Development of Miscanthus Based Concrete.

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Abstract

This paper is aimed at understanding the role Miscanthus x giganteus has in the strength development of concrete. The use of natural fibres to reinforce brittle materials is not a novel idea, but its use has been limited. This paper is designed to provide more knowledge on the topic of natural fibre cementitious composites. Two fibre sizes (2-10mm & 0.5-2mm) were used to develop concrete, the fibres were subjected to two pre-treatments before being used; a separate batch of untreated 2-10mm fibres were used to create concrete with the same cementitious properties. This was done to improve the fibre-matrix interaction. The fibres in the matrix were at 27% of the overall volume of the concrete. The concrete developed utilized sand 0-4mm and gravel 4-20mm; the type of cement used was CEM I 52.5 R with a specific density of 3100Kg/m^3 and the water cement ratio was kept at 0.5. The fibres were treated with an alkali treatment using 5% *wt* NaOH and a separate treatment referred to in this paper as cement pre-treatment; a 1:1 ratio of cement and water was used to coat the fibres to improve the fibres hydrophobicity. The mechanical properties of the concrete were tested; the compressive strength and split tensile tests for all samples were conducted. The results from this test showed the concrete made using cement treated fibres of size 0.5-2mm had the highest compressive strength, while for tensile strength, concrete made using alkali treated 0.5-2mm fibres performed best. The next step in the process was to evaluate the alternatives using a Multiple Criteria Analysis (MCA), for this the method adopted was the Analytical Hierarchy Process (AHP). Using this method, the concrete mixtures were given a score based of five criteria, which are: Cost, Sustainability, Workability, Compressive Strength and Tensile Strength. At the end of the evaluation, the concrete mixture consisting of 0.5-2mm cement treated fibres was found to have better qualities which satisfied all criteria.

Table of Content

Abstract 2

List of Figures 5

List of Tables 5

1. Introduction 6
   - 1.1. Background 6
   - 1.2. Research question 8
   - 1.3. Problem statement 8
   - 1.4. Objectives 8
   - 1.5. Programme of Requirement 9
2. Theoretical Framework 10
   - 2.1. Pre-treatment 10
     - 2.1.1. Cement Pre-treatment 11
     - 2.1.2. Alkali Pre-treatment 12
     - 2.1.3. Silane Pre-treatment 12
     - 2.1.4. Water glass Pre-treatment 13
   - 2.2. Direct comparison between the pre-treatments 13
     - 2.2.1. Water absorption 13
     - 2.2.2. Mechanical Properties 14
3. Method 17
   - 3.1. Materials 17
     - 3.1.1. Binder 17
     - 3.1.2. Mineral Aggregates 17
     - 3.1.3. Bio-based Aggregates 17
   - 3.2. Characterization of Fibre 17
     - 3.2.1. Water absorption test 17
     - 3.2.2. Moisture content 18
     - 3.2.3. Particle size Distribution 18
   - 3.3. Pre-treatment of the fibres 18
     - 3.3.1. Cement Pre-treatment 18
     - 3.3.2. Alkali Pre-treatment 18
   - 3.4. Creating The Matrix 19
   - 3.5. Characterization of Concrete. 20
     - 3.5.1. Fresh Density Test 20
     - 3.5.2. Slump Test 20
     - 3.5.3. Split Tensile strength 20
     - 3.5.4. Compressive strength 21
   - 3.6. Multiple Criteria Analysis 21

3.6.1. The method 21
3.6.2. Criteria 23
4. Results and Discussion 24
4.1. Characterization of Fibre 24
4.1.1. Water absorption test 24
4.1.2. Moisture content 24
4.1.3. Particle Size Distribution 25
4.2. Pre-treatment 25
4.2.1. Alkali Pre-treatment 25
4.2.2. Cement Pre-treatment 26
4.3. Characterization of Concrete 26
4.3.1. Slump & Fresh Density 26
4.3.2. Tensile Strength 27
4.3.3. Compressive Strength 28
4.4. Multiple Criteria Analysis 30
5. Conclusions and Recommendations 33
5.1. Overall 33
5.2. Recommendations 34
5.2.1. Fibre Pre-treatments. 34
5.2.2. Concrete 35
6. References 36
7. Appendix 40
7.1. Pairwise Matrix 40
7.2. Normalized Weight 41
7.3. Consistency check 42

List of Figures

Figure 1. Geographical distribution of the major Miscanthus species. (Lewandowski et al., 2018) 10
Figure 2. Systematic Overview 17
Figure 3. Preparation of Fibres for Cement Pre-treatment 18
Figure 4. Fibres Soaked in Alkali 19
Figure 5. Specification of the materials used. 19
Figure 6. Different classification of slumps. 20
Figure 7. Loading of Cubes to tensile Failure 21
Figure 8. Water Absorption% of the fibres 24
Figure 9. Particle Size Distribution 25
Figure 10. Cement treated fibres. 26
Figure 11. Alkali treated fibres. 26
Figure 12. Tensile strength of tested samples 27
Figure 13. Tensile Failure of Concrete 28
Figure 14. Compressive strength of tested samples 29

List of Tables

Table 1. Comparison between Mechanical Properties of Natural fibre-based Concrete 16
Table 2. Fundamental Scale (Saaty, 1987) 22
Table 3. Random Index for different matrix size (Saaty,1987) 22
Table 4. Moisture Content% of different sized fibres 24
Table 5. Slump and fresh density for fibre size. 27
Table 6. Pairwise Comparison 30
Table 7. Calculating Weight of Criteria 30
Table 8. Consistency check 31
Table 9. MCA results 32

1. Introduction

This research is being carried out as joint effort between the Centre of Expertise Biobased Economy (CoEBBE) and Vibers. CoEBBE is a collaboration between Avans university of applied sciences and HZ university of applied sciences. CoEBBE was set up by the Ministry of Education, Culture and Science to link higher education more emphatically to regional economic spearheads such as biobased economy. They are an action-oriented partnerships in various areas of expertise in which companies and educational institutions, governments and other public organizations together innovate, experiment, and invest. Together they focus on future-proofing vocational education and translating it into professional practice.

Vibers on the other hand is an innovative bio-based company that works on redefining the materials being used in everyday objects. The company was started when the founder was on a vacation in Borneo and witnessed a worldwide problem first-hand. Vast areas of forest being destroyed and beautiful beaches awash in a sea of plastic waste. He then decided to do something about it, he quit his job and started a company. The initial idea for the company was to grow bamboo on building sites, for co-firing in coal plants. This won the Zuid-Holland Prize and reached the finals of the TEDx- Amsterdam Award in 2013, bringing the company to the attention of the media. The company had developed a myriad of new materials that are environmentally friendly, some of this include concrete with elephant grass in it, bioplastics, and premium paper.

1.1. Background

Concrete is the most widely used building material, it has been used in different applications ranging from sidewalks to large multistorey skyscrapers. The versatility of concrete cannot be understated, it can be found almost everywhere and in any shape. Concrete has been linked closely with human advancements and developments. In fact, there is the equivalent of forty tons of concrete for each person on earth and about one ton per person is added with every passing year (Robert Courtland, 2011).

Natural aggregates typically make up 70% by volume of concrete. (Estanqueiro et al., 2016). These aggregates also account for some of the environmental impact of concrete. The main source of pollution surrounding natural aggregates is in the production of these materials. Extracting and processing these resources often times leads to water and air pollution, change to landscape, vibrations, and noise. The transportation of these materials also adds to the overall environment impact. (Estanqueiro et al., 2016; Assefa and Gebregziabher, 2020)

In way to mitigate the effects of the production of concrete there has been a rise of interest into using natural fibres as an aggregate in concrete with the hope of making a greener concrete when compared to conventional concrete. This wave of thinking has mobilized people into carrying out research on this topic and even developing products to be used in residential building.

The idea of reinforcing brittle building materials with different types of fibre has been known since ancient times. Some early examples of fibre reinforced materials were mud huts which were made using baked clay reinforced with straw and masonry mortar reinforced with animal hair. In recent time the earliest modern example of fibre-reinforced concrete was asbestos-cement which was made by combing asbestos, cement, and water. It was later banned due to health concerns surrounding breathing in asbestos fibres (Johnston, 2001). The push to more sustainable practices has led researchers to take inspiration from ancient times and developing countries; where due to their low cost and relative abundance natural fibres are mixed with cement to make concrete.

Natural fibres are more sustainable as an aggregate than synthetic fibres, as most synthetic fibres are made using polymers, whereas natural fibres can be cultivated on a field for multiple years. It is also cheaper to produce than synthetic fibres and has a lower density than synthetic fibres. When incorporated in to concrete these fibres allow for a less dense material which has good thermal and acoustic properties. Natural fibres as seen can have positive effects when used to develop concrete, although adding natural fibres to concrete has benefits, there are still faults that have not led to the widespread adoption of this technique.

Natural fibres come with their specific set of problems; some of which are low elastic modulus, high water absorption, susceptibility to fungal and insect attack, lack of durability in an alkaline environment and variability of properties amongst fibres of the same type. One problem that relates to natural fibres use in concrete composite materials is compatibility with the concrete matrix. This seems to be the most documented problem amongst multiple literature; there are two core drivers behind the incompatibility: one is the physical interaction between the fibres and the concrete matrix; the other has to do with the interaction of the chemical makeup of the fibres with the concrete matrix. These two drivers can be tackled together or individually, in this research both are tackled using one treatment each.

For the purpose of this research miscanthus x giganteus would be used to reinforce concrete. The reason behind using miscanthus is the fact that the grass grows relatively quickly and produces a large dry yield. It is also a perennial crop which are known to sequester more CO_2 than annual crops. This has to do with how they are cultivated, the roots are left undisturbed which allows for root build-up to continue for years after cultivation. (Zang et al., 2018)

1.2. Research question

This research is targeted at optimizing the amount of miscanthus fibres possible in concrete, along with the main research target there are accompanying goals to achieve. These goals have helped frame the questions that this research is aimed at solving.

The main research question is as follows:

What effect does pre-treated miscanthus fibres have on the workability and mechanical properties of concrete?

Sub-questions

- How do the miscanthus fibres and aggregates interact in the concrete?
- How does the pre-treatment affect the fibres morphological and chemical properties?
- Does the pre-treatment offer any benefits over no pre-treatment fibre concrete?
- Can the concrete developed be used to make structural elements for construction?

1.3. Problem statement

Normal concrete production produces large amounts of greenhouse gases. The materials used in the construction industry is also one of the biggest contributors to waste production in many parts of the world. One of the main problems surrounding concrete is how difficult it is to recycle; as a result, concrete debris after demolition is often thrown away. The aggregates that make up concrete take long periods before they form and are essentially non-renewable resources. Essentially when concrete is thrown away the aggregates in the concrete leave the system and cannot be used again.

Introducing more natural, renewable, and sustainable aggregates in concrete production will reduce the reliance and use of conventional aggregates. This process is what this research is trying to tackle; improving the process to reduce the amount of waste and greenhouse gases produced from concrete production by including miscanthus fibres. The addition of natural fibres to concrete is a way of offsetting the greenhouse gases made during production; it also reduces the use of conventional aggregates which are becoming an increasing scare resource.

1.4. Objectives

The main objectives for this research were given by Vibers. This research is being organized by the Centre of Biobased Economy along with Vibers in order to develop a concrete mixture using miscanthus. The concrete mixture to be developed has certain criteria for it to be seen as a plausible substitute for another biobased concrete mixture known as hempcrete. Some of these criteria include:

- A compressive strength of at least 2.5MPa.
- Optimal acoustic and thermal performance.
- Maximizing the use of the biobased content in the miscanthus-based Concrete mixture.
- Optimizing the consistency of the miscanthus-based concrete mixture in order to manufacture blocks on a vibrating press with immediate block release.

1.5. Programme of Requirement

Technical

- Compressive strength greater than 2.5MPa,
- Fibre percentage greater than or equal to 20% of the volume,
- Consistency which allows for blocks to be made on a vibrating press (Compaction & Immediate mould release).

Functional

- Should be able to act as structural element,
- Should have good heat insulating abilities,
- Should have good sound absorbing properties.

2. Theoretical Framework

The fibre in question for this research is Miscanthus x Giganteus, miscanthus is a perennial rhizomatous grass native to East Asia. The grass was first introduced into Europe from Japan in the 1930s by the Danish plant collector Axel Olsen. The hybrid Miscanthus x giganteus is thought to have developed from M. sinensis and M. sacchariflorus. This grass grows under a wide range of climatic conditions and produces high dry matter yield; these specific characteristics have made miscanthus one of the forerunners when it comes to perennial energy grasses (Anderson et al., 2011; Lewandowski et al., 2018).

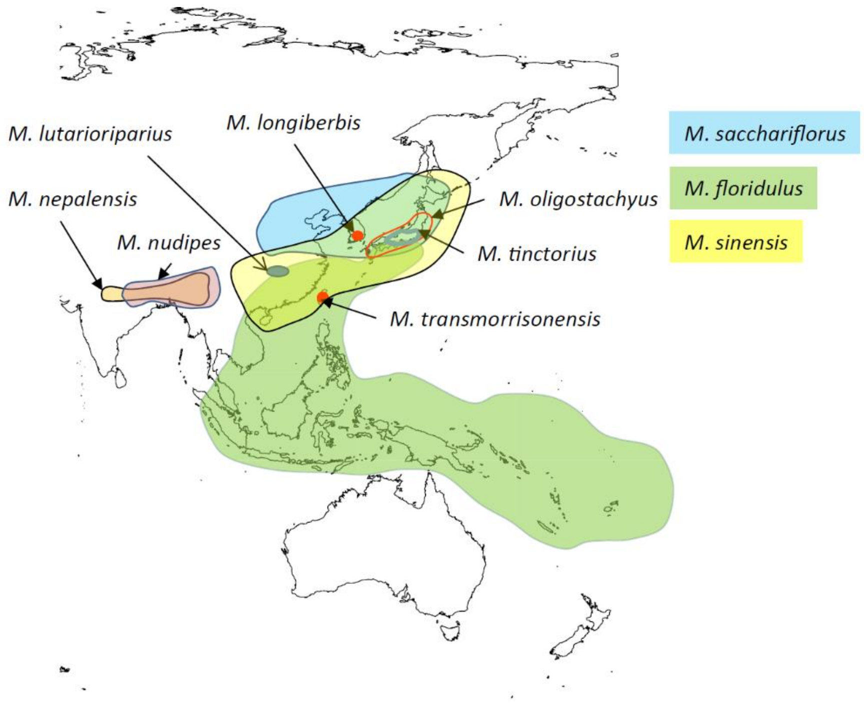

Figure 1. Geographical distribution of the major Miscanthus species. (Lewandowski et al., 2018)

Though this crop is mainly used for energy production its use in other fields as an alternative to conventional materials is fast becoming a trend. There has been a shift in the perception of how organic materials can be used to replace non-organic and non-renewable materials. This has led to researchers investigating the potential benefits of adding natural fibres into materials that consume large amounts of these non-renewable materials. The most common of these materials is concrete as the concrete industry is the largest contributor of CO_2 outside the automobiles and coal-fuelled power plants (Robert Courtland, 2011). It is predicted that the production of cement will account for 17% of the worlds CO_2 by the year 2050 (Galicia-Aldama et al., 2019).

2.1. Pre-treatment

The concept of adding natural fibres to concrete is not a novel idea, it has been studied extensively since the 70's mainly focusing on improving the mechanical properties of the concrete. The mechanical properties of the concrete can be affected by the nature of the chosen fibre, the morphology of the system, the interaction of the fibre-matrix interface and manufacturing technology (Galicia-Aldama et al., 2019). Natural fibres also contain organic compounds such as cellulose, hemicellulose and lignin, which can change the characteristics of the fibre-concrete matrix. To mitigate this problem two approaches have been taking by researchers. One of these approaches involves modifying the matrix to make it more compatible with the fibre, the other approach tackles the fibre modification by making the fibre more compatible with the matrix. The latter can be achieved by carrying out pre-treatments, which is what was done for this paper. (Pacheco-Torgal & Jalali, 2011).

Dias et al. carried out several test to determine the optimal amount of miscanthus that can be used in a concrete matrix. The experiment involved adjusting variables (W/C ratio, cement and miscanthus) in the mixture to achieve the most optimal amount. The fibres used were pre-treated with a silicate coating and in one instance a cement quartz calcium hydroxide solution was used. These coatings guard against water from penetrating the fibres. It was deduced that increasing the fibre content reduces the overall compressive strength, also a correlation between the density and the compressive strength (Dias & Waldmann, 2020).

As seen in Dias et al. it is possible to modify the fibres to improve the interaction with the concrete matrix. The methods used for modifications are often referred to as pre-treatments as they are a precursor to the fibres being used to make concrete. In Ezechiëls the researcher investigated several pre-treatments for miscanthus fibres, the pre-treatments were targeted at reducing the water absorption of the fibres (Ezechiels, 2017). Fibres absorbing water can hinder how well the concrete performs as the fibres can absorb water during the setting of the concrete which in place leaves less water for hydrating the cement; later the fibres lose moisture to the surrounding cement. This results to a gap between the fibre and cement as the fibre shrinks; the gap thus leads to poor mechanical interlocking and reduced density.

2.1.1. Cement Pre-treatment

In Ezechiëls research it highlighted an innovative pre-treatment using cement as a coating to protect the fibres from water absorption; the idea being that the hardened cement will have similar water repelling effects as sodium silicate, sodium sulphite or magnesium sulphate. The process involved coating fibres with a slurry made up of cement and water. The results showed the fibres coated with this slurry having a reduced water absorption than the untreated fibres with the treated fibres absorbing 210% as opposed to 320% for the untreated fibres. When compared with other treated fibres in mortar the cement treated fibres had the highest compressive strength at around 49.65Mpa; this is a 45% increase in strength over the next best treated fibre (Ezechiels, 2017). This treatment improves the hydrophobicity of the fibre and improves the affinity of the inorganic matrix(cement) and the organic filler (miscanthus)

2.1.2. Alkali Pre-treatment

Another common pre-treatment used for modifying surface morphology is the alkali pre-treatment also referred to as mercerization; sodium hydroxide is commonly used as the alkali for this treatment. The treatment breaks down the fibre bundles to release the individual fibres; this process reduces the fibre diameter, which in place increases the aspect ratio which then leads to the development of a rough surface morphology. This rough surface increases the fibre matrix interaction (Jones et al., 2017). In Oushabi et al. alkali treatment was carried out on date fibres, what was observed was a large amount of lignin and hemicellulose were stripped away during the process. The researchers also varied the concentration of the NaOH (sodium hydroxide) to check what effect this may have; the fibres that performed best under tensile strength were those treated with a concentration of 5 *wt%* NaOH any higher and the fibres take on damage from the alkali (Oushabi et al., 2017).

In Ozerkan et al. Date palm fibres treated with a 2.0% solution of NaOH were used to develop concrete blocks. Four mixes of concrete were developed using varying degrees of fibre amounts in the concrete. In the paper the concretes mechanical properties were examined, the trend observed was that increasing the number of fibres reduced the workability, split tensile strength and the compressive strength of the four concrete mixes. Though there were some drawbacks the concrete flexural performance was improved just slightly (Ozerkan et al., 2013).

In Mwaikambo & Ansell the effects of the alkali treatments on Jute, Hemp, Kapok, and Sisal fibres were examined. The fibres were subjected to different concentrations of NaOH. The researchers noted that a high crystallinity index is likely to result in stiff, strong fibres which can be used to develop plant fibre composites. Most fibres developed higher crystallinity indexes as the concentration of the solution increased to about 10% stronger concentrations had lower values. The removal of surface impurities on plant fibres leads to better interaction with the matrix. It should be noted that selecting the right concentration and time of exposure is important to achieve the best result for specific fibres (Mwaikambo & Ansell, 2002).

2.1.3. Silane Pre-treatment

Silanes are coupling agents and are used to increase the cross-linking between fibres. It works by interacting with the hydrophilic groups on the fibre and with the hydrophobic groups in the matrix (Pickering et al., 2016). In Bilba and Arsene alkyltrialkoxysilanes were used to treat bagasse fibres to be used in cementitious composites. It was observed that there was better interfacial bonding when a 6%(weight) solution of silane was used for the treatment, and when the composite was fractured the fibres were covered with the matrix, this was evidence of good adhesion between the fibre and matrix. The water uptake of the fibres was also reduced which avoided the possibility of the fibres competing with the cement for hydration, and the release of sugars from within the fibre. The setting time and the setting temperature were also investigated. This resulted with the highest temperature achieved with a silane concentration below 2% and the shortest setting time with a concentration of 0.5%. (Bilba & Arsene, 2008)

2.1.4. Water glass Pre-treatment

Water glass also known as sodium silicate is used commonly to waterproof concrete by either being incorporated into the concrete or mortar; or a layer is applied on walls and floors as a topical solution to reduce readiness to absorb moisture. The treatment works by forming a Si-O-Si framework when dried, this forms a protective layer on the surface which reduces water absorption. Sodium silicate was used to impregnate poplar wood in Chen et al., this led to a significant increase in the bending strength of the treated fibres. It was observed that the hygroscopicity of the treated fibres was lower when compared to untreated ones. (Chen et al., 2014)

2.2. Direct comparison between the pre-treatments

2.2.1. Water absorption

The water absorption is intrinsic to the type of fibre used, and as it plays an important role in the development of concrete strength is a good basis to use as comparison between the different treatments. The water absorption is also a good indicator on for the workability of the concrete, it also helps to understand the potential limit to the number of fibres in the concrete.

In the work of Ozerkan et al., date palm fibres were treated with 2.0% of NaOH solution, this led to an increase in the water absorption capacity of the mortar when compared to the reference mixture. An interesting trend appeared, where the concrete containing higher fibre percentage had lower water absorption capacity. While in the work of Lam & Yatim the water absorption of kenaf fibres which were treated with a NaOH solution with a pH value of 13 was examined, here the fibres absorbed more moisture by about 9% over the untreated samples. In Hakamy et al. hemp fabric was treated with a 1.7M NaOH solution with a pH of 14. When the cement paste was tested for water absorption it showed a slight improvement over the untreated samples by about 2%, this was attributed to the reduced voids in the fibre matrix interface region. (Ozerkan et al., 2013)

In Bilba & Arsene bargasse fibres were treated with an alkyltrialkoxysilane with varying concentrations. It was observed that increasing the silane content led to a decrease in the water absorption capacity of the fibres. This effect was likely due to the change in the surface morphology of the fibres caused by the fibres swelling increasing their dimensions as mentioned in the paper. (Bilba and Arsene, 2008)

In Chen et al. poplar wood was impregnated with sodium silicate (Waterglass), this resulted with the treated fibres absorbing less water than the untreated ones. With the final water uptake for the treated wood decreasing from 124% to 73%. This effect was partly due to the reactions within the cell wall, masking some of the hydroxyl groups. With the larger polymers forming a barrier on the surface of the lumen, thus reducing the water absorption. (Chen et al., 2014)

In Ezechiel miscanthus fibres were coated in a cement slurry with a water to cement ratio of 0.5. This treatment resulted with the fibres having a reduced water absorption capacity. This was as a result of the cement coating the surface of the fibres, this acted as a barrier preventing water from further being absorbed into the fibres. (Ezechiel, 2017)

2.2.2. Mechanical Properties

In Ozerkan et al. alkali treated palm fibres were used as reinforcement in concrete at vary amount. The trend observed was that with increasing the fibre amount this led to a reduction in both the compressive and tensile strength (Ozerkan et al., 2013). The loss in strength is a common phenomenon amongst natural fibre reinforced concrete. The same trend was observed in Lam and Yatim, where kenaf fibres were alkali treated with NaOH, but here the cube samples failed exhibiting a ductile failure mode where multiple distributed cracks were observed. Here the highest volume percentage used was 2% but this led to about a 50% drop in strength which was around 17MPa (Lam and Yatim, 2015). In Hettiarachchi and Thamarajah coir fibres were treated with an alkali and were used to reinforce concrete at 1% of the volume. Here the inclusion of the fibres led to an increase in both the compressive and tensile strength by 2.57% and 1.12% respectively. (Hettiarachchi and Thamarajah, 2020)

In Ban et al bamboo fibres were treated with a silane treatment and were then added to a cement mortar as a reinforcement at a volume ratio of 2%. As observed with the alkali treated fibres there was a loss in the compressive strength with the inclusion of the fibres. Though the loss in strength was comparatively better than that of the alkali treated fibres. The concrete had a compressive strength above 45MPa. (Ban et al., 2020)

In Ezechiel miscanthus fibres were coated with a solution of Waterglass also known as sodium silicate. The fibres were used to develop a mortar which had a fibre percentage of 5% by volume. The inclusion of these fibres led to a gain in compressive strength over the mortar with untreated fibres. With the treated fibres having a compressive strength of 34.23MPa and the untreated samples having a compressive strength of 26.89MPa, which was a 27% increase in strength.

In the same paper miscanthus fibres were treated with a slurry made using cement and water at a water cement ratio of 0.5. These fibres were then used to create a mortar with a fibre percentage of 5% by volume. This treatment performed best out of the others, with a compressive strength of 49.65MPa which was an 84.6% increase in strength over the untreated samples. (Ezechiel, 2017)

Research Paper	Type of fibre	Concentration	Fibre Percentage	Pre-Treatment	Mix Design	Cement grade	W/C ratio	Compressive strength (MPa)	Tensile Strength (MPa)
Esper et al., 2020	Pineapple Leaf Fibre	4% NaOH 12% NaOH	1% w/w cement	Alkali	2:1(Sand:Cement)	Not available	0.55	Not available	2.028 1.681
Wei Jianqiang & Meyer Christian	Sisal	Na2CO3 saturated solution for 7 days Na2CO3 saturated solution for 10 days	0.25 wt.%	Na2CO3 Treatment	Not available	Type III Portland cement	0.6	37.92 33.5	2.51 2.44
Akinyemi et al., 2020	Bamboo	10% NaOH	1% 1.50%	Alkali	Portland cement was mixed with sand in the ratio 1:2	A general use type of Portland cement with 42.5 rating	0.52	Null	11.9 13.81
Andiç-Çakir et al., 2014	Coir	5% NaOH	0.40% 0.60% 0.75%	Alkali	3:1 (Sand: Cement)	CEM I 42.5 R	0.5	47.5 49.9 52	Not available
Yan et al., 2016	Coir	5% wt NaOH	1% w/w cement	Alkali	Mix ratio by mass of 1:0.60:3.70:2.46 for cement: water: gravel: sand, respectively	CEM I 42.5 normal Portland cement	0.6	24	Not available
Lahouioui et al., 2018	Date Palm fibres	Acetone–ethanol (2:1) in a Soxhlet at 80 °C for 4 h	2.5% wt 5.0% wt 10% wt	Dewaxing	Not available	Portland cement—CEM I	Not available	14.85 4.28 2.26	Not available
Sivaraja et al., 2009	Coir fibres Sugar cane fibres	Not available	1.5% vol	No treatment	Not available	43 grade ordinary Portland cement	0.5	27.8 27.6	3.28 3.92
Wan Jo et al., 2014	Jute	0.5 % NaOH solution for 24 h.	1% wt	Alkali	Cement: sand weight ratio 1:3	Portland pozzolanic cement conforming to IS 1489	0.6	36.2	Not available
CEM2-10 CEM.5-2 ALK2-10 ALK.5-2	Miscanthus x giganteus	Cement Water ratio 1:1 5% wt NaOH	20% vol	Cement Alkali	1.4:2.5:3.5 (cement, sand, gravel)	CEM I 52.5 R	0.5	46.55 48.95 8.06 28.87	9.03 7.1 5.52 11.52

Table 1. Comparison between Mechanical Properties of Natural fibre-based Concrete

3. Method

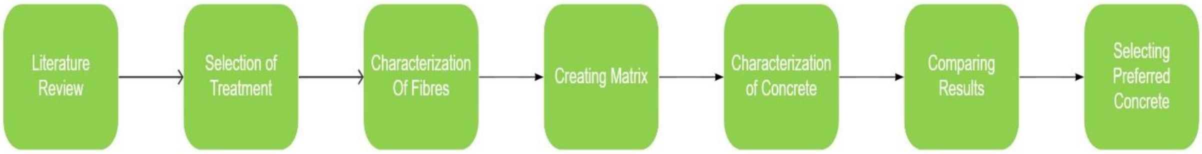

Figure 2. Systematic Overview

3.1. Materials

3.1.1. Binder

The binder for the concrete is important when deciding the strength class that the concrete is intended to reach. As the objective of this research is to create a bio-based concrete which has high mechanical strength, the type of cement chosen to achieve this is CEM I 52.5 R. This type of cement is designed to achieve high compressive strength very rapidly. The cement was provided by Scalda Labs in Vlissingen.

3.1.2. Mineral Aggregates

For this project two types of aggregates were used. The larger aggregate size used was 4-20mm while the finer the aggregate size was 4-20 mm. the aggregates used in this project were provided by Scalda Labs in Vlissingen.

3.1.3. Bio-based Aggregates

In this research the bio-based material used was Miscanthus x giganteus, two different sizes were evaluated to be used in the concrete. The first being 2-10mm as this size was considered to produce the best results when used to develop concrete. The second being 0.5-2mm, this smaller size was chosen for the fact that it is possible to pack more finer particles in a given volume. The fibres were provided by Vibers.

3.2. Characterization of Fibre

3.2.1. Water absorption test

This test is a measure of the amount of moisture present in the sample of fibres. This is imperative to understanding how the water content of the fibres effect the concrete. It helps also to identify the optimum amount of moisture to add to the concrete to preserve the fibres for as long as possible. The test is carried out by placing fibres in water at different time intervals and weighing them to get a percentage of how much the fibres were able to absorb.

$$WA\% = \frac{M_1 - M_2}{M_2} \times 100\% \tag{3.1}$$

Where M1 is the weight of the wet fibres and M2 is the weight of the dry fibres (initial weight).

3.2.2. Moisture content

The fibre moisture content was checked to understand how the presence of moisture in the fibre may affect the setting of the concrete. The fibres are weighed before being placed in an oven until there is no change in the weight after weighing twice. The dry weight is then removed from the wet weight to determine the moisture content.

3.2.3. Particle size Distribution

The particle size distribution is a way of determining the different sizes present in a batch of unsifted fibres. knowing the size of the fibres present is important to understanding the interactions between the fibre and the other components of the concrete matrix. The particle size distribution carried out was done according to NEN-EN 933-1 standard. The fibres were first weighed, and then placed in a sieving column comprising a number of sieves fitted together and arranged, from top to bottom, in order of decreasing aperture sizes with the pan and lid. The sieving column was then agitated for a minute. The individual pans were then weighed to record the mass of fibres retained.

3.3. Pre-treatment of the fibres

3.3.1. Cement Pre-treatment

This pre-treatment is aimed at protecting the surface of the fibre with a cement coating. This coating is a means of protecting the fibres from water penetrating the fibres. A slurry of cement and water made with a ratio of 1:1 is used to coat the fibres. The fibres are then be left out to dry for 7 days before they are ready to be used in concrete.

Figure 3. Preparation of Fibres for Cement Pre-treatment

3.3.2. Alkali Pre-treatment

The alkali pre-treatment was used on a set batch of the fibres. The fibres are placed in a 5%wt solution of sodium hydroxide (NaOH) for an hour before they were removed, and the solution rinsed of with slightly acidic water to neutralise the alkali. They were then left to dry out in the lab for 7 days, this is to ensure the fibres are dry enough to be used to develop concrete.

Figure 4. Fibres Soaked in Alkali

3.4. Creating The Matrix

The concrete was designed using a volume ratio of 1.4:2.5:3.5 (cement, sand, gravel). The miscanthus utilized for this project was kept at 27% of the total volume for the concrete made. This is relatively high but is possible to achieve with the pre-treatments carried out on the fibres. The water cement ratio (W/C) for the concrete is kept at 0.5. In total five batches of concrete were made one for each fibre treatment combination and one cube with no treatment that contained 2-10mm fibres. Mixtures containing alkali treated fibres are denoted with ALK while those containing cement treated fibres are CEM. A separate reference mixture which was made in the same lab using similar materials without fibres was used to compare against the finished products. It was designed to be in the compressive strength class of C20/25.

Materials	Density (kg/m3)	Amount (kg/m3)
CEM I 52.5 R	3100	310.0
Sand 0 - 4 mm	2640	792
Gravel 4 - 20 mm	2640	1056.0
Miscanthus	160	32.0
Water	1000	155.0
Total		2345

Figure 5. Specification of the materials used.

3.5. Characterization of Concrete.

3.5.1. Fresh Density Test

The fresh density test is carried out before the concrete is moulded into cubes, in this case the cubes used were 150x150x150mm^3. The concrete is placed in a container of known volume and weight, the container is then weighed again with concrete inside. The density of the concrete is then calculated using the formula below.

$$D = \frac{m_2 - m_1}{V} \tag{3.2}$$

Where m_2 is the weight of the container filled with wet concrete in kg, m_1 is the weight of the container when empty in Kg and V is the volume of the container in m^3.

3.5.2. Slump Test

The slump test is way of measuring the consistency of concrete. It can be used as an indicator for how uniform the concrete is. It is carried by compacting the fresh concrete into a cone, then the cone is withdrawn upwards, the distance the concrete has slumped when after the cone has been withdrawn is then recorded. The slump tests show how workable the concrete mixture is and the ease at which it can be used to form moulds. There are different ways the concrete can slump for this reason there is only one type of slump is considered the true slump.

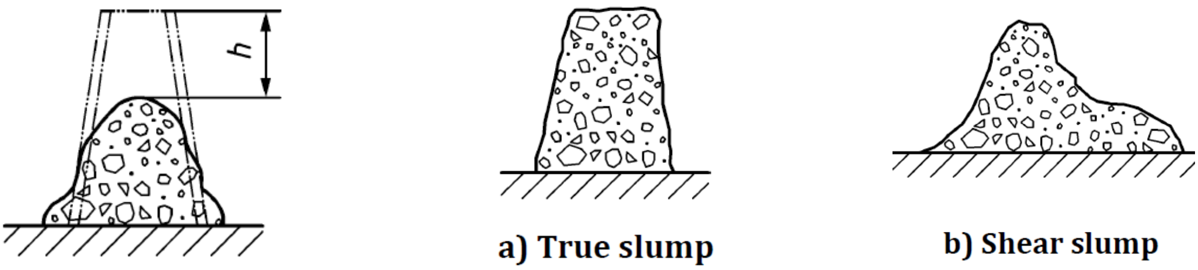

Figure 6. Different classification of slumps.

3.5.3. Split Tensile strength

Tensile strength is one in many ways used to determine the effectiveness of concrete. It is a way of comparing multiple different concrete cubes. This test is carried out according to the NEN-EN 12390-6 with a loading rate between 0.04 MPa/s (N/mm^2·s) to 0.06 MPa/s (N/mm^2·s). After the application of the initial load, which does not exceed approximately 20 % of the failure load. Cubes are placed in a loading machine which slowly increases the force till the cube fails. The test is repeated three times and the results are averaged to get the tensile strength. The *RatioTEC RT 3000 2-D servo* was used for the tensile strength check.

Figure 7. Loading of Cubes to tensile Failure

3.5.4. Compressive strength

The compressive test is also a way of comparing different concrete mixtures to determine the effectiveness of the fibres. This test is done in accordance with NEN-EN 12390-3 with a Loading rate in the range 0,6 ± 0,2 MPa/s (N/mm2·s). After the application of the initial load, which does not exceed approximately 30 % of the failure load. The *RatioTEC RT 3000 2-D servo* was used for the compressive strength check. First the samples were measured (height, width, and thickness) and weighed; after the samples were placed in the press and was switched on. The failure mode was noted to make sure it failed normally.

3.6. Multiple Criteria Analysis

An MCA is a decision aiding method, which through the use of explicit but not necessarily completely formalized models, aims at obtaining responses to the questions posed by the stakeholders. These responses are then used to clarify the decision and used to either recommend or favour a response that leads to better cohesion between the process of evolution and the objectives of the stakeholders. This MCA is used to assess the concretes made at the end of this project.

3.6.1. The method

The method adopted for this analysis is the Analytical Hierarchy Process (AHP) which is used to assign the weights to the criteria. The method involves describing a hierarchy with different levels. The first level is where the goal of the project is situated, the next level is where the different criteria are located, and the last level is where the alternatives are located. This hierarchy creates a clear path between how the alternatives interact with a criterion and how that then effects the goal of the project. The criteria are compared against each other using a rating system developed in (Saaty, 1987). The first step in the process is to identify the criteria to be used, once this is done the next step involves creating a Pair-wise comparison matrix where the criteria are compared against each other using a comparative scale rating.

The criteria being compared is then given a value 1-9, where a larger number means larger differences between criteria levels. This means that for any pair value being compared there is one value that would be a whole number and the reciprocal value which would be a fraction. The scale rating shown below is adopted for relative comparison.

Intensity of influence	Explanation
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, and 8 are the intermediate values	

Table 2. Fundamental Scale (Saaty, 1987)

The first step as mentioned earlier on is to create a Pair-wise comparison matrix, The values are obtained by comparing the criterion on the row against the one on the column using the fundamental scale from Table 2. Once this is done the weight for each criterion is then determined by first normalizing the values in the table, which is achieved by taking the sum of the columns and then dividing the value in the cell by the sum. The normalized weight is then calculated by taking the arithmetic mean of the values in a row.

The last thing to do in this step is to measure the consistency of the results. The AHP method has a means to check whether the decisions made are consistent, the consistency ratio (*CR*) is used to judge whether a matrix is consistent of not, but before the *CR* is found the principal eigenvalue(λ_{max}) must be calculated. The equations for calculating the consistency ratio are shown below.

$$Aw = \lambda_{max} w \tag{3.3}$$

$$CR = \frac{CI}{RI} \tag{3.4}$$

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \tag{3.5}$$

Where *A* is the comparison matrix, λ_{max} is the principal eigenvalue, *w* is the criterion weight from the matrix, *n* is the number of dimensions of the matrix and *RI* is the random index. The value of *RI* is obtained from a table based on the number of dimensions of the comparison matrix. (Dong et al.,2020; Qazi W.A. & Abushammala, 2020; Liang et al., 2017)

N	1	2	3	4	5	6	7	8	9	10
(R.I.)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3. Random Index for different matrix size (Saaty,1987)

The CR value should be less than 0.1 this is the minimum requirement that the matrix should meet. If the value is greater than 0.1 the table needs to be changed with values that meet this requirement.

This process is then repeated with each criterion being used in a Pair-wise comparison between the various alternatives i.e., the alternatives are compared based of one criterion at a time. The weight gotten from each matrix comparison is then multiplied with the weight of the criterion to give a score. The overall score for an alternative is gotten by summing of the corresponding scores for all the criteria.

3.6.2. Criteria

The criteria for this research were gotten through an assessment of the stakeholders needs. This information was achieved through meetings and discussions with the stakeholders.

3.6.2.1. Cost

This criterion is important to the stakeholders as this is the cost associated with the concrete produced. This cost is measured based on how much the pre-treatment cost.

3.6.2.2. Sustainability

As the stakeholders are involved in working with sustainable practices, it is clear that the concrete developed should be sustainable. The sustainability is measured by how much percentage wise the concrete contains organic material.

3.6.2.3. Workability

As requested by the stakeholders the concrete should have a consistency which allows it to be made into blocks on a vibrating press. This criterion is aligned with the goal of the project. This criterion will be measured using the ability of the concrete to slump. Where a higher slump is favourable and a lower one is least favourable.

3.6.2.4. Compressive Strength

As requested by the stakeholders the concrete is intended to be used for construction purposes and must perform well under loads above 2.5Mpa. This criterion is measured using the compressive strength that is obtained after the concrete blocks have been cured.

3.6.2.5. Tensile Strength

The concrete must perform well under tension as this is a requirement for concrete blocks to be used for construction purposes. The strength is then compared against the tensile strength of concrete made with no pre-treatment.

4. Results and Discussion

4.1. Characterization of Fibre

4.1.1. Water absorption test

As seen in the figure below the larger sized fibres absorbs less water than the finer fibres, this is because the much finer fibres occupy less space than larger fibres. This means that in a 50g sample of each there would be more fibres in the finer batch than the larger one. As a result, there is more surface area in finer sample which acts similarly to a sponge when exposed to water.

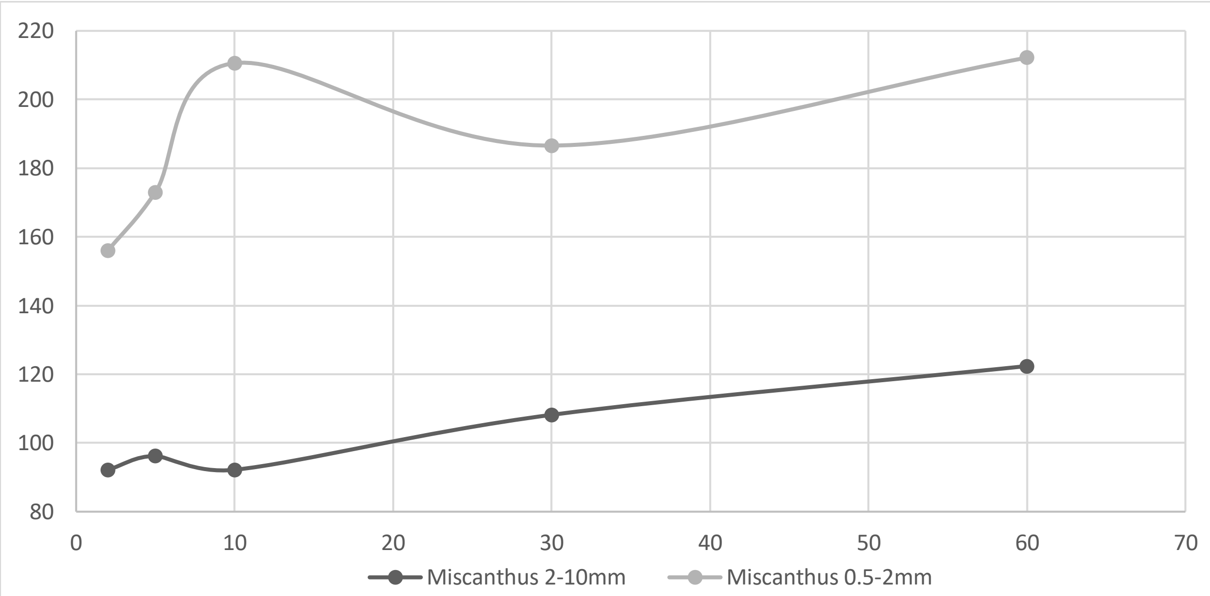

Figure 8. Water Absorption% of the fibres

4.1.2. Moisture content

As seen in Table 4 the larger fibres have a higher percentage of moisture in them. This could be the results of the larger individual fibres having more pores which contain moisture which is then released leading to the reduction in the amount of moisture left.

Fibre	Moisture Content %	
	i	ii
2 - 10 mm	25	25
0.5 - 2 mm	13.5	14

Table 4. Moisture Content% of different sized fibres

4.1.3. Particle Size Distribution

In Figure 9 the particle size distribution for the two fibres used in this project are presented. From the figure below it can be observed that the finer fibre sizes have a more even distribution of fibres between the 0.5mm and 2mm when compared to the larger fibre distribution as around 50% of the fibres are below 1mm and the other 50% is above the 1mm mark. As seen in the figure below the 2-10mm sample has a higher percentage of fibres larger than 5mm, as about 50% of the fibres are below the 5mm mark. From the graph it can be deduced that there is an even distribution of fibres; with the 0.5-2mm samples having a fineness modulus of 4.57 and the 2-10mm samples having a fineness modulus of 3.21.

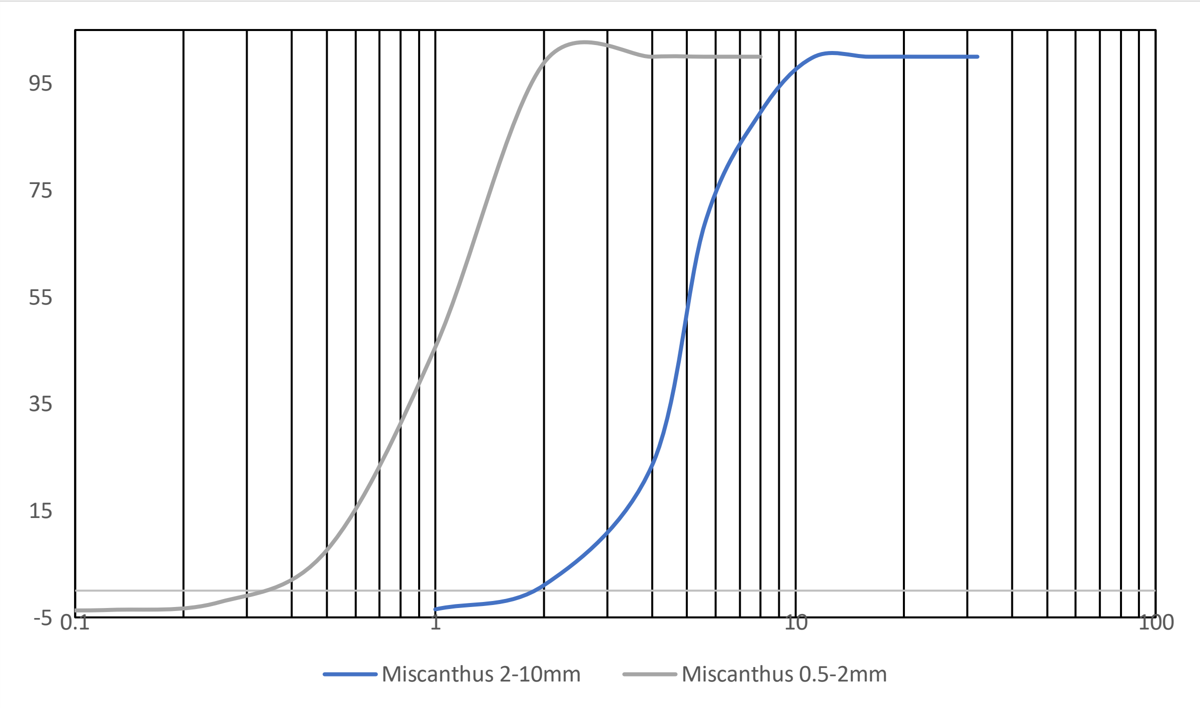

Figure 9. Particle Size Distribution

4.2. Pre-treatment

4.2.1. Alkali Pre-treatment

After the treatment, the colour of the fibres was observed to have changed from a light brown to a yellowish-brown colour. This is a result of the Sodium Hydroxide stripping away the lignin, cellulose, and hemicellulose. The texture of the fibres seemed to have remained unchanged. The first batch of fibres treated were not properly rinsed off and affected the concrete that was made using these fibres. The solution started to deteriorate the fibres more the longer they were present. This led to a loss in strength and the delayed the setting time of the concrete. With this knowledge the second batch of fibres were rinsed thoroughly till the water ran clear. These fibres also experienced a loss in overall strength although the drop in strength was not as significant as with the first batch.

4.2.2. Cement Pre-treatment

The results of this treatment were fibre samples that had been fully coated in concrete. The fibres were easily separated, this was a concern as there was a possibility for the fibres to bind to one another. The reason for the fibres not binding is not clear, but it could be likely that due to the high-water cement ratio the cement was able to hydrate and harden relatively fast thus creating a barrier that prevents the fibres from binding.

Figure 10. Cement treated fibres.

Figure 11. Alkali treated fibres.

4.3. Characterization of Concrete

4.3.1. Slump & Fresh Density

Observed below in Table 5 that the cement fibres have a higher density when compared to their alkali counterpart. It is also observed that concrete made with 0.5-2mm fibres have a higher density than the concrete made using 2-10mm fibres. The slumps of the alkali treated fibres is lower than that of the cement treated fibres, this can be attributed to the alkali fibres absorbing more moisture than the cement treated fibres which have a coating preventing them from absorbing moisture. The slump of the concrete made with 0.5-2mm are considerably higher than the slumps of concrete made using 2-10mm fibres. This is attributed to the ease of the fibres to flow against each other this is due to the large fires which cannot move easily or slide against each other due to the larger side surface area which creates more friction.

Fibre	Treatment	Slump (cm)	Density (Kg/m^3)
CEM2-10	Cement	12.00	2254.70
CEM0.5-2	Cement	21.50	2277.70
ALK2-10	Alkali	2.00	2135.00
ALK0.5-2	Alkali	6.50	2149.40

Table 5. Slump and fresh density for fibre size.

4.3.2. Tensile Strength

4.3.2.1. Tensile Strength comparison between ALK2-10 and ALK0.5-2.

From the results of the tensile strength for the alkali treated fibres it was observed that the fibres with the larger diameters had the least tensile strength, this could be due to the fibres having left over remnants of sodium hydroxide in them. The queues for this test were noted to have been significantly do not sweat then the cubes this is as a result of the cubes not having cared enough thus leading to the lower performance of the cubes.

4.3.2.2. Tensile strength comparison between CEM2-10 and CEM0.5-2.

From the results of the tensile strength for the cement treated fibres it was observed that the largest fibres benefited more from the cement treatment than the smaller ones. There was a 25% difference in tensile strength between the 2-10mm fibre over the 0.5-2mm fibres. The tensile strength for the 2-10mm fibre was measured 32 days after the first concrete had been made while the tensile strength for the 0.5-2mm fibre concrete was measured 37 days after the concrete was made, these were both

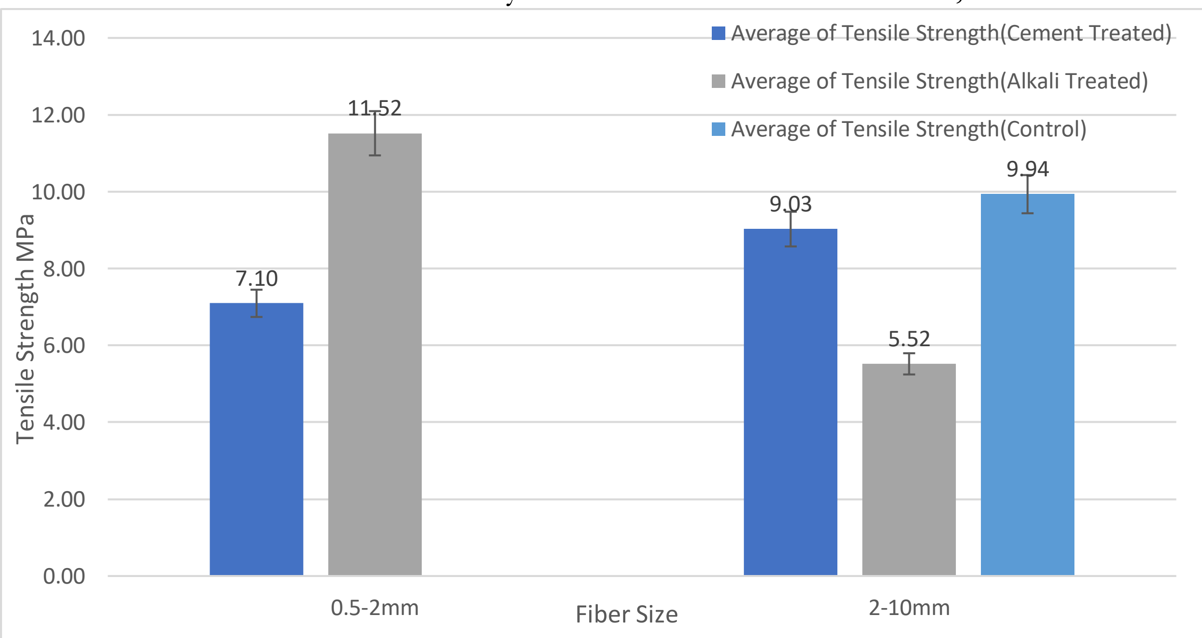

Figure 12. Tensile strength of tested samples

measured after 28 days which is where concrete is said to have reached 95% to 99% of its final strength.

4.3.2.3. Comparison between treatments on CEM0.5-2 and ALK0.5-2.
Comparing the 0.5-2mm fibres it was observed that the tensile strength for the CEM0.5-2 samples was comparatively lower than that of the ALK0.5-2 samples. The tensile strength for the CEM0.5-2 samples was measured 37 days after the concrete was made while the ALK0.5-2 samples was measured 28 days after it was measured.

4.3.2.4. Comparison between treatment on CEM2-10 and ALK2-10.
The ALK2-10 cubes were tested 29 days after they were made while the CEM2-10 cubes were tested 32 days after they were made. From the results shown in Figure 12 above the tensile strength of the control cubes were higher than that of the treated fibres, this deficit in strength for the alkali cubes could be attributed to the fact that the alkali cubes had not fully cured which is a result of the presence of alkali leaching out from the fibres. Though the ALK2-10 cubes were not cured fully it produced a relatively high value as it was 61% of the tensile strength of the CEM2-10 cubes.

Figure 13. Tensile Failure of Concrete

4.3.3. Compressive Strength

4.3.3.1. Compressive strength comparison between ALK2-10 and ALK0.5-2
ALK0.5-2 samples were tested 28 days after they were first created while ALK2-10 were tested 29 days after they were created. The smaller fibres performed better than the larger ones as there was an increase in strength of 258% over the smaller fibres this jump can be attributed to the presence of the alkali in the larger fibres, which could have leached out from the fibres.

4.3.3.2. Compressive strength comparison between CEM2-10 and CEM0.5-2.
CEM0.5-2 samples were tested 28 days after they were first created while the CEM2-10 samples were tested 32 days after they were first created. As seen in Figure 14 the

finer fibres had the larger final compressive strength, it performed better by around 5.2% over the smaller fibres. This difference in performance can be the results of the 1% difference in densities as shown in Table 2. There is strong correlation between the density of concrete and its mechanical properties. In this case seeing as the difference is quite small, it is more likely that the difference in densities is what led to the finer fibres producing the better result.

4.3.3.3. Comparison between treatment CEM0.5-2 and ALK0.5-2.

The CEM0.5-2 samples were tested 28 days after they were first created while the ALK0.5-2 samples were tested 28 days after they were created also. The cement treated fibres performed better than the alkali treated fibres, it performed 70% better than the alkali treatment. This disparity in strength might be the result of the cement treated fibres forming a barrier protecting them from absorbing moisture. As seen with the slump the alkali treated fibres had a lower slump value which was likely due to the alkali fibres absorbing more moisture than the cement treated fibres. There was nothing stopping the alkali fibres from absorbing moisture when exposed to the concrete matrix. It is also a possibility that the alkali fibres were leaching little amounts of sodium hydroxide into the concrete.

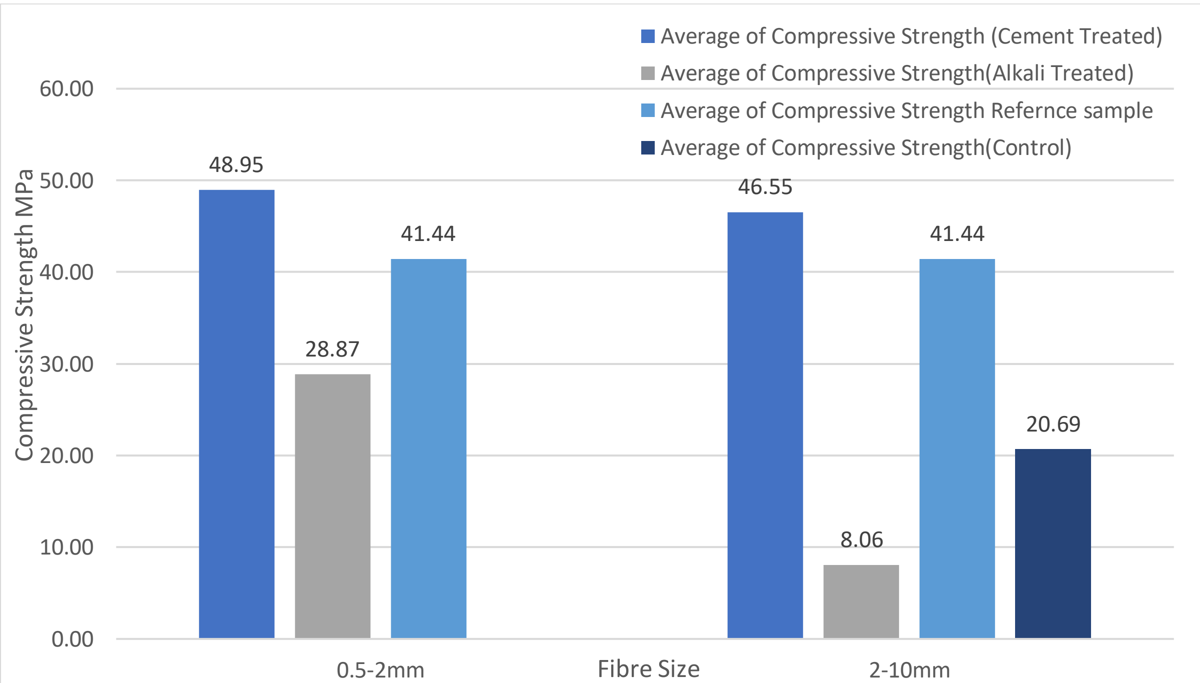

Figure 14. Compressive strength of tested samples

4.3.3.4. Comparison between treatments of CEM2-10 and ALK2-10.

The CEM2-10 samples were tested 32 days after it was created while the ALK2-10 samples were tested 29 days after they were first created. The CEM2-10 samples compressive strength as seen in the figure below performed much better the ALK2-10 samples, it was 4.8 times stronger. The difference in strength between these two treatments on this fibre is likely due to the same reasons as that of the other fibre size, the cement treatment improved the fibres interaction with the matrix and the hydrophobicity. The cement treated fibre also performed better than the control sample, it was 120% stronger than the control sample, this difference is likely driven by the presence of unwanted substances contained in the fibres of the control sample.

4.3.3.5. Comparison between concrete with fibres and concrete without

The only concrete that had no fibres in it was the reference sample, this concrete was made and tested in the same lab in early 2018. It was designed to be in the compressive strength class of C20/25. As seen in the graph above the cement treated samples performed better than the reference sample, with an 18% strength difference between CEM0.5-2 and the reference sample.

4.4. Multiple Criteria Analysis

	Cost	Sustainability	Workability	Compressive strength	Tensile Strength
Cost	1.00	2.00	3.00	0.25	0.50
Sustainability	0.50	1.00	2.00	0.25	0.50
Workability	0.33	0.50	1.00	0.33	0.50
Compressive strength	4.00	4.00	3.00	1.00	3.00
Tensile Strength	2.00	2.00	2.00	0.33	1.00
Sum	7.83	9.50	11.00	2.17	5.50

Table 6. Pairwise Comparison

The above table shows the results of the pairwise comparison; the criteria on the left column of the table is compared against the criteria in the next column based on which is more important to the project. A score is then given based on the values shown in Table **2**. The sum of each column is then added up and shown in the table. Once this is done the next step is to calculate the weight of each criterion; this was achieved by using the values in the pairwise matrix; the sum of each column was then used to divide the values in the column. The arithmetic mean of each row was then calculated in the Normalized Weight column.

	Cost	Sustainability	Workability	Compressive strength	Tensile Strength	Normalized weight
Cost	0.13	0.21	0.27	0.12	0.09	0.16
Sustainability	0.06	0.11	0.18	0.12	0.09	0.11
Workability	0.04	0.05	0.09	0.15	0.09	0.09
Compressive strength	0.51	0.42	0.27	0.46	0.55	0.44
Tensile Strength	0.26	0.21	0.18	0.15	0.18	0.20

Table 7. Calculating Weight of Criteria

Once the weight for each criterion was calculated the next step was to check the consistency of the values in the table; this is a property of the AHP method which is used to verify whether the decisions made are sensible ones. This part of the process is carried out in a similar format with the other process done till now. The values in the pairwise matrix column is then multiplied with the weight for the corresponding criterion. In the table below the cell corresponding with Workability for the row and sustainability in the column was obtained through by multiplying the pairwise value by the weight. In this case that would be 0.50 multiplied by the weight of sustainability (0.11) which gives a value of 0.06. Once this is carried out for each cell the sum of each row is then divided by the weight of the criterion for that row to obtain the λ value. λmax is the average of the λ in the table. To obtain the CI and CR the equations mentioned in chapter 3 were used, this resulted in a CI of 0.07 and CR of 0.06 which is lower than the acceptable limit of 0.10. This indicated that the decisions made during this process is consistent and the values obtained can be used to help guide in the decision-making process. These steps are then repeated for each Criterion-alternative pair, the results of which are shown in the appendix.

	Cost	Sustainability	Workability	Compressive strength	Tensile Strength	λ
Cost	0.16	0.22	0.26	0.11	0.10	5.22
Sustainability	0.08	0.11	0.17	0.11	0.10	5.15
Workability	0.05	0.06	0.09	0.15	0.10	5.13
Compressive strength	0.65	0.45	0.26	0.44	0.59	5.40
Tensile Strength	0.33	0.22	0.17	0.15	0.20	5.42

Table 8. Consistency check

The table below shows the results from the MCA carried out in this paper for the different alternatives and their scores. The weights of the criteria were gotten through the Pair-wise comparisons that were carried out. The compressive strength received the most weight (44%) as this is a factor that is most aligned with the goal of this project. The criterion that received the least weight was the workability, this was because when compared with the other criterion the workability was not as important as the others when it came to achieving the final goal. Since the concrete is to be used in a vibrating press where the blocks are set in a mould, the workability is not as important as if it were to be used as conventional self-consolidating concrete.

From the table, the alternative with the highest score was CEM0.5-2 which had a score of 0.39. The second highest scoring alternative was also the other concrete made using cement treated fibres (CEM2-10), the difference between the first and the second was only 0.05. Both performed well during compression and tensile testing with CEM2-10 performing better under the tensile strength, this performance was not enough as CEM0.5-2 performed better under the compressive testing which carries the most weight amongst the criteria.

ALK0.5-2 performed best out of the other alternatives under tensile testing but failed to perform as well under the compressive strength test. This better performance under tensile load is common and consistent with other findings as seen with the different fibres compared in Table 1.

	Cost 16%	Sustainability 11%	Workability 9%	Compressive strength 44%	Tensile Strength 20%	Overall Score
CEM2-10	0.06	0.03	0.03	0.15	0.06	0.33
CEM0.5-2	0.06	0.03	0.04	0.23	0.02	0.38
ALK2-10	0.02	0.03	0.00	0.02	0.01	0.08
ALK0.5-2	0.02	0.03	0.01	0.04	0.11	0.20

Table 9. MCA results

5. Conclusions and Recommendations

5.1. Overall

The results of this study have shown the benefits of adding miscanthus fibres into concrete. It has also highlighted the success pre-treatment has on fibres, and the ability for natural fibre-based concrete to perform on par with conventional concrete. This is important in understanding the role fibre-based concrete could play in reducing our dependence on conventional concrete.

The pre-treatments used in this study yielded positive results, with the concrete made using fibres from both pre-treatments being able to achieve compressive strengths much larger than the minimum required value of 2.5MPa. From the results, it was evident that the concretes made using fibres that had been treated with cement were able to withstand larger compressive load than those made using alkali treated fibres. This was likely due to the increased density that the cement adds to the fibres. Though the alkali treatment was favourable for the tensile load test cubes, the treatment did not have the same desirable effect as the other treatment.

The fibre choice was also examined in this study, the results for the compressive strength showed that smaller fibre sizes performed better than larger ones. For cement treated fibres the difference was about 5% while for alkali treated fibres it was 258%. The difference for alkali treated samples is likely due to a high concentration of alkali in one of the samples. For the tensile strength of cement treated fibres, the larger sized fibres performed better over smaller ones; while for the alkali treated sample, the reverse was the case, the smaller sized fibres performed better than the larger one. These two contrasting results would need to be further studied to understand why the tensile performance varies from the compressive one.

From the results of the MCA the concrete mixture that had the best overall score was CEM0.5-2, apart from having the highest compressive strength it also had one of the highest workability's. This mixture would be used as a basis for the next steps in the development of blocks. With the insights from this study, it is possible to develop a system that takes advantage of this concrete mixture, as the cost is relatively low, and the materials can be readily found.

The goal of this study was to answer the questions that were setup at the beginning, these questions are a measure of how well the study was at tackling the problem. For some of the questions this study was unable to answer them, E.g. How does the pre-treatment effect the fibres? Due to the lack of specific equipment this question could not be answered fully. As pertaining the effect mixing methods has on the concrete, this was unable to be answered due to time constraints. The remaining questions were mostly answered, and the result is a better understanding of how using pre-treated miscanthus fibres affects the workability and the mechanical properties of concrete.

The last two pre-treatments (Silane and Waterglass) were not able to be carried out, the silane treatment required special handling as silanes are highly reactive substances and needed to be properly looked after. The time also required to tackle this treatment was longer than anticipated. The waterglass pre-treatment on the other hand was a relative straight forward process, but due to time constraints this test was not performed.

Using the data gotten from this research and the information gathered on the pre-treatments, predictions could be made on how the silane and waterglass treatments would have ranked compared to the other treatments. The high cost of the silane would have negative effects on the score, but the mechanical properties observed in literature from using this treatment would give it an advantage in the tensile and compressive strength. Based on this it could be assumed that the silane treated samples would have placed closely behind the cement treated samples. While for the waterglass samples the treatment was cheaper than all other except the cement treatment. It was also noted in literature that the waterglass pre-treatment was able to largely reduce the water absorption of fibres, which improves the workability of the concrete. The treatment also had a relatively low impact to the reduction of strength of concrete. Knowing this it could be speculated that the waterglass pre-treatment would perform similar to the silane pre-treatment as both involve a silicon bonding occurring on the surface of the fibres.

5.2. Recommendations

5.2.1. Fibre Pre-treatments.

The results from the alkali treatment showed a decrease in strength of the concrete. This was expected but not to the level as seen in this paper. This could have been due to an overexposure to the alkali. This could be mitigated in the future by adding a couple drops of acetic acid to the water to help neutralize some of the remaining alkali in the fibres. As was mentioned in (Mwaikambo & Ansell, 2002.)

Concrete pre-treatment proved to attain a high compressive strength when compared to the other treatment but failed quicker under tensile loading. The reason for this is not clear and research into the tensile behaviour of cement treated fibres would be important in garnering a wholistic understanding of the effect of this treatment.

To fully understand what happens when these fibres are treated will require more robust testing methods. One type of test would involve the use of a Scanning Electron Microscope (SEM) for analysis. This analysis looks at the individual fibres to deduce what chemical and morphological changes were observed. This would provide more conclusive evidence on the effects of this treatment on the fibres as was done in (Oushabi et al., 2017).

5.2.2. Concrete

The mixture developed for this report was designed to achieve high compressive strength. Its intended purpose was to be used for structural purposes, the materials were fixed and only the fibres were changed. This mixture could be further optimized for other purposes by adjusting the other elements in the concrete mixture. As one of the requirements was to have a consistency that could be used on a vibrating press with immediate mould release. A follow up study investigating this property would be required.

The sound and heat insulating properties were not able to be investigated in this paper. As is known, natural fibres have the ability to improve these properties of concrete once incorporated. A follow up study identifying the benefits of using these treated fibres to improve the sound and heat insulating properties should be explored.

The concrete developed attained relatively good mechanical properties, this alone is not enough for the material to be adopted into practical use. The durability is another aspect of this concrete that needs to be investigated before use. This would involve understanding the effect of water penetration as well as the resistance to freeze and thaw. Research into this would highlight ways to improve the durability of concrete.

Cubes used to compare the compressive and tensile strength where not all cured for the same period. Most were cured longer than 28 days which may affect the results of the data. In the future all samples would ideally be cured for the same amount of time. So as to attain a baseline for the comparison between the samples.

A shorter period for testing the compressive and tensile strength of the sample would help understand the strength development of the mixture. This could include a 7 day and 14 day compressive and tensile strength test as it would help track how the strength develops in the concrete.

6. References

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7. Appendix

7.1. Pairwise Matrix

Sustainability	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2
CEM2-10	1.00	1.00	1.00	1.00
CEM0.5-2	1.00	1.00	1.00	1.00
ALK2-10	1.00	1.00	1.00	1.00
ALK0.5-2	1.00	1.00	1.00	1.00
Sum	4.00	4.00	4.00	4.00

Workability	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2
CEM2-10	1.00	0.50	7.00	3.00
CEM0.5-2	2.00	1.00	8.00	4.00
ALK2-10	0.14	0.13	1.00	0.50
ALK0.5-2	0.33	0.25	2.00	1.00
Sum	3.48	1.88	18.00	8.50

Compressive Strength	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2
CEM2-10	1.00	0.50	8.00	6.00
CEM0.5-2	2.00	1.00	9.00	7.00
ALK2-10	0.13	0.11	1.00	0.33
ALK0.5-2	0.17	0.14	3.00	1.00
Sum	3.29	1.75	21.00	14.33

Cost	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2
CEM2-10	1.00	1.00	3.00	3.00
CEM0.5-2	1.00	1.00	3.00	3.00
ALK2-10	0.33	0.33	1.00	1.00
ALK0.5-2	0.33	0.33	1.00	1.00
Sum	2.67	2.67	8.00	8.00

Tensile Strength	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2
CEM2-10	1.00	4.00	7.00	0.33
CEM0.5-2	0.25	1.00	3.00	0.17
ALK2-10	0.14	0.33	1.00	0.14
ALK0.5-2	3.00	6.00	7.00	1.00
Sum	4.39	11.33	18.00	1.64

7.2. Normalized Weight

Sustainability	CEM2-10	CEM0.5-2	ALK 2-10	ALK 0.5-2	Normalized Weight
CEM2-10	0.25	0.25	0.25	0.25	0.25
CEM0.5-2	0.25	0.25	0.25	0.25	0.25
ALK2-10	0.25	0.25	0.25	0.25	0.25
ALK0.5-2	0.25	0.25	0.25	0.25	0.25

Workability	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2	Normalized Weight
CEM2-10	0.29	0.27	0.39	0.35	0.32
CEM0.5-2	0.58	0.53	0.44	0.47	0.51
ALK2-10	0.04	0.07	0.06	0.06	0.06
ALK0.5-2	0.10	0.13	0.11	0.12	0.11

Compressive Strength	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2	Normalized Weight
CEM2-10	0.30	0.29	0.38	0.42	0.35
CEM0.5-2	0.61	0.57	0.43	0.49	0.52
ALK2-10	0.04	0.06	0.05	0.02	0.04
ALK0.5-2	0.05	0.08	0.14	0.07	0.09

Cost	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2	Normalized Weight
CEM2-10	0.38	0.38	0.38	0.38	0.38
CEM0.5-2	0.38	0.38	0.38	0.38	0.38
ALK2-10	0.13	0.13	0.13	0.13	0.13
ALK0.5-2	0.13	0.13	0.13	0.13	0.13

Tensile Strength	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2	Normalized Weight
CEM2-10	0.23	0.35	0.39	0.20	0.29
CEM0.5-2	0.06	0.09	0.17	0.10	0.10
ALK2-10	0.03	0.03	0.06	0.09	0.05
ALK0.5-2	0.68	0.53	0.39	0.61	0.55

7.3. Consistency check

Sustainability	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2	Sum/w		R.I	0.90
CEM2-10	0.25	0.25	0.25	0.25	4.00		λmax	4.00
CEM0.5-2	0.25	0.25	0.25	0.25	4.00		Consistency Index	0.00
ALK2-10	0.25	0.25	0.25	0.25	4.00		Consistency Ratio	0.00
ALK0.5-2	0.25	0.25	0.25	0.25	4.00			

Workability	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2	Sum/w		R.I	0.90
CEM2-10	0.32	0.25	0.39	0.34	4.04		λmax	4.03
CEM0.5-2	0.65	0.51	0.44	0.46	4.06		Consistency Index	0.01
ALK2-10	0.05	0.06	0.06	0.06	4.00		Consistency Ratio	0.01
ALK0.5-2	0.11	0.13	0.11	0.11	4.02			

Compressive Strength	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2	Sum/w		R.I	0.90
CEM2-10	0.35	0.26	0.34	0.52	4.24		λmax	4.13
CEM0.5-2	0.69	0.52	0.39	0.60	4.22		Consistency Index	0.04
ALK2-10	0.04	0.06	0.04	0.03	4.03		Consistency Ratio	0.05
ALK0.5-2	0.06	0.07	0.13	0.09	4.04			

Cost	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2	Sum/w		R.I	0.90
CEM2-10	0.38	0.38	0.38	0.38	4.00		λmax	4.00
CEM0.5-2	0.38	0.38	0.38	0.38	4.00		Consistency Index	0.00
ALK2-10	0.13	0.13	0.13	0.13	4.00		Consistency Ratio	0.00
ALK0.5-2	0.13	0.13	0.13	0.13	4.00			

Tensile Strength	CEM2-10	CEM0.5-2	ALK2-10	ALK0.5-2	Sum/w		R.I	0.90
CEM2-10	0.29	0.41	0.36	0.18	4.26		λmax	4.19
CEM0.5-2	0.07	0.10	0.15	0.09	4.08		Consistency Index	0.06
ALK2-10	0.04	0.03	0.05	0.08	4.04		Consistency Ratio	0.07
ALK0.5-2	0.88	0.62	0.36	0.55	4.36			