds as well. On top of these issues is that concrete is a hard material to recycle, thus produces tons of waste. Within the construction industry 150 million tones of waste through demolition and construction are left behind and only about 46 million tons is recycled annually. (mpa The Concrete Centre , 2022)

The amount of waste concrete produced is not the only main concern, another big concern is the availability of aggregates for the mixture to produce concrete. These aggregates, are sand and gravel, that are being depleted and so becoming harder to find too. This means that the aggregates will have to be transported from even further away, adding to the cost and to the CO_2 levels.

Very little is known about adding natural fibres into concrete, because of this a lot of different tests and experiments will be done on the material to best understand the characteristics of the product.

1.3 Research Question

For this research the main objective is to understand the effect fire would have on biocrete, as well as optimizing the amount of Miscanthus fibres into the mixture to make biocrete that is still strong enough for internal walls, as well as sub-research objectives that will be researched and accomplished through the multiple tests that will be run. These objectives helped compile and answer the main research question that is going to be researched and tested.

Main Research Question:

What impact does fire have on biocrete when considering the percentage of Miscanthus fibres with in the mixture?

Sub-questions:

- How much cement is attached during pre-treatment?
- Is plasticizer needed?
- Can the workability of the mixture be kept at its optimum state?
- Does the biocrete keep its strength to be used structurally?
- What fire test would best test the mixtures?
- How does the fire effect the test cubes physically appearance?
- Does fire have an effect on the strength of the concrete?
- How does biocrete differ from conventional concrete when it comes to heat transfer during a fire?

1.4 Objectives

As Vibers is the main Organisation in charge and so the main objectives where received from them. The research itself is done by Center of Expertise Biobased Economy in collaboration with Vibers and De Hoop to optimize and obtain a biobased concrete. In order to make a bio-crete, a natural material needs to be added, for this research the biobased material is Miscanthus fibers. For the biocerete to be valid a number of objectives need to be achieved.

Objectives:

- A compressive strength of at least 2.5MPa.
- Maximizing the use of biobased material, miscanthus fibers, within the concrete mixture, >27%.

- ➢ A workability of class S2 or S3 that allows for blocks to be made on a vibrating press.
- ➢ Able to withstand extreme fire temperatures.
- ➢ After a fire the biocrete is able to withstand a compressive strength of at least 2.5MPa.

1.5 Program of Requirements

Technical:

- ➢ Compressive strength greater than 2.5MPa.
- ➢ Fiber percentage greater than 27% of the mixture volume.
- ➢ Workability that allows for blocks to be formed on a vibrating press (Compaction & Immediate mold release) slump = 8cm ± 2cm.
- ➢ Compressive strength kept above 2.5MPa after fire test.

Functional:

- ➢ Have a good heat insulation characteristic.
- ➢ Have a good sound absorbing characteristic.
- ➢ Able to withstand high heats from fire.
- ➢ Used for aggregate replacement.

1.6 Stakeholder Analysis

For this analysis, a more in depth look into the parties and stakeholders that have a claim or interest in the problem and their influences on the solution. Below in figure 1, you will see the

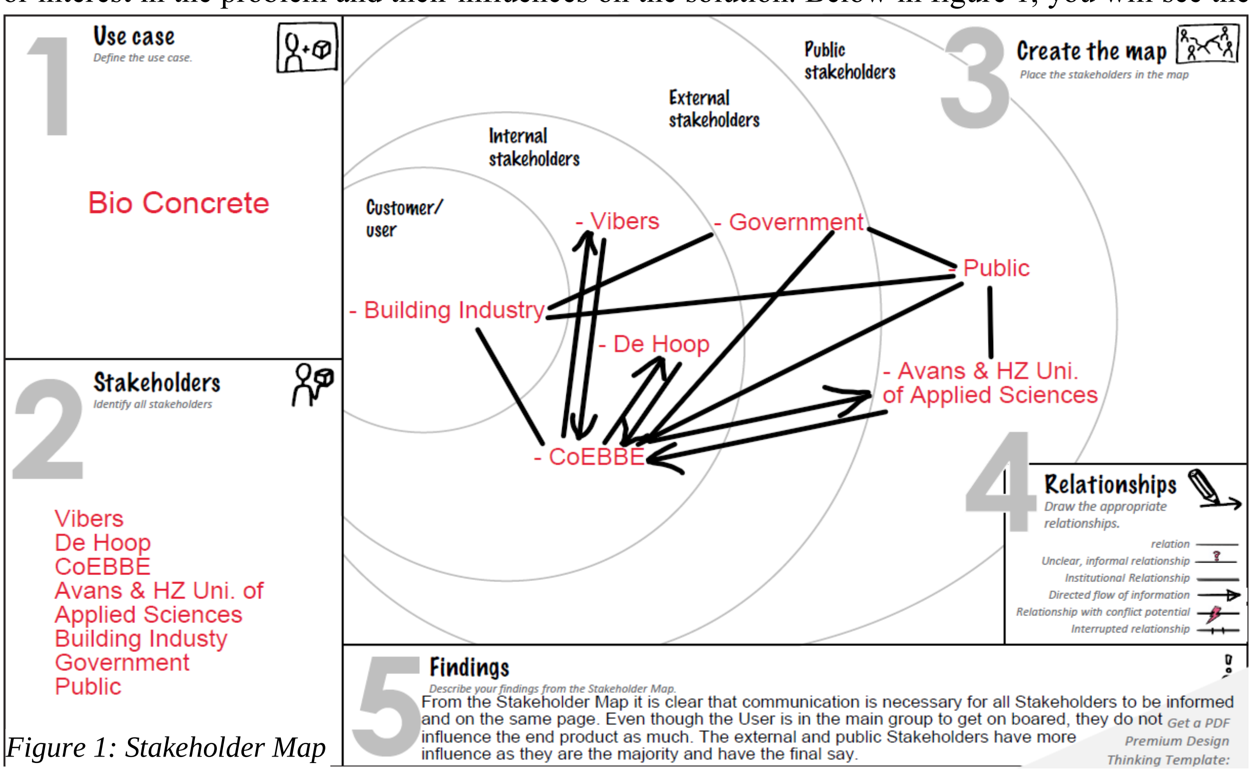

Figure 1: Stakeholder Map

steps taken to identify the different parties and to group them according to their level of participation, interest and influence in a Stakeholder Map.

With in figure 1, the map shows the direct of communication between the internal stakeholders and with the universities in the public zone. This ensures all information is shared and theses stakeholders are also highly involved in the research. The rest of the stakeholders are less involved, however have a big role in the success of the research as they are the stakeholders that will need to use the research and make it reality by applying the research. For a better understanding of the power and interest each stakeholder has the matrix below in figure 2 is used. (Stakeholder Analysis, 2021)

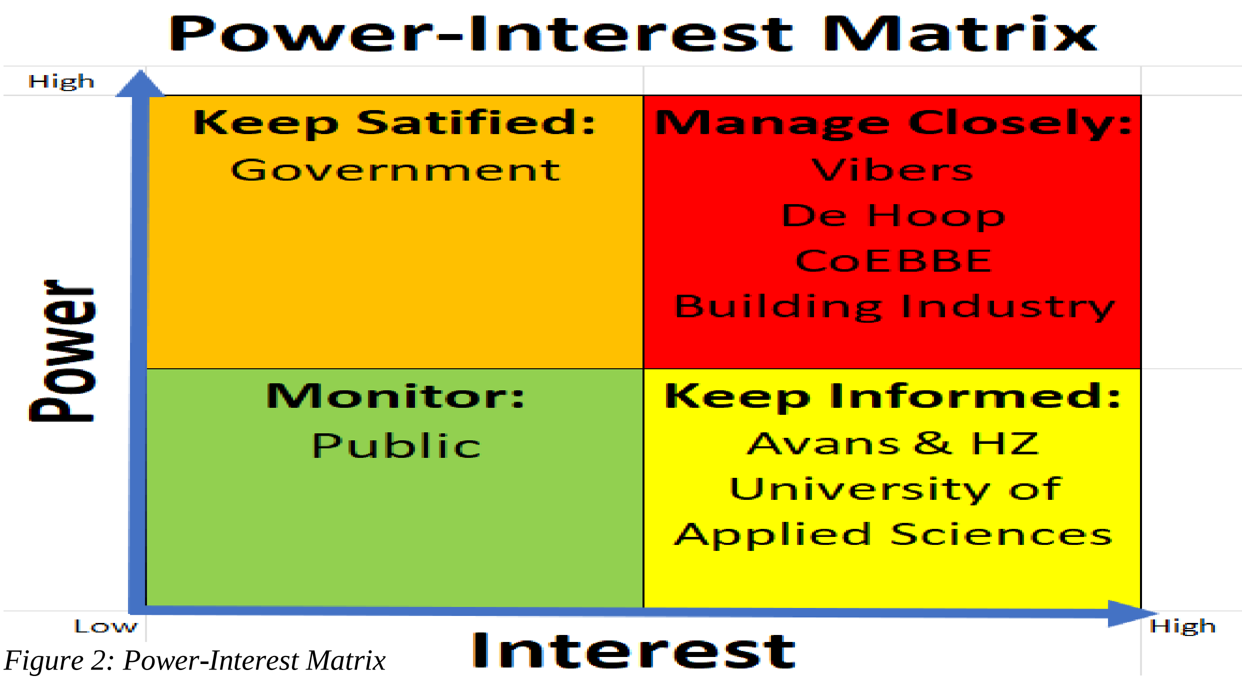

Figure 2: Power-Interest Matrix

The matrix in figure 2 uses the power a party has on the research to keep it going or to stop it (vertical) compared to the level of participation the different parties have on the research (horizontal).

If a party has a high power and a high interest they fall into the red block labeled as Manage Closely, as these are the most important stakeholders. Vibers, De Hoop and CoEBBE are all very interested in the research and have a high power in the research as they are the parties involved in doing the research. The Building Industry is found in the red block too, this is because they have a high power influence as they will be the main user of the research. They are also highly interested as a new means of sustainable concrete is yet to be found to be viable, thus the success of this research is important for the future of the industry.

A party with a high power and a low interest are found in the orange block called Keep Satisfied, this is because of their influence to either stop or keep the research going they need to be kept satisfied. The Government/Municipalities fall into this block as they have the power to ensure the research is used in the future or whether it is not necessary and the research can stop. However, because of their low interest they do not need to be kept in constant contact about the progress, they are more interested in the final result.

Parties with a low power and a high interest find themselves in the yellow block, named Keep Informed, they are needed to be informed on a regular basis to ensure they don’t run into issues and are kept on track with the rest of the research.

Lastly, any party with low power and low interest are found in the green block, called Monitor. Here parties are kept informed periodically, to ensure they understand what has happened, what is happening and what will happen. With in this block is the Public, who again are more interested in the final outcome of the research rather than each step and also don’t have much say on the research itself as it is something that is needed for the construction world to be more sustainable.

2 Theoretical Framework

For this section research is done to create a clearer understanding of the materials and tests that are going to be researched and used. As well as to be able to compare the current research to those already previously done. Some information on different natural materials are researched as well as different fire tests to determine what would be ideal for the biocrete.

2.1 Boundaries & Limitations

2.1.1 Boundaries

The following preconditions were decided on and known prior to the start of the research. These preconditions are mentioned to ensure clarity and understanding of the product that will be delivered. The preconditions and limitations mentioned refer to the ingredients used, mixing method and tests used. As well as concentrating on important variables such as the amount of fibres present with in the mixture as well as the results of the strength and fire tests. The boundaries that were set for this research are as follows.

- Standard ingredients used (Cement, Sand, Gravel, Water, Plasticizer and Fibers).
- Ingredients are tested and certified before use, ensure it to be the same every time.
- Concrete is Bio-Based by adding Miscanthus fibers.
- Research on different types of biocrete and fire resistant tests.
- Each mixture receives a percentage more fibers than the previous mixture.
- Each mixture allowed to set for a minimum of 28 days and then tested.
- Each mixture is tested under the same circumstances and with the same equipment.

2.1.2 Limitations

Limitations are the circumstances or the conditions that might affect the process of the research. These might slow down the research, but will contribute a lot of ideas to improve the project quality on the result. We can see the limitation as the motivation to innovate and adapt with the condition in the surrounding that are not able to be changed. The limitations for this research are as follows.

- A lot of research is limited to desk research.
- Ingredients come from a certified source, need to be ordered if ingredients run low, consider lag time.
- Time – Each mixture needs 28 days to harden and be ready for tests, as well as 7 days for pre – treated fibres to harden.
- Human – As the making of the biocrete and testing is done by people there may be some mistakes.
- Equipment – Not having the correct machinery or the right shape mould for the test.
- Building/Lab availability – The building used to make the biocrete and run the tests is closed on holidays, weekends and may be occupied by other users.

2.2 Miscanthus/Elephant grass

Miscanthus or Elephant grass still has some research going on to better understand the crop and all its variants. Until now, it is known that originates from Asia. It is proven that miscanthus grass is a fast grower, easy to maintain as it requires few cultivation handlings other than planting and harvesting. Miscanthus can grow in varies conditions one of them being in cold temperatures, making it ideal for higher altitudes too. This grass has a high biomass, which makes it to have the same energy value as coal, however the miscanthus grass would be a renewable source and at the end of its life cycle it remobilizes the nutrients to the roots which will then be reused in the new growing season. This allows for the decrease in usage of fertilizer and an increase of possibilities of the miscanthus fibers to be used in for example animal bedding or furnace fuel, but it can also be used to make paper, bioplastics, biofuels as well as building materials like bio concrete. (Trinadade, 2022)

2.3 Hempcrete

Hempcrete is made from plant shives that are ground to 5-40mm, lime which is the mineral binder and water. Hemp itself is another widely used product where it is useful from the start of its life cycle, where it grows out of the ground. During its life cycle it is able to replenish the ground by killing off tiny crops or other unwanted weeds. The plants residue acts as a natural botanical insecticide and inhibits nematodes and fungi to grow in the soil. Other than being useful while its alive, the plant is also useful once it has been harvested. Hemp can be used to make bioplastics as its flexible, textiles like yarn to create fabrics that show better performances in air permeability, anti-mold and UV protection. Hemp can be used in medical turns where it is squeezed into an edible oil, as well as a biofuel as it has a high biomass. The plant is also used in the construction industry as insulation and acoustic purposes, because of the few ingredients to make hempcrete it is also found to be a super light concrete. However, the physical properties are not ideal for load baring structures, the compressive strength on average is below 1MPa. To obtain a higher compressive strength, the voids would need to be reduced and in doing so the insulation and acoustic properties are compromised (Ahmed, Islam , Mahmud, Sarker, & Islam, 2022).

2.4 Materials

2.4.1 Binder

Cement is the binding agent which is activated once water is introduced. Once the slurry of cement and water is mixed with other ingredients, such as sand and gravel, concrete is formed and held together by the cement. Cement does not only hold everything together, it also plays an important role within other aspects of the mixture. Firstly, while the mixture is still fresh and wet the cement content affects the workability, the larger the cement content the more water is needed to retain a good workability. Once the concrete has hardened the cement content affects the compressive strength, drying shrinkage and durability. An increased cement content in terms of compressive strength it found to only increase the strength in the earlier stages of the concrete, whereas after 28 days the strength evens out. Having a further look at the cement content compared to drying shrinkage and durability there is a clear correlation between an increased cement content and increased cracks. This occurs because the increased cement absorbs more water, drying out the concrete allowing drying shrinkage cracks to appear. This in turn decreases the durability of the concrete (LeBow, 2018).

The cement used for this research is CEM I 52.5 R grey Portland cement. This is the commonly used cement worldwide and it has a high mechanical strength, which is reached rapidly. The cement is certified and supplied by De Hoop in Terneuzen, Netherlands.

2.4.2 Aggregates

Mineral aggregates are a key ingredient when making concrete. This is because aggregates make up 60% - 70% of the volume of concrete, they also decrease the intake and amount of water and cement needed for the mixture. Aggregates also add to the mechanical strength of the concrete by making the product more compact (CEMEX, 2022).

There are two types of aggregates that are used. The first one is coarse aggregates which are the larger particle pieces such as gravel which for this research range is from 4mm – 16mm. The second form is fine aggregate which has particle sizes smaller than that of gravel, for this research the particle size ranges is from 0mm – 4mm. De Hoop is the company that provide both types of aggregate with a certification.

2.4.3 Fibers

The last dry material that is being used in this research are the fibers from a tall grass called Miscanthus X Giganteus. The fibres are split into two groups, the first is the smaller fibres which range from a size of 0.5mm – 2mm and the larger fibres which range rom 2mm – 10mm. For this research the larger fibres are used, as the smaller fibres were tested in an earlier phase of the project and it was found that too much cement is used for pre-treatment. These fibres are produced and supplied by Vibers.

2.4.4 Water

The first and main wet material is water, water plays a main role when it comes to producing concrete. Water combined and mixed in with cement starts a chemical reaction called hydration. Hydration is the activation of the cement molecules, through water, which binds everything together. Because these two materials are closely connected it is very important to have a good balance or ratio between the two in order to obtain a strong and workable concrete (MAST, 2022).

The water that was used for this research is obtained from the lab where the research is taking place. The laboratory name is Scalda, located in Vlissingen, the Netherlands.

2.4.5 Plasticizer

Plasticizers are admixtures which are used to reduce the water needed in the concrete mixture and/or to increase the workability. There is more than one mechanism that occurs once a plasticizer is introduced, however they all help slow down the rate cement particles are hydrated. In turn ensuring water is available for fluidity and workability (Shraddu, 2022). Plasticizer is measured and used in ratio with the amount of cement.

The plasticizer used for the research is called CUGLA LR-1500 con.30% SPL and is supplied by CUGLA Concrete Solutions (Cugla BV, 2022). The plasticizer through out the research was used as a 1.25% of the cement used.

2.5 Fire Resistance

Fire resistance is the amount of resistance a material or structure has to fire (Dictionary.com, 2022). When looking at the Eurocode of fire resistance to concrete, mainly dealing with parts 1-2, the design of structures accidently exposed to fire. Only the passive method of fire protection will be covered, where no added fire protection layers are applied, known as an active method. Prestressed structures by external tendons as well as shell structures will not be covered however, Part 1-2 of EN 1992 [2-3] does cover and can be applied to normal weight concrete up to a strength class of C90/105 and for lightweight concrete up to a strength class of LC55/60. Fire resistance is an important safety design for structures, as fire resistance is a requirement such as mechanical resistance and stability (Bellova, 2013).

In order to determine the fire resistance of an object, tests will have to be done on the objects. These tests are often done using live flames exposed to the object, with a critical design temperature ($\theta_{d,cr}$) extended over a design period of time of fire classification for a standard fire ($t_{fi,d}$). It is not always ideal to set a time to cut off the test as it would be better for the tests to be done until the object fails. This way most of the data can be obtained, as the object could fail one minute later or after a much longer time (Farkas & Jarmai, 2008). As most companies want to obtain a certain classification here are how the Eurocode characterizes fire resistance. The first three classifications are able to withstand exposure of a standard fire for 60 minutes. The first being class E 60, object meets the integrity criterion, the second, class I 60, objects meet thermal insulation criterion and the third, class R 60, object meets load bearing capacity. Lastly, class M 90, object meets mechanical resistance criterion for 90 minutes within a standard fire (Bellova, 2013).

2.6 Fire Test Furnace

There are different sized furnaces available for different size test samples for a fire test to be done. They vary from 1.8 meters wide by 1.2 meters depth by 1.2 meters tall for a small Horizontal/Vertical Test Furnace sample. To a test sample of 4 meters wide by 3 meters depth by 3.4 meters tall. (ArmilCFS, 2022) To test a horizontal structure the tilting furnace is used lying down with the structure lying on the furnace. Once in position the furnace is turned on and the temperature starts to increase according to a standard fire curve as seen in figure 3. (IPM, 2022)

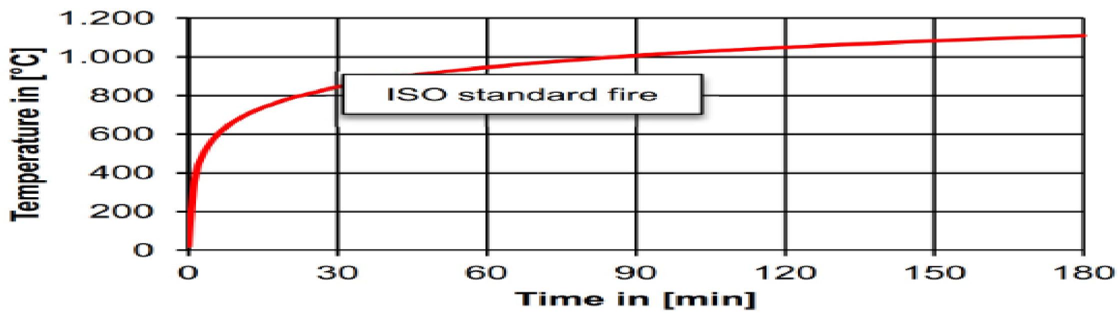

Figure 3: Standard Fire Curve

The furnace's temperature increases relatively at the same rate as the standard fire curve, where the temperature would be over 800ºC within 30 minutes and continues to increase to just under 1000ºC within one hour. Other curves can be programed and tested with the furnace as well for example the external fire curve or the hydrocarbon curve. During the test the surface temperature, radiation and flame density are assessed and more. (PEUTZ, 2022)

2.7 Pool Fire Test

This test is used to determine the fire resistance of structures such as columns, beams and walls. The test is mostly done outdoors in order to obtain large flames that accompany large hydrocarbon pool fires. With the ability to control gas or liquid fuel for the fire, a wide variety of fire scenarios can be tested to obtain all data possible. The pool fire test looks at predicting thermal exposure as well as the material performance in the different scenarios. However, the pool fire test does not provide data on the gasses that are being produced, which could be harmful. It also does not allow the ability to have a look at the reactions joints or connections would have within the fire, nor can the spread of fire on the surface of the object be traced. (ASTM , 2022)

2.8 Burner Fire Test

A burner fire test is done using a flamethrower type of tool that is able to direct the flame into the direction/area that needs to be tested and concentrated on, as seen in figure 4. The reason for the flame to concentrated on one location is to ensure all the heat is focused on that location too, ensuring a severe fire threat is tested. The extent to which the flames continue on the structure itself to be able to spread can also be seen if the test fire is only coming from one starting location. (Ochs, 2012)

Figure 4: e.g. Burn Fire Test(ACCU Fleet International , 2022)

3 Method

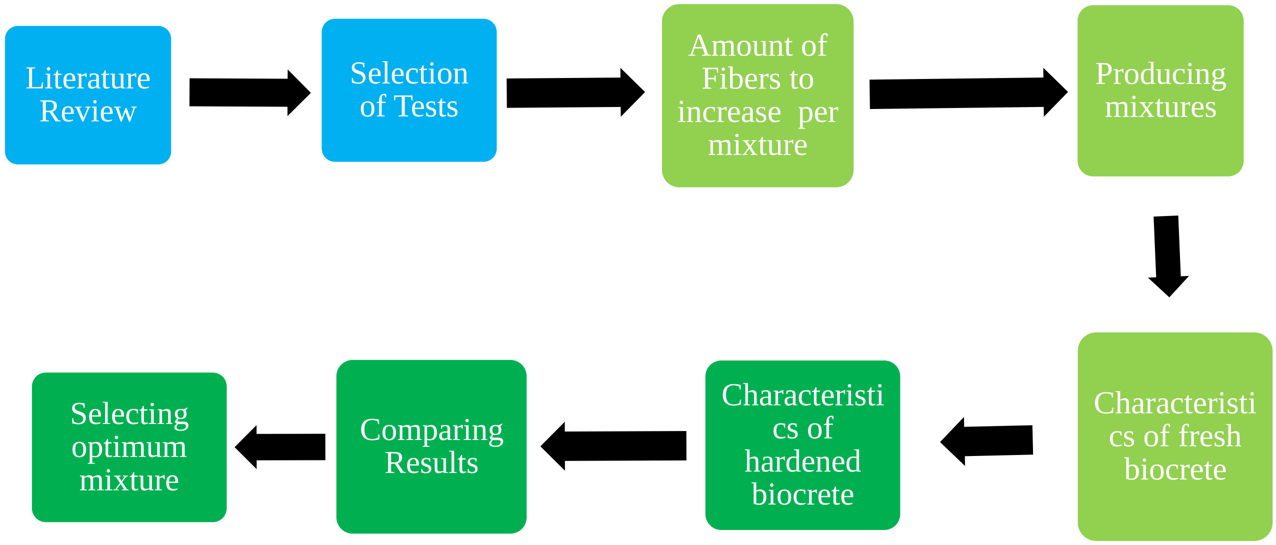

Figure 5: Flow Chart of Research

For this research, two types of research methods were used to fulfill the objectives of this project. As seen in the flow chart above in figure 5, the first two blocks in blue represent the start of the project, were "Literature Review" represents the desk research that has been made and "Selection of Tests" is the lab test that have been done to test the research. The next three blocks in the flow chart represent the design phase of the biocrete mixture as well as results of the mixture while its still wet. The last three blocks represent the last part of the research where the dry concrete is tested and the results analyzed to obtain the best mixture for the biocrete.

3.1 Process

This part of the research will explain the steps taken in order to obtain, as well as the tests that are done further in the research.

3.1.1 Sieve analysis

A sieve analysis is a method used to determine particle size distribution of a granular material, which is sand and gravel for this research. The sieve analysis involves several layers of different sized sieves, which range from 0,125mm to 16mm. The sieves are arranged by smallest sieve opening size at the bottom and then increases in particle size towards the top. The granular material is then added to the top sieve and closed off. The machine is then turned on for the material to be sifted, this means the sieves begin to vibrate at a high frequency causing particles to fall through the larger sieve sizes until the sieve hole size is too small (CORROSIONPEDIA, 2022). Once all the material is sifted, the material in each sieve is weighed and recorded into a table.

3.1.2 Pre-treatment

A cement pre-treatment is done to the Miscanthus fibres. Without the pre-treatment the cement does not bond with the natural fibres causing voids to appear with in the biocrete which are weak points where cracks can easily form along. The cement pre-treatment is not the only

Figure 6: Pre-Treated Fibers Hardening

treatment method, however it was proven to be the most viable method by a previous phase of the project. (Adebiyi, 2021).

The fibres which are between the diameters of 4mm – 10mm, at 500g a sample, are soaked in a slurry of cement with a 1:1 cement to water ratio, each of the two weighing 5kg. Once soaked in the slurry, the fibres are strained and laid out to dry/harden for seven days as seen in figure 6.

After the week the samples are scraped of the board and weighed. The results are recorded and used to calculate the ratio of cement to fibre. This is then used to calculate the amount of natural un-treated fibres that is used in the mixture and with that the amount of extra cement through the pre-treatment can be calculated.

3.1.3 Creating the Mixture

The concrete design has a constant amount for cement: sand: gravel, these three materials are kept constant for all mixtures. Plasticizer has been removed from the mix as the workability of the mix is still good, so there is no need for it. The water used stayed at a constant water:cement (W:C) ratio at first, however the mixtures that follow differ, as well as the % of fibers used within the matrix. This is because the amount of pre-treated fibers is increased per mixture. In total four batches of concrete were made, each batch increasing the pre – treated fiber content by 1kg. The fibers used for these four mixtures are the larger sized ones from 4mm - 10mm. The following table 1, represents the control mix, which was obtain from previous research done on the topic (Adebiyi, 2021).

Table 1: Control Mix CBp

Materials	Density: (kg/m3)	Amount: (kg)
CEM I 52.5 R	3100	20.755
Sand 0 - 4 mm	2640	32.076
Gravel 4 - 20 mm	2640	44.930
Pre-Treated Fibers	160	0.000
Water	1000	10.616
Plasticizer		0.000

3.2 Characteristics of Concrete

In this section of the research a description of the tests, as well as the reason for the test will be explained.

3.2.1 Fresh Density Test

The fresh density test is done to obtain the density of the mixture which can be obtained by using the following formula:

$$D = \frac{(m2 - m1)}{V}$$

D – Density (kg/m3)

m2 – Weight of filled container (kg)

m1 – Weight of empty container (kg)

V – Volume of biocrete (m3)

This test is done before the cubes are molded as the concrete is still fresh and workable. Before the wet concrete is added to the container, the empty container needs to be weighed first. Once the weight is recorded the next step is to record the dimensions of the contain to obtain the volume. After the data was recorded it is time to fill the container with vibrating in between and adding concrete when necessary. As soon as no more concrete can be added, the filled container is weighed and the data recorded. At this point the formula is used to obtain the fresh density of the biocrete.

3.2.2 Slump Test

The slump test is done to measure the workability and consistency of fresh concrete. The following figure 7, shows the equipment used for the slump test.

Figure 7: Slump Test of MixB1p - 16cm

As seen in figure 7 a cone shape mold is used with a rode which is lying horizontally on the top of the cone. The steps taken for the test are as follows:

First the cone and rode are cleaned with some water, which also helps make sure the concrete does not stick to the cone.

Next, pouring is done in three stages. This is done by filling the cone with the biocrete in thirds, after each third is filled, compaction needs to happen. This is where the rode plays a role, the rode is used to compact each layer. To compact a layer the rode is pushed down into the layer that needs compacting 25 times. After the third compaction the top is leveled with the cone by adding biocrete when needed. Once leveled the cone is slowly lifted and placed next to the fresh concrete. At this point the concrete has either a true slump, a shear slump or collapsed, the difference can be seen in figures 8 and 9.

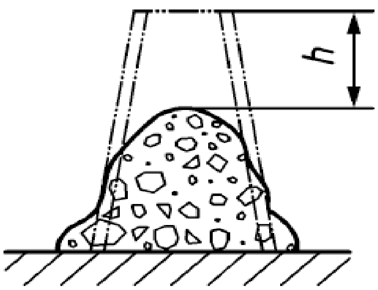

Figure 9: e.g. Ideal Slump Test

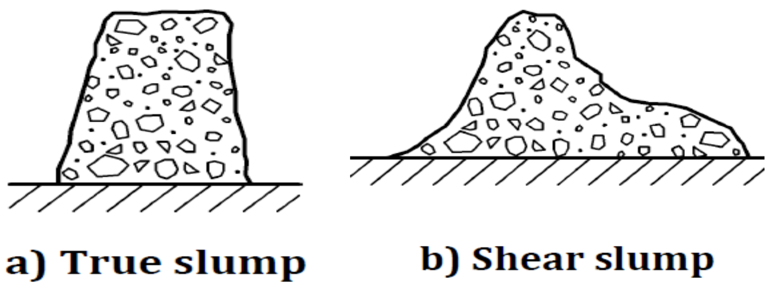

Figure 8: e.g. Slump Test Results

The slump is then measured by placing the rode horizontally on the top of the cone, stretching across the biocrete. The slump as seen in figure 8, (h) is measured with a ruler which is placed vertically on the highest point of the biocrete, up until it passed the rode and the height is recorded from the bottom of the rode.

For this research the slump will be classified according to BS EN 206-1 : 200, a true slump is desired with a slump of 80mm give or take 20mm, which would be between a medium and high slump ending in class S2 or S3. The following figure 10 shows the classifications and the slumps that belongs with the classification.

Classification of workability	Slump mm
S1	10–40
S2	50–90
S3	100–150
S4	⩾160

Figure 10: Classification of Workability

3.2.3 Air Content Test

This test is done to determine the amount of air trapped inside of the mixture. Each time air content increases within the mixture it increases the following properties (Liebmann, 2021):

Figure 11: Air Content Test B3p 10%

- Resistance to freeze-thaw
- Workability
- Durability
- Resistance to chemical attack
- Cohesion

However, increasing air content is not always the best as it does decrease a few properties too, such as (Liebmann, 2021):

- Strength
- Weight
- Potential honeycombing

Figure 11 shows the tool used to run the air content test. The next few steps explain how the test is run. First the top is unlatched so the container can be washed with water and placed on a level surface. Next, the container is filled in three equal layers and each layer is compacted with a rod, striking the mixture 25 times. After this the base of the container is hit with a mallet 12 to 15 times spread around the outside of the container. Once the 8 liter container is filled it is leveled and smoothed at the surface and the rim of the container cleaned.

Next, the top is latched back on tightly and the two red valves are opened to allow water to be pumped in to fill up any air voids that are left. Once the air voids are filled and enough water was used the valves are closed. The meter at the top is then pressurized with a built-in hand pump until zero is reached. After waiting a few seconds to let the meter stabilize the pressure is released at the top and then the air-void content can be read on the dial at the top. (Concrete Network, 2020)

3.2.4 Forming of Cubes

After the fresh tests have been completed the fresh concrete is poured in the molds, each with dimensions 150mmx150mmx150mm. These cubes will be used to test the hardened concrete to research how the fibers influence the characteristics.

Figure 12: Mix B1p in Cube Mold

To mold the cubes, a black mold is used as seen in figure 12. First the mold is oiled to ensure the hardened cube does not harden to the mold, allowing for an easy extraction of the cube. Next a plug is placed at the bottom of the mold where a hole is located to pump air in to remove the hardened cube. With the plug in place the fresh concrete is shoveled into the mold which is stationed on top of a vibrating table. Once the mold is filled the table vibrates for 5 seconds, ensuring all air voids are vibrated out and a uniformly distributed of the material and a compacted cube is left. Once the cube is filled to the top and leveled off a label is placed on top and then left to harden for two days. After the two days the cubes are removed from the mold through removing the plug at the bottom and by placing an air compressor at the opening which once turned on pushes the cube out of the mold. With all cubes removed from their molds, the cubes are left to harden further for a total of 28 days, allowing the cubes to obtain their maximum strength.

3.2.5 Compressive Strength Test

The compressive test is used to research the amount of pressure the concrete can resist before it collapses. This test will be done three times, the first will be at 28 days after, the second will be done at 56 days and the third will be done after the fire test. Through this test the results are used to compare the different mixtures to compare the effect the different amount of fibers have on the mixtures. For this research the test is done according to NEN-EN 12390-3 and R*atio TEC* RT 3000 2-D *servo* was used for the compressive strength test. The tests were carried out at Scalda on a concrete press bench which can be seen in figure 13.

After 28 day three cubes are tested in compression to be able to obtain an average. The cubes are first measured and weighed before being placed one at a time into the machine. Once in the machine the cube is centered, and the safety door is closed, and the machine turned on. The machine starts to apply pressure onto the cube, which increases until the cube fails, and the highest pressure is recorded. The cube is removed and looked over to make sure it has failed normally.

3.2.6 Tensile Strength Test

The tensile test is another way to determine the effect fibers have on the concrete. The method used is an indirect one as the machine used is a compression machine. The process is similar to that of the compression test, however once the cube is centered two narrow pieces of wood is placed in the center of the cube at the top and bottom of the cube. The safety door is then closed and the machine turned on, which then lowers and starts to apply pressure onto the sticks that act as tension points in the cube. Pressure is increased until the cube fails, once the cube has failed it is removed and inspected to ensure a normal failure occurred. For this research the test is done according to NEN-EN 12390-3 and R*atio TEC* RT 3000 2-D *servo* was used for the tension check. Figure 13 shows a tested cube and shows how the pieces of wood are placed.

Figure 13: Tensile Test B1p

3.2.7 Fire Resistance

For this test the hardened cubes were sent to a company called Efectis, who have specialized equipment such as a small fire furnace as seen in figure 14.

Figure 14: Fire Furnace

With in the furnace the hardened cubes will be subjected to a standard fire curve for 60 minutes. During the 60 minutes 1D heat penetration will be tested and results recoded to track how the materials transfer heat and to be compared. This is done by suspending the cubes at the top of the furnace and covering them with aerated concrete around the sides and rockwool on top to ensure no heat escapes around the cubes. The temperature inside the furnace is measured with four thermocouples which are averaged to find the temperature of the furnace. One thermocouple is placed on the top of each cube that is then used to compare with the average furnace temperature.

Another more physical property that will be tested is the physical degradation of the cubes. This is the deformation that occurs as the heat causes the materials to expand. For this the cubes will be measured before and after.

The compressive strength of the cubes will be tested after the exposer of the standard fire curve. The cubes will be tested at Scalda in the compressive concrete press bench, seen in figure 13 and the results recorded and compared.

3.3 Multi-Criteria Analysis (MCA)

A Multi-Criteria Analysis is a tool used to grade the different variables against chosen criteria. Each criteria is given a weight of importance which is then multiplied with the score each variable received in each of the criteria. The winning variant is decided by accumulating all the scores per variant from all the criteria, from this depending on the scoring system either the highest or the lowest overall score is the preferred variant.

3.3.1 Criteria

The main part of a MCA is the criteria that is set for the variants to be graded against. In this part of the report each criteria will be defined and assigned weights to their importance according to the main research question.

3.3.1.1 Fiber Content

The main goal of this research is to increase the amount of fibers with in the mixture as much as possible as it is supposed to be used as a replacement for the usual aggregates. The amount of natural fibers is calculated from the pre-treated fibers and is what is being considered for this criteria.

3.3.1.2 Fire Resistance

This test is another main interest for this research, since the focus of the research paper is on the results of the fire resistance test it will be in a similar weighing as the fiber content. Here two structural properties of the cubes will be looked at after being exposed to the standard fire curve for an hour.

3.3.1.2.1 Deformation & Strength

As the cubes will be exposed to high heats deformation is expected as the aggregates will expand increasing the size of the cubes. The cubes will then be weighed and tested for compression to get a understanding of how the boicrete will react when exposed to fire. For this criteria the results of the compression test will be used, the higher the strength the better.

3.3.1.2.2 Heat Penetration

During the fire test D1 heat penetration is tested too, here the variants will be tested to see how fast the heat transfers through the cube. Here the slower the heat is transferred through the cube the better. The lower the temperature is after the 60 minutes compared to the control variant the better the variant is.

3.3.1.3 Compressive Strength

According to the objectives from the client, the final variant needs to have a minimum of 2,5 MPa. This is the strength needed for an insolation brick, from this it is able to determine that the higher the strength the better the variant is.

3.3.1.4 Tensile Strength

With the addition of fibers to concrete, which have a high tensile strength it is assumed that the fibers would increase the tensile strength of the concrete too. Thus the higher the tensile strength the better for the final variant.

3.3.1.5 Cement Content

The amount of cement used in a construction point is nit as important however, from an environmental view the amount of cement is important. Thus using less cement where possible is necessary, but since the best method of pre-treatment for the fibers is with cement, the extra cement is taken into account and will be considering the total amount of cement in the variants. Which means the less cement with in a variant the better the score.

3.3.1.6 Workability

Workability refers to how easy the mixture is to work with, as well as how fluid the mixture is too. This is tested with the slump test, with a low workability having a slump of 2.5cm–5cm, medium workability being between 5cm–10cm and high workability between 10cm–17.5cm. The ideal workability would be in the medium range, this is because if a mixture is too workable there is a greater chance of segregation to occur. Which is the separation of materials, the larger aggregates will sink and the lighter material will float. (Slump Test, 2021)

3.3.2 Weight Factor and Score System

For the weighting for the criteria that was explained above, the pairwise comparison is used to identify the order of importance of the criteria and so the weighting for the criteria. Below is table 2 that shows how the criteria has been organized.

Table 2: Pairwise Analysis

	Criteria:	Fiber Content	Deformation & Strength	Heat Penetration	Compression Test	Tensile Test	Cement Content	Workability
1	Fiber Content	1	1	1	1	1	1	1
2	Deformation & Strength	1	2	2	2	2	2	2
3	Heat Penetration	1	2	3	3	3	3	3
4	Compression Test	1	2	3	4	4	4	4
5	Tensile Test	1	2	3	4	5	5	5
6	Cement Content	1	2	3	4	5	6	6
7	Workability	1	2	3	4	7	6	7
	Criteria:	1	2	3	4	5	6	7
	Count:	6	5	4	3	1	1	1
	Rank:	1st	2nd	3rd	4th	5th	5th	5th

The way the pairwise comparison was used is that each criteria was compared to the rest of the criteria. Of the two criteria being compared the one that is more important for the biocrete will win a point, which is done by placing the number of the criteria in the box and this is repeated for each criteria as seen in table 2. Once that is done the numbers are added together which can be seen in table 2 at the bottom in the "Count" row. The criteria with the highest count is ranked as the best and thus obtains a higher weighting which can be seen in table 3. Criteria with the same ranking obtain the same weighting.

Table 3: Criteria Weighting

weighting:	0.30	0.25	0.20	0.10	0.05	0.05	0.05

In the table above, table 3, the weighting is split between the criteria that has been ranked from 1st till 5th in table 2. The higher ranked criteria recieves the higher weighing which is determined by splitting 100% between the criteria. Starting witht the most important criteria for this report is the fibre content, which also received the highest ranking and thus obtains the highest weighting of 30% or 0.30. In second place is deformation and strength giving it a weighting of 25%, which is 0.25, third place is heat penetration and has a weighting of 20% equale to 0.20. Fourth ranked criteria is compression strength which has a weighting of 10%, equale to 0.10 and the last three criteria have an equale weighting of 5%, which is 0.05. The last three criteria are tensile strength, cement content and workability, they all ranked the same at 5th and so have the lowest weighting too.

Now that the weighting has been determined it is time to specify the scoring system. The weighting of each criteria is used to multiply with the score the mixtures obtain in each criteria. The score that is used is 1 to 3, where 1 is the lowest and 3 is the highest and best score for each criteria. Each mixture will be judged using the score sheet below in table 4.

Table 4: Score Sheet

		Score:		
Criteria:	**Weighting:**	**1**	**2**	**3**
Fiber Content	30%	x < 17%	17% < x < 20%	20% < x
Deformation & Strength	25%	x < 5MPa	5MPa < x < 15MPa	15Mpa < x
Heat Penetration	20%	x > 100°C	100°C > x > 90°C	x < 90°C
Compression Test	10%	x < 20MPa	20MPa < x < 25MPa	25MPa < x
Tensile Test	5%	x < 5MPA	5MPa < x < 8MPa	8MPa < x
Cement Content	5%	x > 14%	14% > x > 13%	x < 13%
Workability	5%	x < 5cm or x > 15cm	5cm < x < 7cm or 12cm < x < 15cm	7cm < x < 12cm

From table 4 each of the criteria is defined with a score of 1 till 3 and to gain a score the results of the tests run on each mixture is used. For the number one ranked criteria, fibre content, the percentage of the volume of natural fibres with in the mixture is calculated and used to gain a score from 1 till 3 where the higher the percentage gives the mixture a higher score.

The second criteria, deformation and strength, is scored by testing the cubes of each mixture under pressure and seeing how they compare after they have been placed in the furnace. The score is obtained by using the results of the compressive strength, where the more force the cube/mixture can take the higher the score will be.

For the third criteria, heat penetration, the score is determined by how well the cubes/mixtures stop the temperature from transferring through it. This is tested be measuring the temperature difference on each cube/mixture by recording the temperatures inside the furnace and on the outside of the cube. The cube/mixture with a lower temperature on the outside gains a higher score.

The fourth criteria, compression strength, each cube/mixture is compressed to see how much force it can take. The higher the force the cube/mixture can take the higher the score will be.

For the fifth criteria, tensile strength, the same concept as above applies where each cube/mixture is tested to see how much force they can resist and the higher the force the higher the score.

The second last criteria, cement content, is scored by calculating the percentage of volume of cement that is used with in the whole mixture. The mixture that has the lowest percentage receives the better score.

The seventh and last criteria, workability, is scored by using the results of the slump test which is determined by measuring the distance the mixture drops as the mold is removed from the wet mixture. If the drop/slump is not in between the ideal length for the best score then if will either be to much of a slump which is below 7cm or the slump is above 12cm for a lower score.

4 Results

In this section all the results from the different tests will be shown and explained for each of the different mixtures/variants. From each result a conclusion will be reached which explains what was seen and what is recommended during and after the test.

4.1 Sieve Analysis

The results of the sieve analysis were graded according to NEN-EN 933-2 for gravel and NEN-EN 12620 for sand. The results are used to plot a line graph which can be seen below in figure 15. The optimum mix of sand and gravel is obtained as long as the combined line (red) stays between the upper (yellow) and lower (grey) boundary lines, which is seen in the graph below.

A uniform distribution of the material combined, the red graph (Sand + Gravel), which

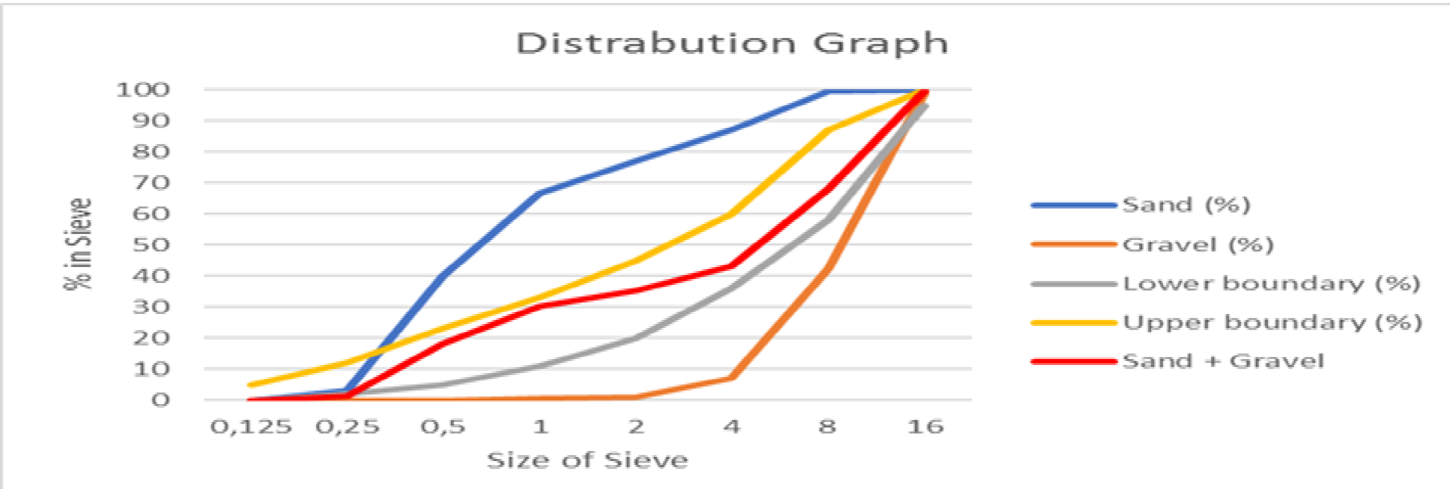

Figure 15: Distribution Graph

stays in between the yellow graph (Upper boundary) and the grey graph (Lower boundary) is needed to ensure a good distribution of the aggregates, which is achieved as seen in figure 15.

4.2 Pre-Treatment

In this section the results of the pre-treated fibers will be shown and explained. Below in table 5 each batch is numbered in the first column, with a total of 17 batches. The second column shows the amount of fibers in grams used for each batch, which was 500g for each batches. The third column shows the total weight in grams of the dried/hardened batches, this total weight is the combined weight of the fibers and the cement that has hardened onto the fibers after letting the batches dry for 7 days. The last column shows the weight of the cement in grams, which is achieved by using the equation shown below.

$$Cement\ (g) = Total\ Weight\ (g) - Fibres\ (g)$$

Table 5: Pre-Treatment Results

Cement Pre-Treatment of Miscanthus Fibres			
Batch Number	Fibres (g)	Total (g)	Amount of Cement (g)
1	500	1619	1119
2	500	1616	1116
3	500	1739	1239
4	500	1865	1365
5	500	1709	1209
6	500	1918	1418
7	500	2266	1766
8	500	2168	1668
9	500	2335	1835
10	500	2046	1546
11	500	2127	1627
12	500	1521	1021
13	500	1542	1042
14	500	1511	1011
15	500	1514	1014
16	500	1319	819
17	500	1618	1118
Average		**1790.176471**	**1290.176471**

Fibres:Cement Ratio	**0.388**
Fibres:Total Weight Ratio	**0.279**

From the results of table 5, the average weights from the total weight and the amount of cement is calculated. This is done by summing up each column and dividing the total by the total number of batches (17). The averages are then used to calculate the ratios of fibres to cement (0.388:1) and fibres to total weight (0.279:1). To obtain these ratios the equation used is shown below.

$$Ratio = \frac{Fibers\ (g)}{Average\ (g)}$$

The ratio of Fibres to Total Weight is used to calculate the amount of natural un-treated fibres that is found with in the mixtures and the amount of extra cement that is added to the mixtures through the pre-treatment can be calculated and seen in table 6.

The formulas used are as follows:

$$UnTreated\ (g) = PreTreated(g) * \ Ratio\ of\ Fibers{:}Total\ (0.279)$$

The amount of cement that is added is then calculated by subtracting the amount of un – treated fibres from the amount that was pre – treated.

$$Cement\ (g) = PreTreated\ (g) - UnTreated\ (g)$$

The results of these calculation can be seen in table 6 for each mixture.

Table 6: Amount of Materials (kg)

Pre-Treated Fibers with in Mixtures			
Mixture:	**Pre-Treated Fibers: (kg)**	**Cement: (kg)**	**Un-Treated Fibers: (kg)**
B1p	5.6	4.036	1.564
B2p	6.6	4.757	1.843
B3p	7.6	5.477	2.123

From table 6 it was made clear that with each kilogram of pre – treated fibres added there will be an extra 0.28kg of un – treated fibres, as well as 0.72kg of Cement. This is important to know as cement is a large cause of co2 emissions, thus if more cement is used is the biocrete still eco-friendly, this is being researched further by the CoEBBE. From the results it is clear that further research is needed to understand whether the amount of cement used is still feasible for biocrete, however the pre – treatment is successful and for the mixtures a pattern can be seen for each kilogram added.

4.3 The Mixtures

The final three mix designs are shown and explained below in the following tables 7, 8 and 9. Each of these mixtures are designed according to the control mixture CBp from table 1 where the Sand, Gravel and water amounts stay the same. The differences between the mixtures comes from the adding of the pre – treated fibres where the first mixture B1p starts with 5.6kg and is increased per mixture by 1kg, making mixture B2p with 6.6kg and mixture B3p with 7.6kg.

From the results of the pre – treated fibres it is known that extra cement, as well as the un – treated fibres are being added to the mixture. This is why the pre – treated fibres is divided into cement and fibres, which are un – treated. This causes the amount of cement to change per mixture, as well as the total volume which can be seen in the following tables 7, 8 and 9.

Table 7: Mixture B1p

Mixture B1P				
Mass [kg]				**Volume [m^3]**
Sand	32.076			0.01215
Gravel	44.93			0.01701893939
Cement	20.755			0.00669516129
Water	12.736			0.012736
Pre-Treated Fibres	5.6	Cement	4.036	0.001301905932
		Fibres	1.564	0.009775572569
Plasticiser	0			0
			TOTAL	**0.05967757919**
Volume of Total Cement in Percentage				**13.40%**
Volume of Fibres in Percentage				**16.38%**

Table 8: Mixture B2p

Mixture B2P				
Mass [kg]				**Volume [m^3]**
Sand	32.076			0.01215
Gravel	44.93			0.01701893939
Cement	20.755			0.00669516129
Water	12.736			0.012736
Pre-Treated Fibres	6.6	Cement	4.757	0.001534389134
		Fibres	1.843	0.01152121053
Plasticiser	0			0
			TOTAL	**0.06165570035**
Volume of Total Cement in Percentage				**13.35%**
Volume of Fibres in Percentage				**18.69%**

In each of the tables 7, 8 and 9, the total volume of cement is shown in percentage, which is the 20.755kg from the control mixture CBp plus the cement from the pre – treated fibres. The volume of un – treated fibres is also calculated and shown in each of the tables 7, 8 and 9. As more pre – treated fibres are added per mixture the percentage of un – treated fibres increases too. Mixture B1p has 16.38%, mixture B2p has 18.69% and the last mixture B3p has 20.85% of un – treated fibres.

One of the objectives was to reach a fibre volume percentage of 27% or more. This was not possible with the time available, however CoEBBE with the help of Vibers will keep researching and testing new mixtures with even more pre – treated fibres added until the 27% mark is reached or the research concludes.

Table 9: Mixture B3p

Mixture B3P				
Mass [kg]				Volume [m^3]
Sand	32.076			0.01215
Gravel	44.93			0.01701893939
Cement	20.755			0.00669516129
Water	12.736			0.012736
Pre-Treated Fibres	7.6	Cement	5.477	0.001766872336
		Fibres	2.123	0.01326684849
Plasticiser	0			0
			TOTAL	**0.06363382151**
Volume of Total Cement in Percentage				**13.30%**
Volume of Fibres in Percentage				**20.85%**

4.4 Fresh Density Test

The fresh density is obtained through using the following formula:

$$D = \frac{(m2 - m1)}{V}$$

D – Density (kg/m3)

m2 – Weight of filled container (kg)

m1 – Weight of empty container (kg)

V – Volume of biocrete (m3)

This test is done to check whether the fibers that have been added have any effect on the density of the mixture. Table 10 shows the results from the test for each of the mixtures. For conventional concrete we designed a control mixture which had a density of 2243.25kg/m³ and will be used to compare the new mixtures with. Table 10 shows that the density decreases as more fibers are added. However, mixture B2p does not fit into this pattern, but is still below the density of the control mix.

Table 10: Fresh Density Results

Fresh Density Test [kg/m^3]	
Control Mixture	2243.25
Mix B1P	1999.3125
Mix B2P	2022.75
Mix B3P	1889.75

The results therefore prove that adding fibers to the mixture does indeed decrease the density, meaning that the biocrete will be lighter than conventional concrete.

4.5 Slump Test

From the slump test the workability is tested and the water to cement ratio will be look at in this section. It is important to have a workable mixture as it allows the cement mixture to flow into any mold and ensure that the mixture is well mixed/homogeneous through out.

Table 11: Slump Results

Slump Test [mm]	
Control Mixture	Collapsed
Mix B1P	160
Mix B2P	160
Mix B3P	115

The results of the slump test can be seen in table 11, from these results it is clear that the workability of the mixtures are very high. The control mixture CBp, the test failed, this means that the mixture was very liquid, however does not mean that the mixture is bad. The ideal slump is around 80mm give or take 20mm. Looking at the next two mixtures B1p and B2p the slump test is double that of the slump that is wanted. This shows that the mixture is still quite fluid and workable. The last mixture B3p has decreased in its workability, but still has a high workability with a slump of 115mm.

Seeing as the workability is still high it means more fibers/material can be add to the same mixture to decrease the slump and in turn increasing the volume of un – treated fibers with in the mixture.

Table 12: Water: Cement Ratio

Water/Cement Ratio	
Control Mixture	0.511
Mixture B1P	0.514
Mixture B2P	0.499
Mixture B3P	0.486

For the water to cement (w:c) ratio it is important to keep in mind that it is an important part of the mixture design. This is because the ratio explains the amount of water in grams needed depending on the amount of cement used. The minimum ratio needed to ensure cement is completely hydrate is around 0.38. This means that there is enough water to react with all the cement with in the mixture.

Table 12 shows the w:c rations of each mixture. To start with the control mixture with a ration of 0.511 is used as that is the recommended ratio for strong structural concrete. From there it can be seen in table 12 that the ratio decreases, meaning there is less water with in each mixture. This is because of the pre – treated fibers that are add, which adds more cement, changing the ratio.

Looking at mixture B3p with a ratio of 0.486 also proves that more fibers can be add until the minimum ratio is reached or that there is no more slump.

4.6 Air Content Test

Table 13 shows the results of the air content with in each mixture. The air content represents the voids present with in a mixture.

The air content of conventional concrete is around 2.0%, which is similar to the result of the control mixture seen in table 13 with a result of 2.5%. The air content quickly increases to 8.0% once the fibers were added in mixture B1p. Mixture B2p has a air content of 7.7% which is slightly less than mixture B1p however is still significantly higher than that of the control mixture. The last mixture B3p has an even higher air content of 10.0%.

Table 13: Air Content Results

Air Content [%]	
Control Sample	2.5%
Mix B1P	8.0%
Mix B2P	7.7%
Mix B3P	10.0%

These results show that when fibers are added, more voids are immediately present. In turn this correlates to the results of the fresh density test. When more fibers are added the lighter the mixture become as there are also more voids present.

4.7 Compression Test at 28 Days

Here the results of the compression test can be seen in table 14. In column one the names of the mixtures can be seen, four mixtures in total. From there the second to fourth columns are numbered #1 till #3, which are the three cubes that have been tested. Beneath each number are the results of each cube per mixture. The last column is where the average compression test is calculated with the following formula.

$$Average = \frac{(\#1+\#2+\#3)}{3}$$

Table 14: Compression Test Results

	Compression Strtength (kN)			
	#1	#2	#3	AVRG
Control Mixture	1008,7	1029,677	992,322	1010,233
Mixture B1P	642,431	575,315	579,294	599,0133333
Mixture B2P	600,477	566,118	550,928	572,5076667
Mixture B3P	372,159	364,771	387,815	374,915

From the averages of each mixture a line graph is used to show how the strength of the cubes decreases as the amount of fibres is increased as seen in figure 16.

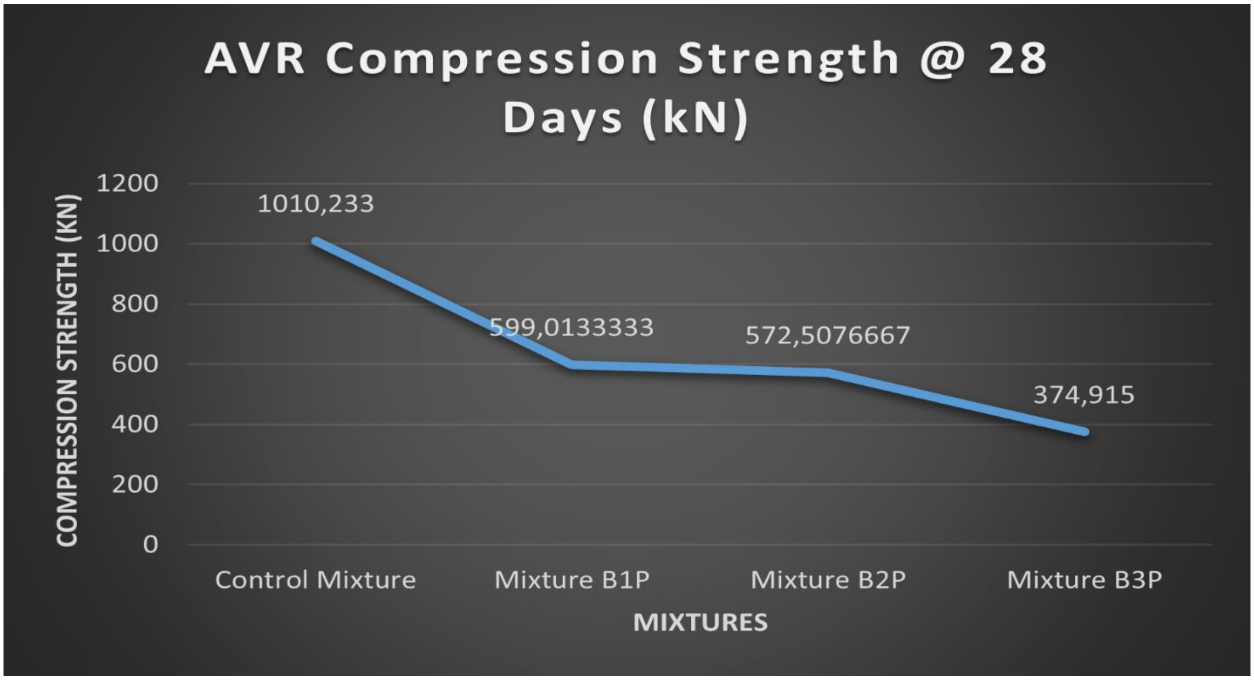

Figure 16: Line Graph of Compression Results

From the graph in figure 16 it can be seen that the control mixture which is the most conventional form of concrete has the highest strength which is above 1000Kn which is approximately equal to 44Mpa. There after is mixture B1p, with 16% of fibres, having around 600Kn which is approximately equal to 26Mpa of strength. Mixture B2p, with 18% of fibres, has a strength of 570Kn which is approximately equal to 25Mpa which is similar to mixture B1p. the last mixture, mixture B3p, has 20% of fibres and has a strength of 370Kn which is approximately equal to 16Mpa.

From the results it is clear that the objective to obtain a biocrete that has a compression strength of more than 2.5Mpa which is achieved. Further research and tests will be done on biocrete with higher percentages of fibres as the results prove that more can be added.

4.8 Compression Test at 56 Days

In this section the strength of the mixtures at 56 days is considered as concrete continues to get stronger over time. The same machine is used as the one used for the compression of the cubes at 28 days. The results of the test can be seen in table 15, two cubes were tested from each mixture and the average of these two cubes were calculated using the formula below.

$$Average = \frac{(\#1 + \#2)}{2}$$

Table 15: Compression Strength at 56 Days

Compression Strength @ 56 days (kN)		
#1	#2	AVRG
1025,492	1114,566	1070,029
726,287	688,053	707,17
599,754	606,987	603,3705
391,586	368,904	380,245

From the results a graph is made to better understand the results, which can be seen in figure 17.

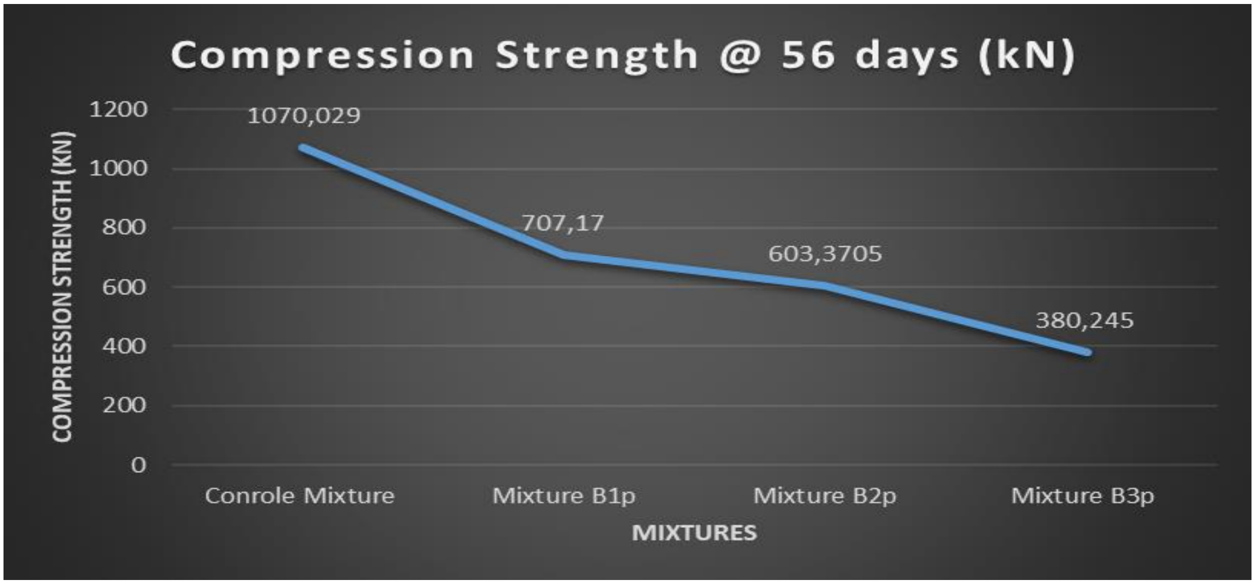

Figure 17: Compression Strength at 56 Days

When looking back at the compression strength at 28 days in figure 16 compared to the strength at 56 days in figure 17 there is a clear increase of strength over time. This is better illustrated in figure 18 where the graphs are combined.

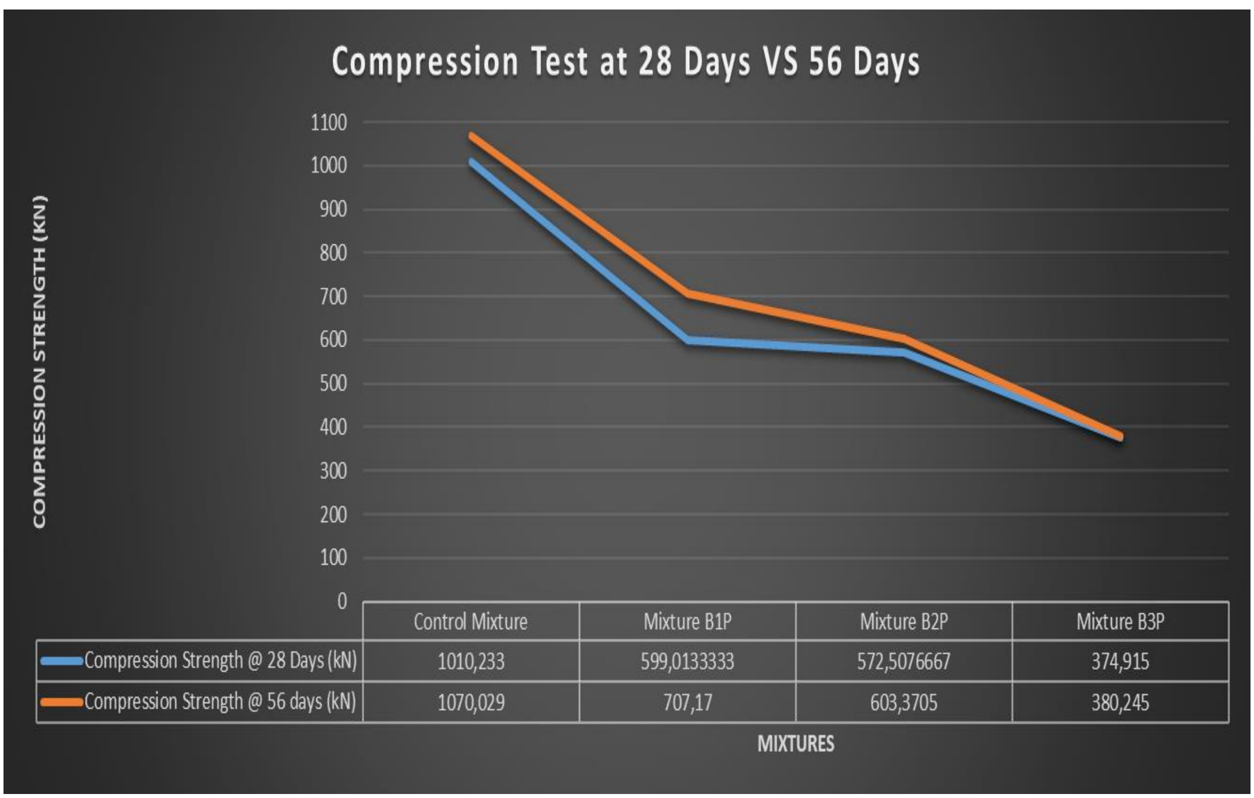

Figure 18: Compression Strength at 28 Days VS 56 Days

In figure 18 it can be seen that the strength of the concrete increases however, once fibres are added the increase of strength over time is less. Also when looking at mixture B3p, the mixture with the most fibres, the strength has barely increased.

From the results it can be concluded that biocrete increases its strength a lot slower than conventional concrete. This is because the bonds between the fibres and cement are not as strong and there is also a higher air content meaning there are more air voids which makes it easier for cracks to form.

4.9 Tensile Test at 28 Days

Below in table 16 displays the results of the indirect tensile test that has been conducted. The first column shows the names of the mixtures that have been tested, being a total of four mixtures. Each mixture has two cubes that has been tested and the results are found in column two and three. The last column shows the average of the tests for each mixture. The average is calculated using the following formula.

$$Average = \frac{(\#1+\#2)}{2}$$

With table 16 a line graph can be plotted to make the results easier to see and read, which can be seen in figure 19.

Table 16: Tensile Test Results

	Tensile Strength [kN]		
	#1	#2	AVRG
Control Mixture	98,684	132,52	115,602
Mixture B1P	72,076	115,27	93,673
Mixture B2P	138,262	102,353	120,3075
Mixture B3P	233,226	233,123	233,1745

From the graph in figure 19 it shows the averages of the testes per mixture, the first mixture being the control mixture. This mixture is the base line of the research as it represents the

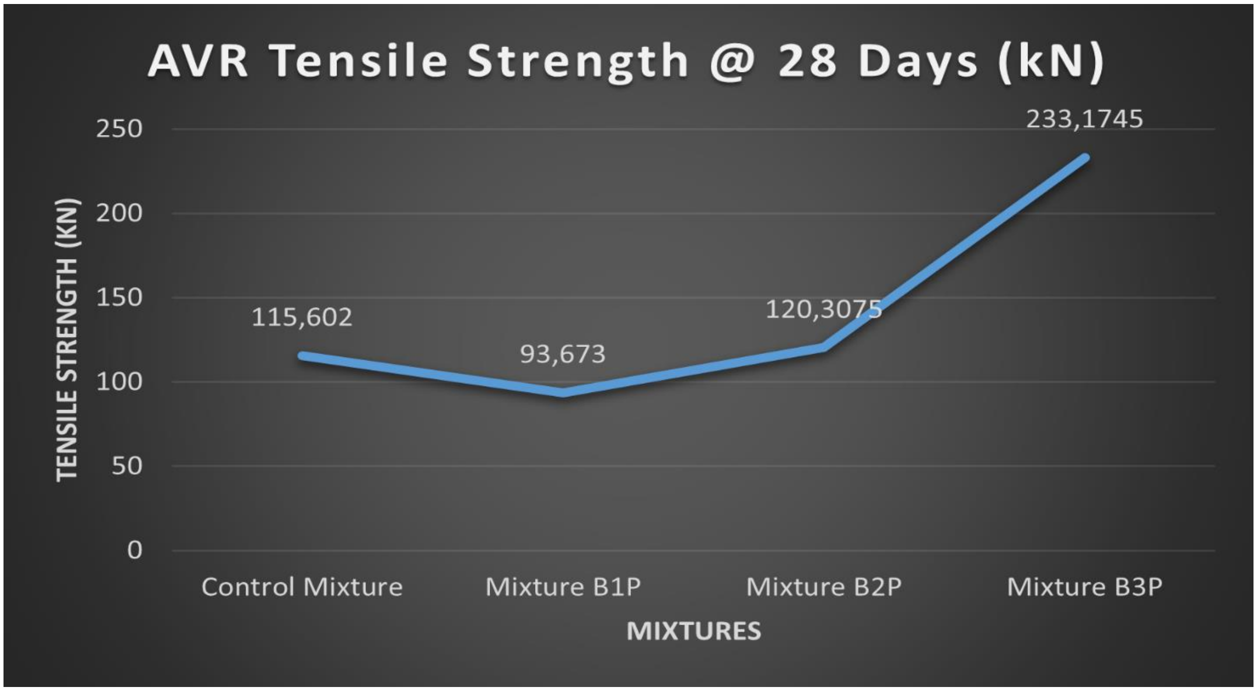

Figure 19: Tensile Test Results

conventional concrete that is used around the world today. The results of the control mixture is around 115Kn which is approximately equal to 5Mpa, once some fibres have been added to the mixture, such as mixture B1p, the tensile strength decreases to around 90Kn which is approximately equal to 4Mpa. However, as more fibres are added such as in mixture B2p the tensile strength increases to 120Kn which is approximately equal to 5Mpa. As seen in figure 19 with another kilogram of fibres added for mixture B3p, the tensile strength increases to 233Kn which is approximately equal to 10Mpa.

From the results it can be concluded that as more fibres are added the tensile strength increase too, this is because the fibres spread throughout the concrete stopping cracks from forming and keeping the concrete together.

4.10 Fire Test

This fire test was outsourced to a credited source company called Efectis, who run fire testes on all sorts of objects from fire doors to already existing tunnel walls. The test was done on two cubes from each mixture resulting in eight cubes being tested. Figure 20 and 21 shows how the cubes where tested, top and bottom view.

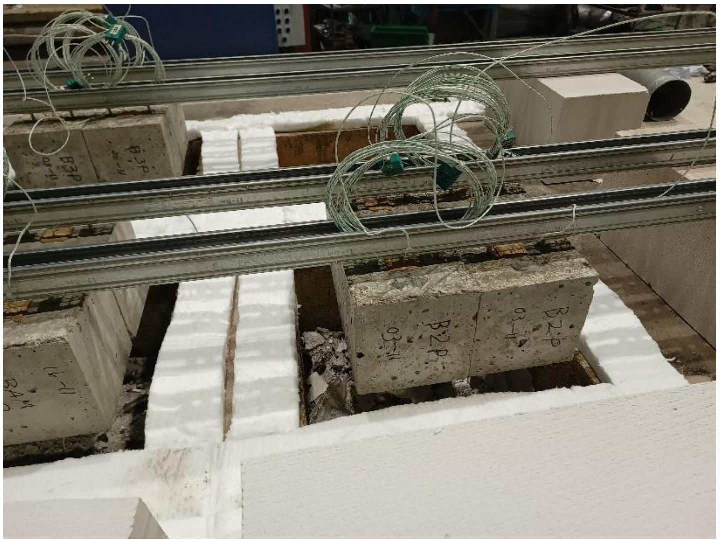

Figure 20: Top view of Cubes

Figure 21: Bottom view of Cubes

4.10.1 Heat Transfer

First part of the test was done to see how the heat of a standard fire would penetrate through the cubes of 15cm thick. The results of the test where plotted into graphs to have a clearer image of the outcome, which makes it easier to understand.

In figure 22 it shows four line graphs which represent the four thermocouples which were used to record the temperature inside the furnace during the test. They were used to calculate the average temperature inside the furnace, which was under constant surveillance to ensure the temperature stayed on the wanted standard fire curve as the test was carried out.

In figure 23 it shows eight lines, one for each cube. Each line shows the results of the temperature on the unexposed side of each cube. These lines will be compared to the control mixture which is labelled as T cbp 1 & 2.

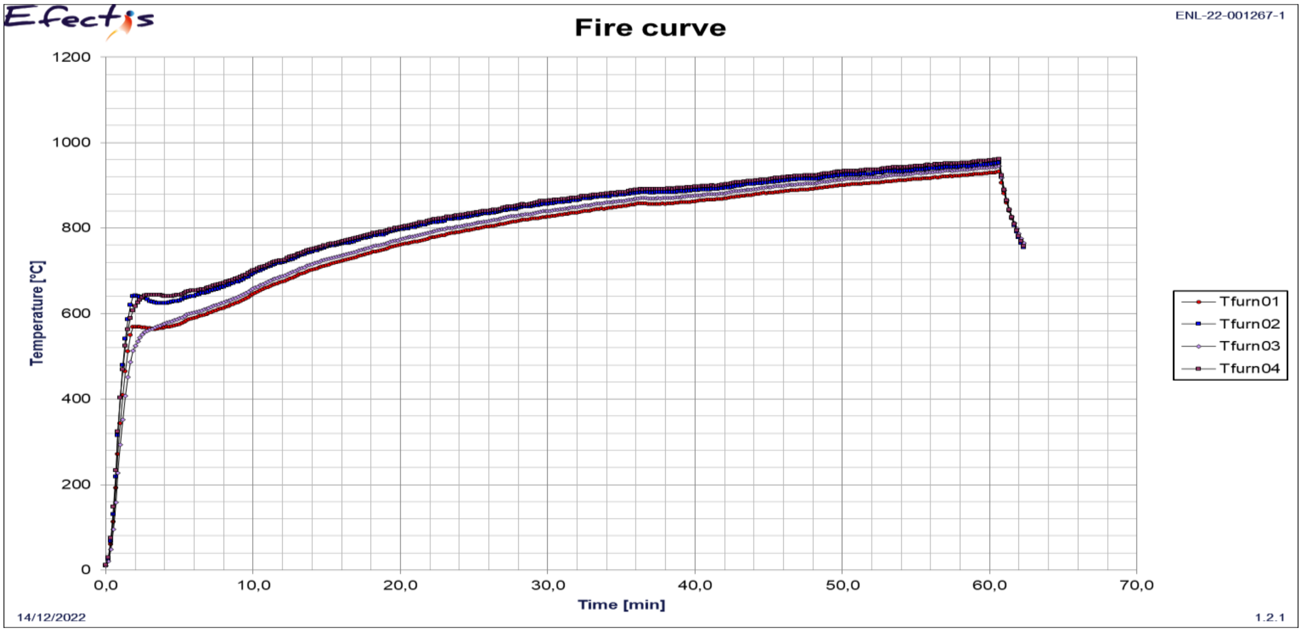

Figure 22: Furnace Temperature

From figure 22 it can be seen that at the start of the test for about two minutes the temperature was unstable as the furnace had to warm up and then adjusted to fit the standard fire curve.

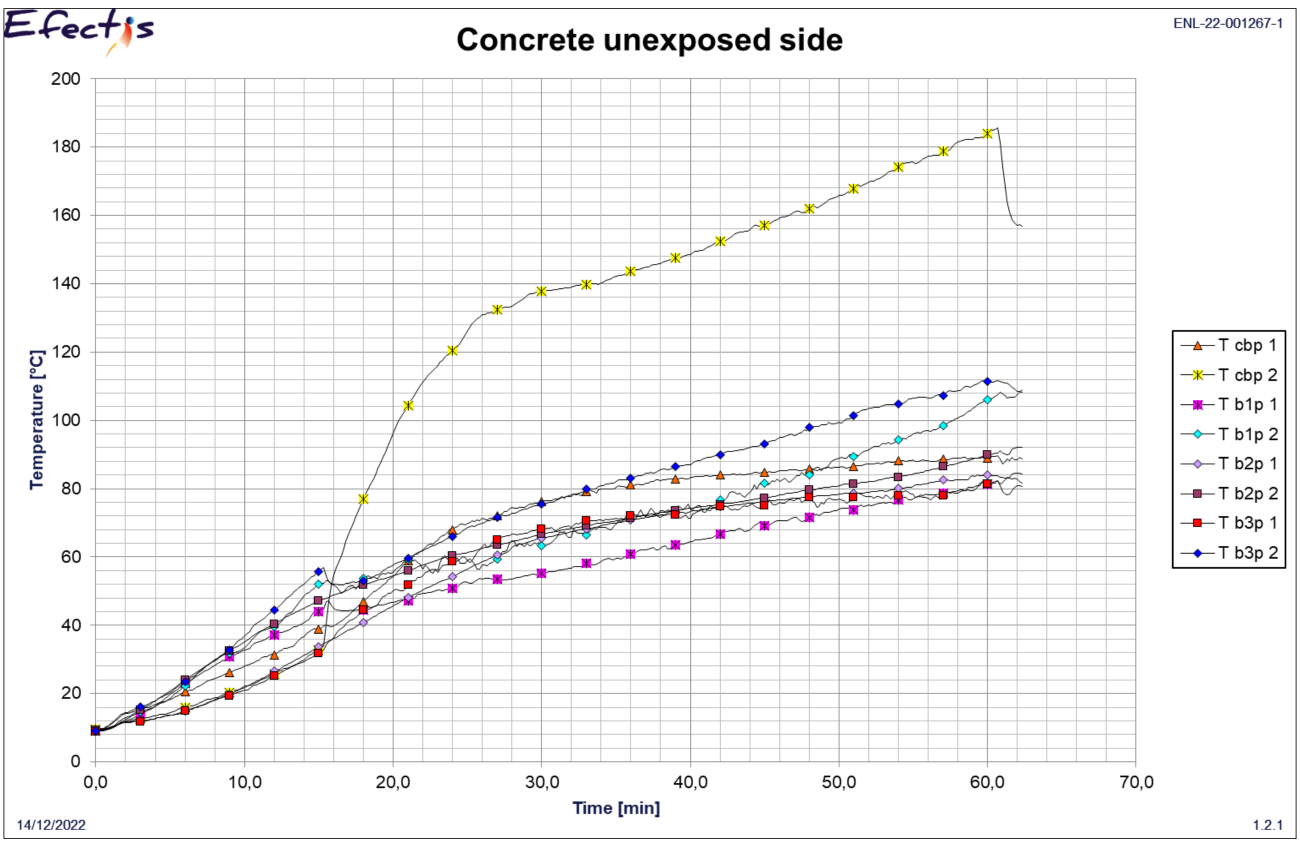

Figure 23: Unexposed Side Temperature

In figure 23 each line represents a cube that has been tested under the same conditions however, it is noticeable that each cube did not react the same way. The first result that stands out is the graph in yellow which represents the control mix, cube 2 labelled as T cbp 2, this result is not considered as the outcome deviates a lot from the rest of the graphs.

Looking further into the graph the control mix, cube 1, is identified as the line graph with orange triangles as markers and labelled as T cbp 1. This line represents conventional concrete and is used to compare the other mixtures with fibres to it. T cbp 1, shows a smooth curve which coincides with the standard fire curve however, the cubes temperature is significantly lower than that of the furnace. T cbp 1 climbed slowly for 30 minutes where it reached 75°C, after that it plateaued and reached a highest temperature of 90°C on the unexposed side in 60 minutes.

From the results above a new graph was produced where each cube of the same mixture was added and divided to find the average performance of each mixture compared to the one control mix, Tcbp 1. The graph can be seen in figure 24.

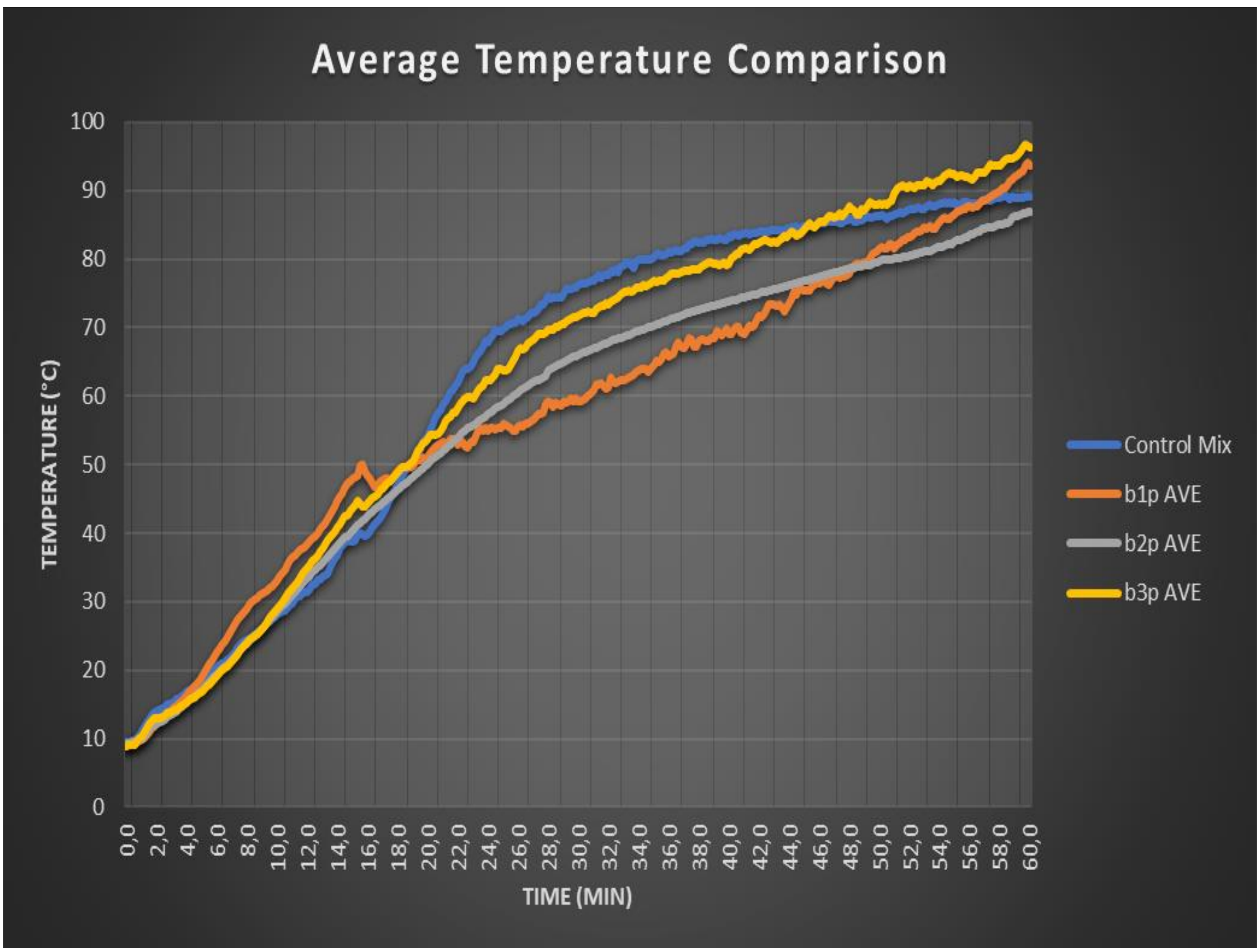

Figure 24: Average Results of Fire Test

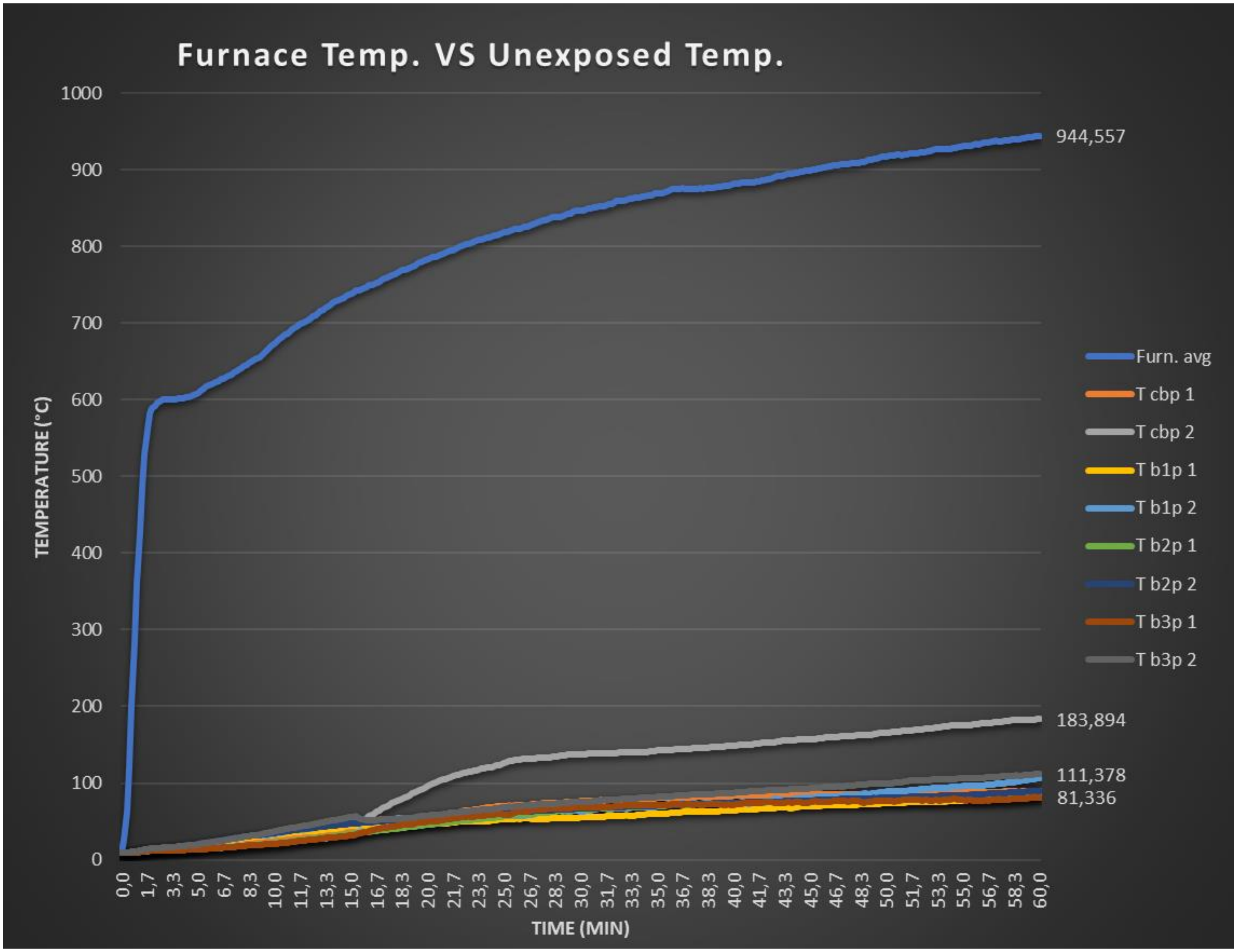

Figure 25: Furnace Temp. VS Untreated Side Temp.

From figure 24 it can be seen that at the start of the test all mixtures behaved similar in the way that the rate of temperature increased is stable till about 20 minutes into the test. At 20 minutes into the test the difference in temperature is 5°C, from 50°C - 55°C for all four mixtures, where the furnace temperature is at 783°C.

From 20 – 45 minutes into the test each mixture takes an individual line, which shows a correlation with the amount of fibres present in each mixture. As more fibres are added to the mixture the more heat is transferred through the cube however, they are all lower than the control mix. When looking at the middle of the time interval, which is at 32 minutes the furnace temperature is at 859°C, the pattern between the mixtures can be seen. Starting with the control mix (blue) with the highest temperature at 78°C, shows that conventional concrete allows heat to transfer faster and in a shorter time than that of concrete with fibres. Second is b3p (yellow) at a temperature of 74°C and has the highest percentage of fibres with in the mixture, 20%. There after is b2p (grey) at a temperature of 68°C, which has 18% of fibres present with in the mixture and lastly is b1p (orange) with a temperature of 62°C, as well as having the lowest fibre content of 16%. This shows that biocrete does not allow heat to travel as fast as conventional concrete from one side of the cube to the other.

For the last 15 minutes of the test the graph in figure 24 shows that the cubes with elephant grass fibres continues to increase at a steady rate. When looking at the end of the test at 60 minutes, the furnace temperature reaches a maximum of 945°C where as on the unexposed side of the cubes none of them passed 100°C. Starting with b3p (yellow) at the top with 96°C, also having the most fibre content with in the mixture at 20%. Next is b1p (orange) with 93°C, the mixture with the least amount of fibres being 16%, both of these two mixtures show a steady rate in temperature increase at 60 minutes. Where both mixtures ended above the control mixture (blue), which is at 89°C, the control mixture decreases its rate of temperature increase. This can be seen in figure 24 at approximately 40 minutes into the test the increase of temperature was not as fast as what it was before. The last 20 minutes of the test the temperature increased by 6°C compared to the 20 minutes before where the temperature difference was 29°C. Lastly is mixture b2p (grey) which had the lowest temperature at the end of the test at 60 minutes with a temperature of 87°C with a fibre content of 18%. However, similar to that of the other two mixtures with fibres the rate of temperature increase stays constant. This means that conventional concrete will take a longer time to allow high temperatures to transfer through it compared to biocrete with elephant grass fibres, which will allow a faster transfer of high heats through the biocrete.

Figure 25 shows the difference between the furnace temperature and the temperature 15cm away, on the untreated side of the cube. As mentioned before T CBp 2 will not be considered as there was a fault with the test.

From the results and the explanation above it can be concluded that concrete with elephant grass fibres present have a steady rate of temperature transfer. The more fibres present means more heat is able to pass through and if the heat stays constant and high, biocrete is more likely to allow the heat to continuously pass through. Where as conventional concrete would decrease its rate of heat transfer. From figure 25 it can be concluded that all mixtures that with elephant grass as well as the conventional concrete will not burn with in 60 minutes of a fire and stop the heat transfer well as the averages in figure 24 show that the mixture don’t pass 100°C while the furnace is above 900°C.

4.10.2 Degradation and Strength

In this part of the report first the shape and structure is considered there after the compression strength of the cubes after the fire test will be considered.

From figures 26 and 27 it is seen that the fire had a different reaction between conventional concrete compared to the biocrete. This can be see in figure 26, which is the control mixture. In figure 26 it can be seen how the cube crumbles and breaks after reaching a compression strength that causes the cube to fail. Compared to figure 27 where the cubes are made with the biocrete. These cubes stayed together after being compressed, the cubes are more sturdy after reaching its maximum strength which caused the cube to fail.

Figure 26: CBp Compressed After Fire

This result shows that the biocrete is better in and after a fire as the fibres help hold the cube together, causing a slower failure compared to conventional concrete which disintegrates into dust with any extra force.

Figure 27: B2p Compressed After Fire

Next the cubes where split down the centre to be able to see how the fire affected the centre of the cubes. This can be seen in figure 28 and 29, where figure 28 is the control mixture representing conventional concrete and figure 29 show the cubes made with biocrete.

In figure 28 there is a clear colour change with in the cube, where the colour goes from darker grey on the outside, the side that was heated, compared to the centre and untreated side, which is a lighter grey. The colour change is because of the fire and its high temperatures that has dried the treated side of the cube, causing it to start to crack and break apart.

Figure 28: CBp Split

Where as figure 29 shows the split cube of the biocrete, there it can be seen that the colour change is also present. However, the colour change extends to the centre of the cube, which can be seen in figure 29. The colour of the cube inside is darker

Figure 29: B1p Split

on the treated side and towards the centre, but then lightens up again as one moves towards the untreated side of the cube. This again shows how the high temperatures of the furnace dry out the treated side and start to move inwards. This also proves that the fibres of the biocrete help spread the heat evenly through the cube and not keep the heat of the treated side until a sudden failure occurs as it would with conventional concrete. When taking a closer look at the biocrete it can be seen that on the treated side some fibres started to burn inside of the cube, which may cause a problem after 60 minutes in a fire, further studies and tests need to be taken to better understand what would happen after.

Next the results of the compression strength of the cubes will be tested and discussed. Below in table 17 are the results of the mixtures compressive strength after the fire test.

Table 17: Results of Compression Test After Fire

	Compression Strength After Fire Test (kN)		
	#1	#2	AVRG
Control Mixture	644,1	718,7	681,4
Mixture B1P	360,9	342,66	351,78
Mixture B2P	296,1	358,93	327,515
Mixture B3P	247,69	173,96	210,825

In table 17 it can be seen that two cubes of each mixture was tested and recorded with in columns two and three labelled with #1 and #2 respectively. In column one are the different mixtures starting with the control mixture there after each mixture increases in fibre content. From B1p having 16% of fibres with in the mixture, next B2p has 18% and B3p has 20% of fibre content. The fourth column shows the average strength of each mixture, these results are plotted into a graph to help better understand the outcome of the results.

Figure 30 is a line graph that shows the average compressive strength of each mixture. When looking at the graph a clear trend is present which is a decrease in strength as more fibres are added to the mixture. However, the strength of the biocrete after a fire is still higher than 2.5MPA which was one of the objectives for the biocrete to obtain to be a able to use for internal walls.

When taking a further look into the results in figure 30 it is noticeable that the control mixture has the highest strength at 681.4kN which is approximately equal to 30MPa. Next would be Mixture B1p with 16% of fibres present in the mixture, the strength once fibres are added decreases to almost half of that of the control mixture at 351.8kN which is approximately equal to 16MPa. Mixture B2p, which had 18% of fibres is similar to that of B1p, B2p is slightly less at an average of 327.5kN which is approximately equal to 14MPa. There after is the lowest strength from B3p at 210.8kN which is approximately equal to 10MPA, which is still significantly larger than the minimum of 2.5MPa.

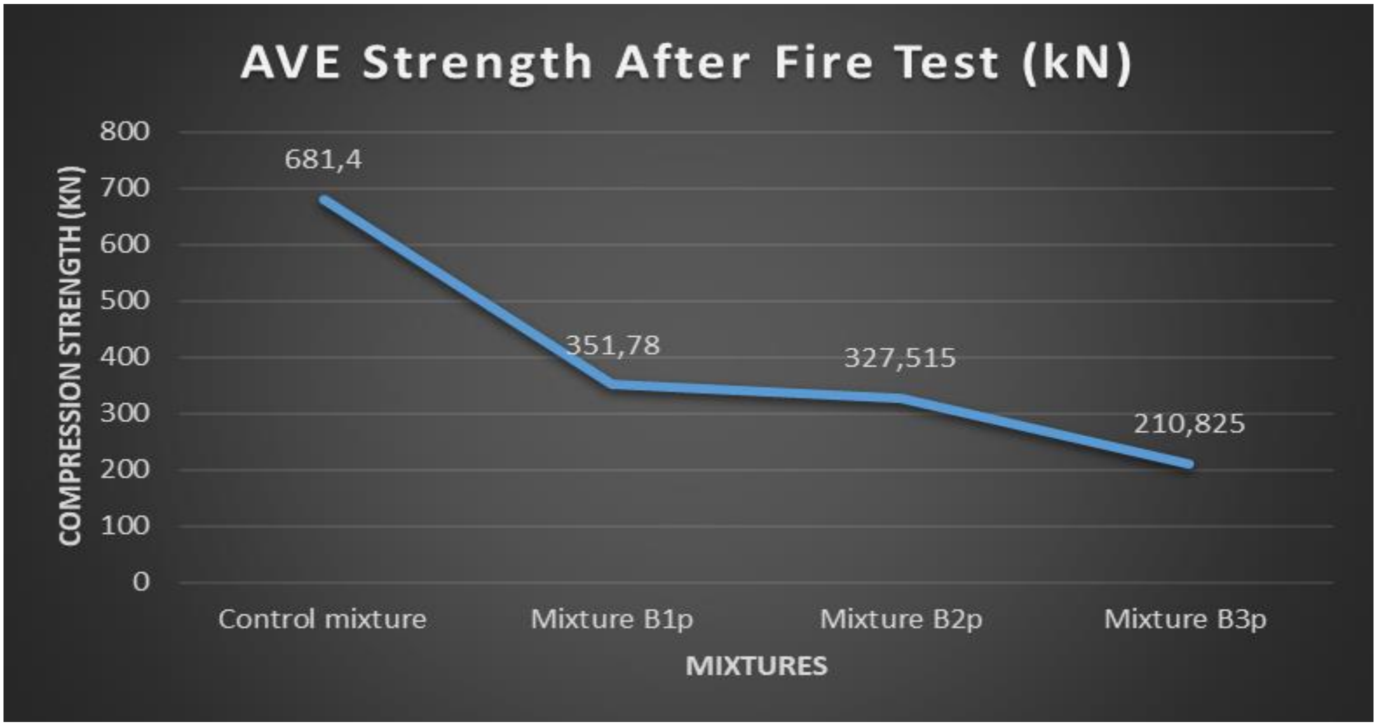

Figure 31: Average Compression Strength After Fire

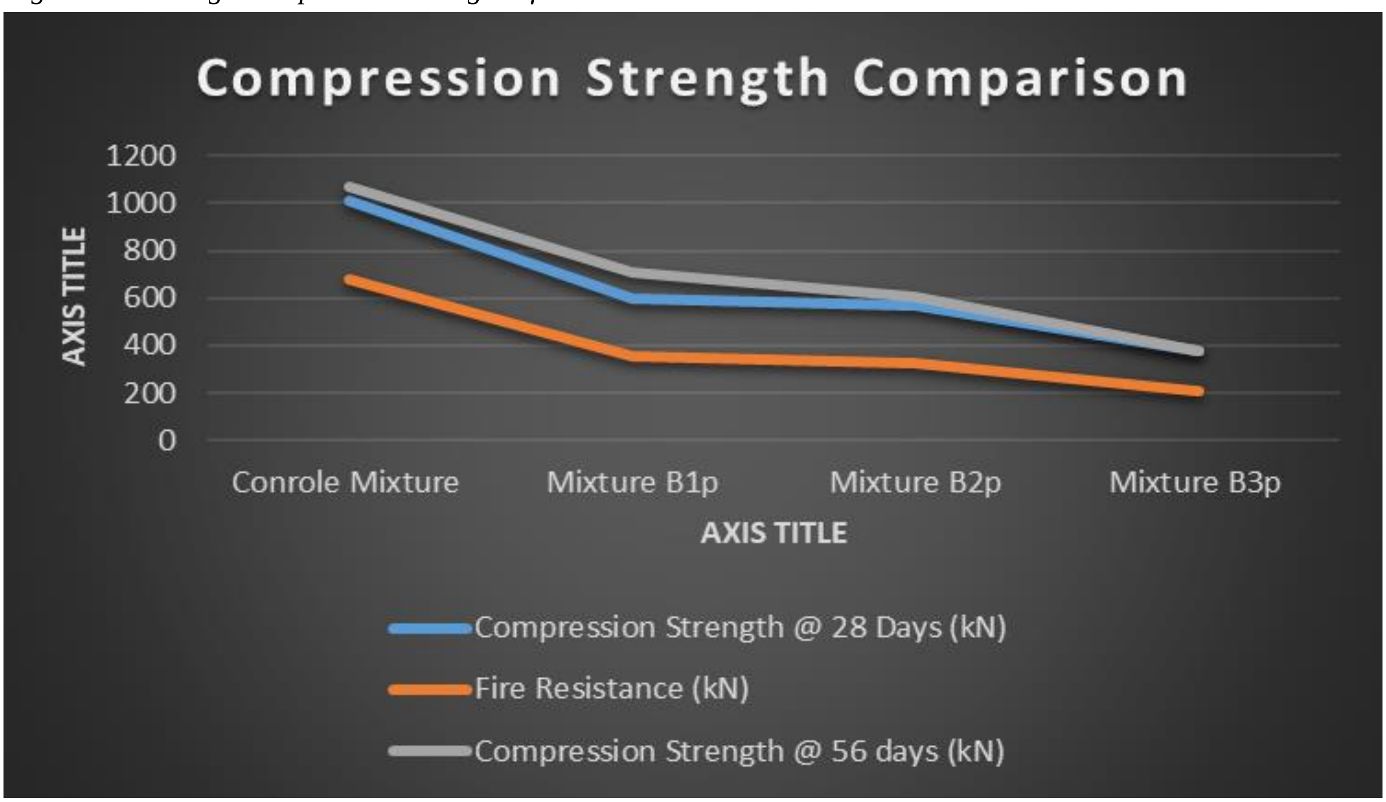

Figure 30: Average Compression Strength After Fire

Figure 31 shows all the average compression strengths of the mixtures for each of the tests run. The top line (grey) represents the strength of the mixtures after 56 days of hardening, underneath that line is the strength of the mixtures after 28 days of hardening (blue) and lastly is the strength of the mixtures after a standard fire for 60 minutes.

From figure 30 and the explanation there of it can be concluded that there is still room for more fibres with in a mixture as the mixture B3p with 20% of fibres is four times as strong as the minimum strength needed for an inner wall. This also proves that fibres are a good replacement for the conventional aggregates of sand and gravel.

4.11 Multicriteria Analysis

In this section of the report the score sheet seen in table 4 is used to compare and grade each mixture to the same standards. Each result of each test is plotted against the score sheet by seeing which score it falls under, either being 1, 2 or 3. Once the score is found that number being 1 for a low or bad outcome till 3 for a good result, is multiplied by the weighting of the criteria which was determined using the Pairwise process. The results of each test is added together per mixture to obtain the total score for the mixtures, which can be seen at the bottom of table 18.

Table 18: Results of MCA

		Score:			Results:			
Criteria:	**Weighting:**	**1**	**2**	**3**	**Control Mix**	**Mix B1p**	**Mix B2p**	**Mix B3p**
Fiber Content	30%	x < 17%	17% < x < 20%	20% < x	0,3	0,3	0,6	0,9
Deformation & Strength	25%	x < 5MPa	5MPa < x < 15MPa	15Mpa < x	0,75	0,75	0,5	0,5
Heat Penetration	20%	x > 100°C	100°C > x > 90°C	x < 90°C	0,6	0,4	0,6	0,4
Compression Test	10%	x < 20MPa	20MPa < x < 25MPa	25MPa < x	0,3	0,3	0,3	0,1
Tensile Test	5%	x < 5MPA	5MPa < x < 8MPa	8MPa < x	0,1	0,05	0,1	0,15
Cement Content	5%	x > 14%	14% > x > 13%	x < 13%	0,05	0,1	0,1	0,1
Workability	5%	x < 5cm or x > 15cm	5cm < x < 7cm or 12cm < x < 15cm	7cm < x < 12cm	0,05	0,05	0,05	0,15
				Total:	**2,15**	**1,95**	**2,25**	**2,3**

From table 18 it can be seen that mix B3p is the winning variant with 2.3 out of a total of 3. This is only 0.05 away from second place which is mix B2p with a score of 2.25 out of 3, in third place is the control mix which as a score of 2.15 out of 3 and in last place is mix B1p with the worst score of 1.95 out of 3.

These results prove that biocrete would be a viable and good solution for a situation that considers the criteria that was used in the MCA. For other criteria further studies and test would need to be done on biocrete with elephant grass.

5 Conclusion

To conclude through out all experiments the outcomes were better than expected and that can also be seen in the tables and graphs for each of the tests as well as in the muti criteria analysis (MCA). From the MCA it was determined that mixture B3p, which had the most percentage of natural fibres present with in the mixture (20%). Although it is not the wanted percentage of fibres (27%), the results have shown that there is still the possibility for more fibres to be added. The results conclude that biocrete with long Miscanthus fibres is a viable and valid option for inner walls of a construction, because of its availability as a material and the fact that using elephant grass in the concrete mixture increases the total volume gained. It also decreases the weight making it easer to move once hardened for precast units and the fact that the concrete with fibres becomes carbon neutral which will help decrease pollutions entering the atmosphere. Miscanthus fibres are a viable replacement for the conventional aggregates that are becoming increasingly harder to find and more expensive.

6 Recommendations

As a recommendation further studies need to be made in the insolation properties of the mixtures as there was not enough time for it to be covered in this report, as well as making more variants with increased amounts of fibres to see if a percentage of 27% or more can be obtained.

Further research is needed on the pre – treatment of the fibres either for a different pre – treatment type or to test and see what minimum ratio of water to cement can to be used to make the slurry the fibres are soaked in to try and minimize the amount of cement used. Also a test on the time the fibres are left to soak in the pre – treatment would be recommended as that could have an effect on the bonds between the fibres and cement.

Lastly a recommendation to test the mixtures with a similar fibre such as bamboo to better understand the differences between biocrete and conventional concrete. Having two different biocretes to compare against conventional concrete would form a better understanding of the difference of the pros and cons of the two.

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