Special Course

Development of Zerowaste clay material

Research immersion

Natacha Helena Bill Makkonen, s113098

Supervisor
Professor Per Goltermann

Department of Civil Engineering
Technical University of Denmark
December, 2016

Contents

Preface

This report is compiled as a 5 ECTS point special course at the MSc program in Civil Engineering. Compilation of this project has taken place in the period from 29th August 2016 to the 22nd December 2016 and is developed by Natacha Helena Bill Makkonen. I would like to thank the supervisor of this project Professor Per Goltermann and Ph.D student Ida Maria Geisztor Bertelsen from the Department of Civil Engineering for assistance to the project.

1 Introduction

This project is developed in collaboration with the Ph.D project compiled by Ida Gieszto Bertelsen containing the study of reusable fishing nets. The fishing nets are separated into small plastic fibres. These fibres can be used for many different proposes, among others, these can be used for improvement of structural building material properties, and thereby achieving less waste, pollution and improved building materials to a less CO_2 emissions under the production of the materials.

Use of fibres in construction materials, typically increases the ductility and toughness, in the efforts to investigate the most non-polluting building materials and to examine the fibres effects on different kinds of building materials, clay is studied in this project. The clay used in this project are from Greenland and is cast as unfired elements as desired to make prisms, which can be produced in Greenland, since there is no brick work in Greenland and thus would be inconvenient to transport the clay to e.g. Denmark, and then transport the burned clay elements back to Greenland. For this reason the clay elements in this project is moulded in small batches and dried in a small industrial oven at low temperatures.

The clay in this project is tested for flexural strength, ductility and compressive strength, as these parameters are the primary loads structural elements are exposed.

In this report there will be a short description of each material used in the project and which consideration there have been done. Hereafter a description of the mixing and casting process is introduced, subsequently an explanation of the conducted tests and setup is made, followed by a presentation of the results. Analysing the results, the impact of the fibres is discussed and other aspects to further investigation is suggested.

2 Practical considerations

In order to design the different mixtures and determine which parameters that is of interest to investigate the plastic fibres impact on the clay with respect to the workability, the bending strength, the compression strength, the porosity, the shrinkage, etc. it is necessary to look into each material properties and characteristics.

2.1 Materials

Clay or glacial flour
The clay used in this project is collected in Greenland along the coast in the area of Nuuk, Fig.(2.1) shows the clay used in this project.

Figure 2.1: The clay used for this project.

The clay is fine-grained, the reason for this is that the Greenland inland ice has moved steadily across significant distances. In the process, the underlying bedrock has been crushed and grinded to a fine powder, called glacial flour in Danish "gletsjermel", with which the melt water is lead to lakes and inlets, where it has deposited as mud. Over the past millennia there has been allocated enormous amounts of this fine mud along the coasts of Greenland.
Unlike many of Greenland's other raw materials, this material constantly forms new material that can be utilized without risk of contamination of the environment [1].

It is discussed whether the material is considered as a clay or not. There are some criterias that must be fulfilled in order to determine whether a soil is a clay or not. The general criteria are that the soil must contain a certain amount of clay minerals and another criteria is that the grain size should be smaller than 0.002 mm [2]. The glacial flour does not contain very large amounts of the minerals but it fulfil the requirement of the grain size, and is therefore, in this report considered as and called a clay in the following.

Gravel
The gravel used in the mixes is extracted from raw materials of the tray in Kallerup in Denmark. The gravel is a clayey gravel consisting of grain sizes in the range of 4-8 mm, Fig.(2.1) shows the gravel used in this project.

Figure 2.2: The gravel used for this project.

Plastic fibres
The plastic fibres are from old fishing nets mainly collected in Denmark. All the fibres are made of polyethylene. The fibres have a mean diameter of 0.3 mm, but varies a lot in both diameter and length. The fibres provided to this project are containing a great deal of dirt, probably from the sea in general, the seabed, fish etc. In this project, it is decided to investigate whether there is an impact from these impurities by making a series of unclean fibres and one with clean fibres with varying fibre content. It should be noted that in this report when referring to a material content in percentage, the content is in weight-%. The fibre content varies for bending tests from 0 % (reference) to 2%, with increments of 0.25% fibres. In addition it is also chosen to make specimens with 3% and 4%. For the compression tests it is decided to investigate fibre contents of 0%, 1% and 2%, as it is not expected to see large contributions from the fibres to the compressive strength.

Ida Maria Gieysztor Bertelsen has in previous studies investigated the requirements for the grain size of unburned clay tiles. These studies has shown that because of the significantly fine grain size of the clay, the requirements are not met, see Fig.(2.3).

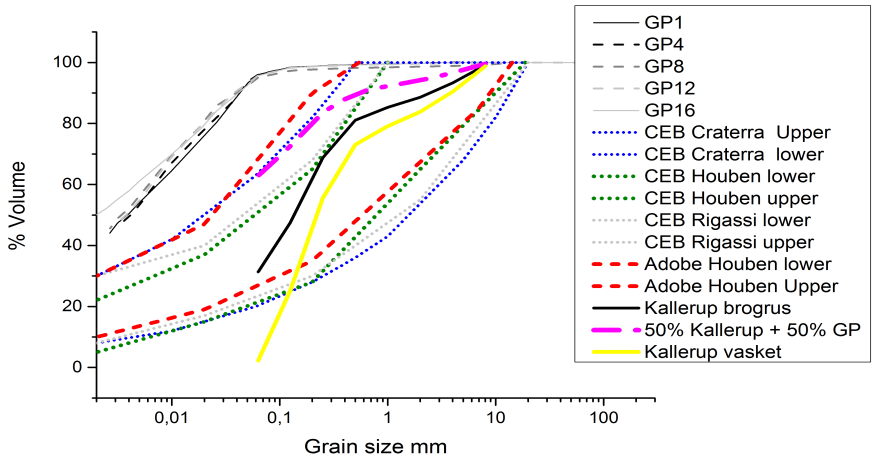

Figure 2.3: Grain size distribution analysis for the Greenland clay, Kallerup gravel and the different requirements of unburnt clay. Conducted by Ida Maria Gieysztor Bertelsen.

Where GP1, GP4, GP8, GP12 and GP16 denotes tests performed on the clay, in which all portions of the clay is collocted from the same area to insure homogenity. Craterra, Houben and Rigassi is different standards/studies applied for clay that is used for unfired clay tiles. As seen on Fig.(2.3), the GP alone does not fulfil any of the standards, since the curves for GP is out side of the envelope of the standards because of the clay is too fine-grained. From the figure it can be seen that the grain size distribution of the Kallerup gravel is fulfilling the standards, thus a mixture of 50 % GP and 50 % Kallerup gravel lies within the Adobe Houben and the CEB Craterra standards. Because of these investigations it has been considered in this project whether the mixtures should be pure clay/fibre mixtures or if it should be clay/gravel/fibre. Casting of the two proposals has been conducted and it was decided that the specimens should consist of a mix of 50 % clay and 50 % gravel, since the pure clay mixture resulted in a poor workability during casting and cracked completely through after drying, see Fig.(2.4).

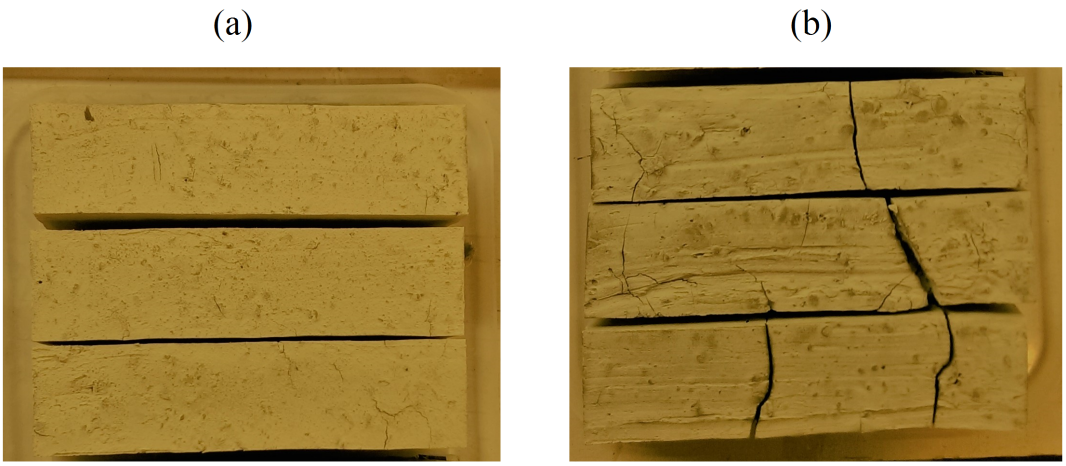

Figure 2.4: (a) Rectangular specimen with 50% gravel and 50% percent clay. (b) Rectangular specimen with pure clay.

In addition to the considerations of the different materials it has also been considered which water content, the mixtures must contain. A number of specimens (1% fiber, 50% clay and 50% gravel) were cast, with varying water content. These tests showed that by very small increases in water content, the sample was very fluid, shrunk a great deal during the drying and had precipitation of the gravel and it was thus decided that the added water content in the samples would have to be 10% ,(where the natural water content of the clay has been measured to be approximately 15%), in order to still be workable and avoid as much shrinkage as possible.

3 Bending and compression theory

3.1 Bending theory

According to DS/EN 1992-1-1 a beam must have a span which is larger than or equal to 3 times the cross-sections total height and the beam should have a width there is equal or less than 5 times the total height.
These definitions is in reality substitutive for the real definition, which is that a beam is a construction element that can be analysed from the conditions there is applicable for beams. Beams primary exposure is bending, which is theoretical and experimental well documented. Bending is determined from the geometrical condition, which says that plane cross sections remains plane, this means that the strains are calculated linear. It is noted that the condition applies regardless from whether the concrete is cracked or not, which means that in a cracked cross section it is assumed that the concrete and the reinforcement follows each other. By the calculations of beams the 3 following conditions is used [6]:

- The geometrical condition, i.e plane cross sections remain plane.
- The physical condition, i.e the correlation between strains and stresses.
- The statical condition. i.e there must be equilibrium between the cross sections stresses and the sectional forces that acts on the cross section..

The requirements there are listed for the serviceability of a construction is called the serviceability limit state. The serviceability limit state is normally considered for loads, which are so small compared to the structures bearing capacity, that the construction can be assumed to act linear elastic, i.e. calculations in the serviceability limit state normally applies the elasticity theory.
Considering the ultimate limit state the plasticity theory is often considered, i.e. the structure has a non-linear behaviour. The most common parameter of interest in the ultimate limit state is the ultimate strength, but in many cases the material behaviour is of interest, which the ultimate strength does not tells much about. For this reason the toughness of the element can be analysed, which is the area under the stress-strain curve.

In this project the flexural performance of toughness is considered as the area under the load-deflection curve, which is obtained by tests on simply supported beams under third-point loading. The determination of the toughness in these terms is an indication of the capability of the energy absorption, and the magnitude is directly dependent on the geometrical characteristics of the tested element. A typical load-deflection curve for fibre reinforced concrete bending specimen is shown in the figure below [5].

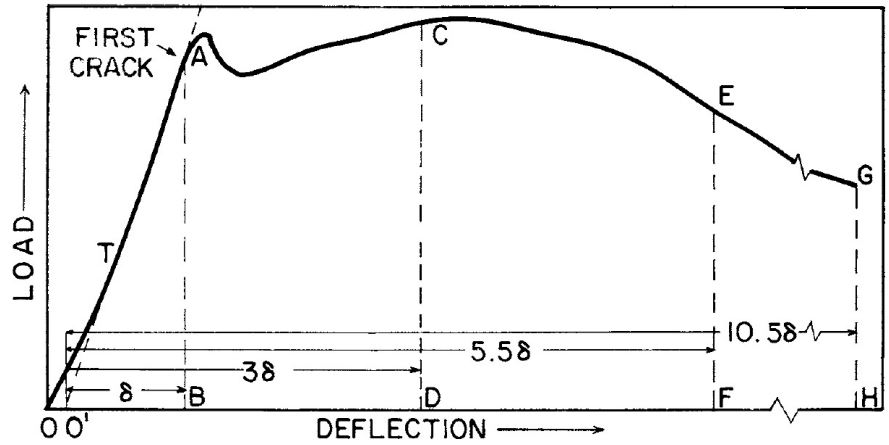

Figure 3.1: Load-deflection curve for a fibre reinforced concrete specimen [5].

Determining the toughness the standard ASTM International [5] suggest different divisions of the area under the curve. The toughness has to be determined from the deflection of the first crack (Point A), up to a deflection of 3, 5.5 or 10.5 times the first crack deflection (Point C, E or G) [5], in this report 10.5 times the first crack deflection is used i.e. point G on Fig.(3.1.

3.2 Compression theory

Compression tests is normally performed as short time tests, i.e. experiments that only last for a couple of minutes. By such tests a short time strength and a short time stress strain curve is obtained.
At small stresses the correlation between stresses and strains is almost completely linear. However there is a tendency of the stress-strain curve to have a curvature and the tendency gets more apparent at higher stresses. For strains beyond the strain corresponding to the maximum stress, the stress decreases and the fracture occurs when the strain reaches the fracture strain. The principal compression stress-strain curve is illustrated below [6].

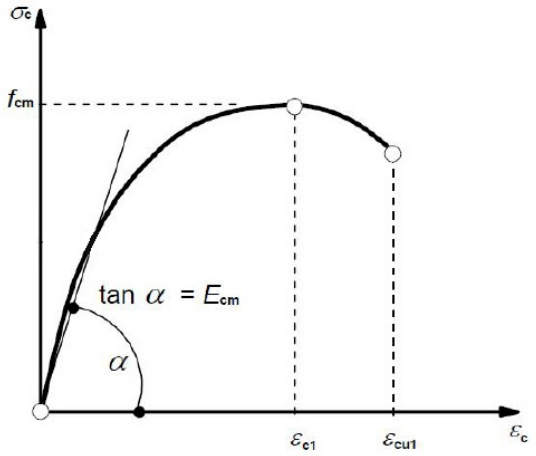

Figure 3.2: Typical compression stress-strain curve for concrete.

4 Mixing and casting

4.1 Cleaning fibres

To mould the two series of specimens with unclean fibres and clean fibres, it is necessary to clean out the impurities of the fibres. The following things are used in the process.

- Plastic fibres.
- Industrial bucket.
- Water.

A jug is filled with the unclean fibres and poured into the industrial bucket, then the bucket is filled with 4/5 water. Hereafter the fibres and the water in the bucket are stirred for approximately 5 minutes. The water is then sieved from the fibres and the procedure is repeated three times. After rinsing the fibres three times, the fibres are spread out on paper and set to dry for 24 hours at room temperature.

4.2 Mixing

4.2.1 Components

The mix designs can be found in appendix A.1 and appendix A.2.

Figure 4.1: Components to be used for mixing and casting. Left: Oven - Memmert UF 160. Left center: Toni, industrial mixer. Right center: Materials and industrial mixing bowl. Right: Specimens and compression piston.

- Oven, Memmert UF 160.
- Toni, Industrial mixer.
- Industrial mixing bowl.
- Materials, (clay, gravel, fibers and water)
- Specimens, rectangular prisms ($16cm \times 4cm \times 4cm$) and cylinder specimens ($12cm \times 6cm$).
- Compression piston

4.2.2 Mixing procedure

Figure 4.2: The mixing process. Left: Dry mixture (clay, gravel and fibers). Right: Mixing in Toni, industrial mixer

- Preheat the oven to 30 °C
- Measure the desired amount of each material (clay, gravel, fibers and water) in containers adequate in size.
- Spray the specimens and the piston with mould oil.

The dry materials (clay, gravel and fibres) are being mixed by hand in a industrial mixing bowl, first the clay and fibres together, hereby, the gravel is mixed with the clay and fibres (making the specimens it was observed that a higher fibre content than 4% would almost be impossible to mix properly). When the dry materials are properly mixed, the bowl with the dry materials is attached to the industrial mixer. Make sure to have a jug with the desired amount of water next to the mixer before starting the mixing. Start the industrial mixer and pour gently the water in the mixture, let the mixer continue the mixing for approximately two minutes.

4.3 Casting

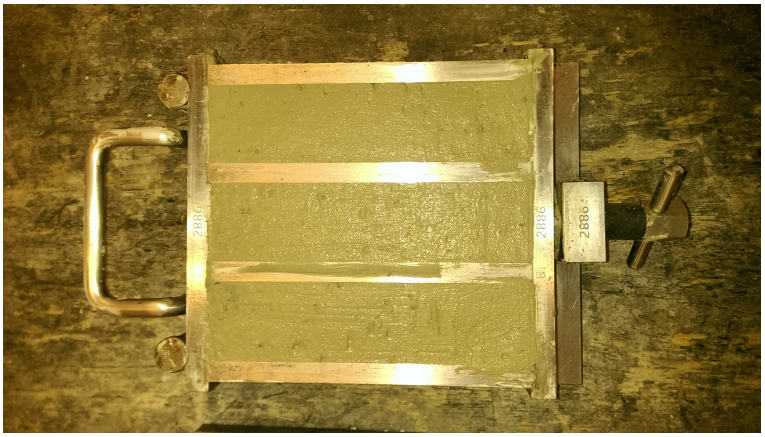

Figure 4.3: Casting of the specimens.

Pour the mixture into the specimens. If the mixture is not fluid enough, shovel the mixture carefully with at spoon into the specimens. After filling the specimens, compress the mixture further into the specimen with the piston, then pour some more of the mixture into the specimen and compress with the piston again, repeat this until the specimen is completely full and compact. Scrape excess material off the specimens, to ensure the surface is smooth. The specimens is then placed in the oven for 48 hours at 30^oC.

Some tests was carried out investigating the drying temperature at approximately 50^oC in 48 hours with 1% fibre content. The tests showed that 50^oC was to high a temperature, since the specimens cracked in each test, see Fig.(4.4), thus the temperature was chosen to 30^oC for the following tests.

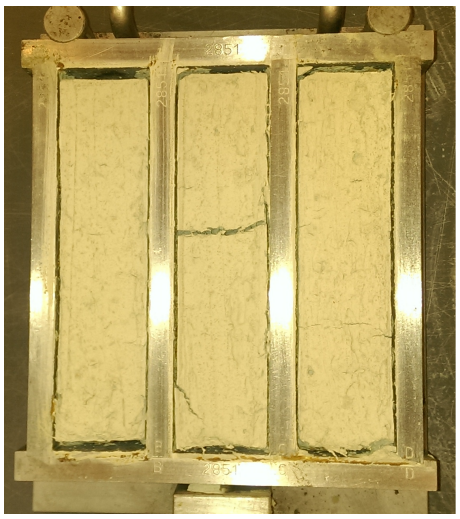

Figure 4.4: Cracked specimens after drying in 48 hours under 50^oC.

During the drying of the cylinder specimens the drying time of 48 hours at 30^oC showed not to be enough, since the specimens still was wet after this drying time. Thus, a

reference mass for each fibre content with clean and unclean fibres was determined from the density achieved from the rectangular specimens. Hereafter the mass of each cylinder specimens was measured every 24 hours under room temperature until the reference mass was achieved by most of the cylinders, which was estimated in average to be 96 hours after taking out of the oven, see Fig.(4.5).

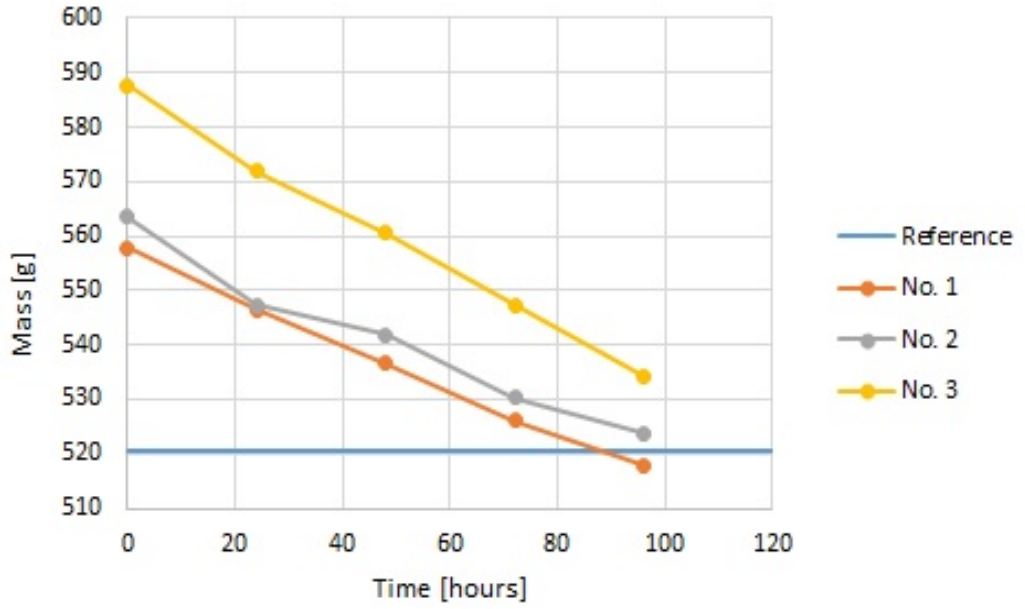

Figure 4.5: Estimation of drying time and mass for the cylinder specimens relative to the rectangular specimens. Mass achieved from cylinder specimens with 2% clean fibres.

The plots for estimating the drying time for the rest of the specimens can be found in appendix A.3.

5 Testing

5.1 Bending test

The specimens for bending tests were moulded as prisms with quadratic cross-section, with a height of 40 mm, a width of 40 mm and a length of 160 mm, see Fig.(5.1).

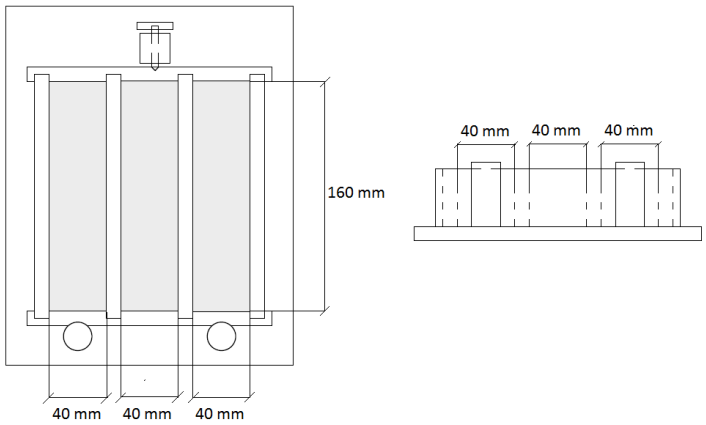

Figure 5.1: Drawing of quadratic prism.

The bending tests were performed as a three-point bending setup, with 100 mm between the supports, and the load acting at the center of the specimen see Fig.(5.2). The tests were conducted in a 10 kN instron testing machine with an Instron control system. For the bending tests, the machine was installed by entering the desired test parameters into the control center. The bending tests in this project was loaded at a rate of 1 mm/sec.

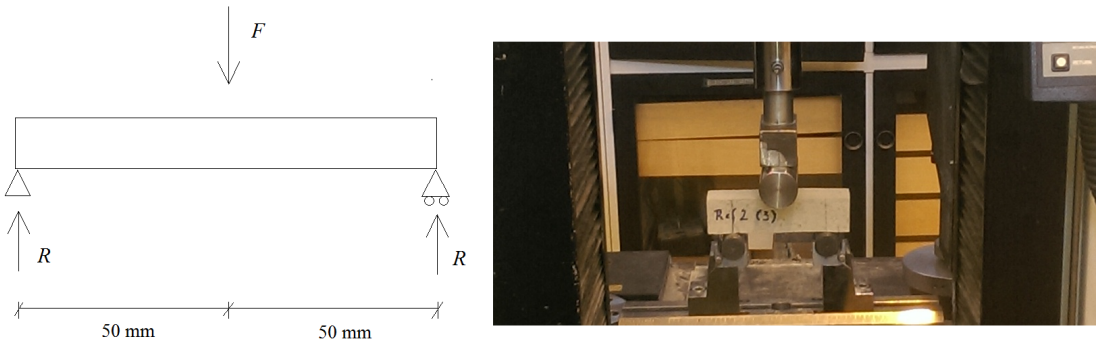

Figure 5.2: Setup of three-point bending test: Simply supported beam, loaded with a point load at the center.

5.2 Compression test

The specimens for the compression tests were cast cylinders with a diameter of 60 mm and a height of 120 mm, see Fig.(5.3). The compression test is in correspondance with the Eurocode [3].

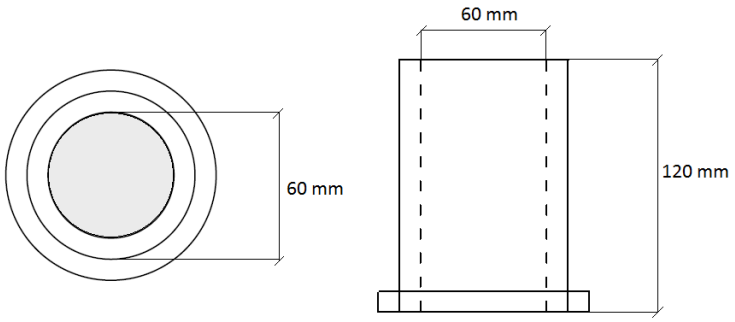

Figure 5.3: Drawing of cylinder.

The compression tests were performed in a 10 kN Instron machine with an Instron control system. The compression tests were loaded at a rate of 1 mm/sec, and the tests were performed until fracture was detected, which can be seen in a large decrease in the acting load.

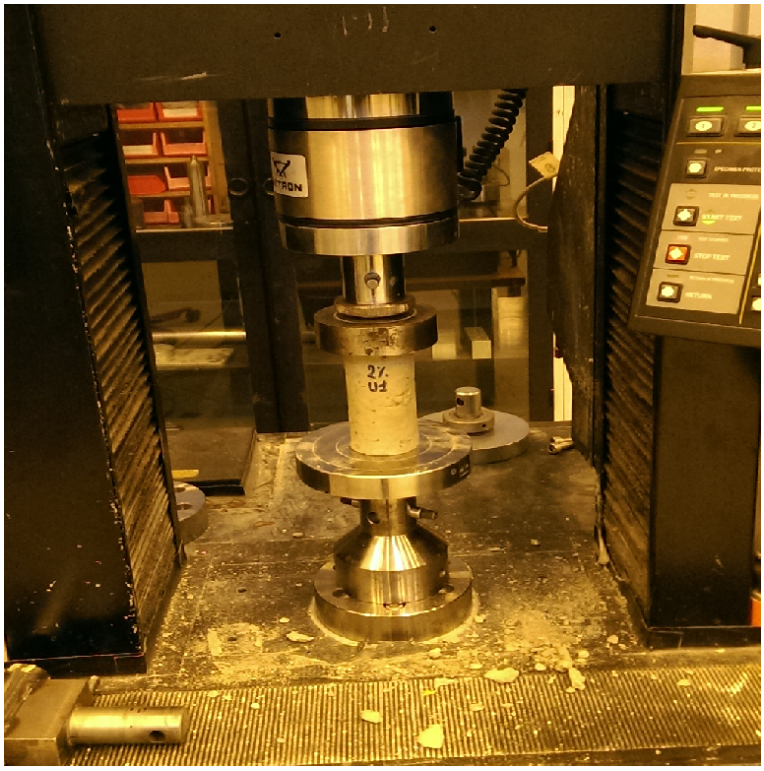

Figure 5.4: Setup of compression bending test.

6 Results

6.1 Bending test

In the bending tests two main parameters is analysed in two different areas of the beam behaviour during the bending test, namely in the elastic area and the plastic area. In the elastic area, the first fracture strength is considered see Fig.(6.1) and Tab.(6.1). In the plastic area, the energy absortion capability also called the toughness is considered see Tab.(6.2).

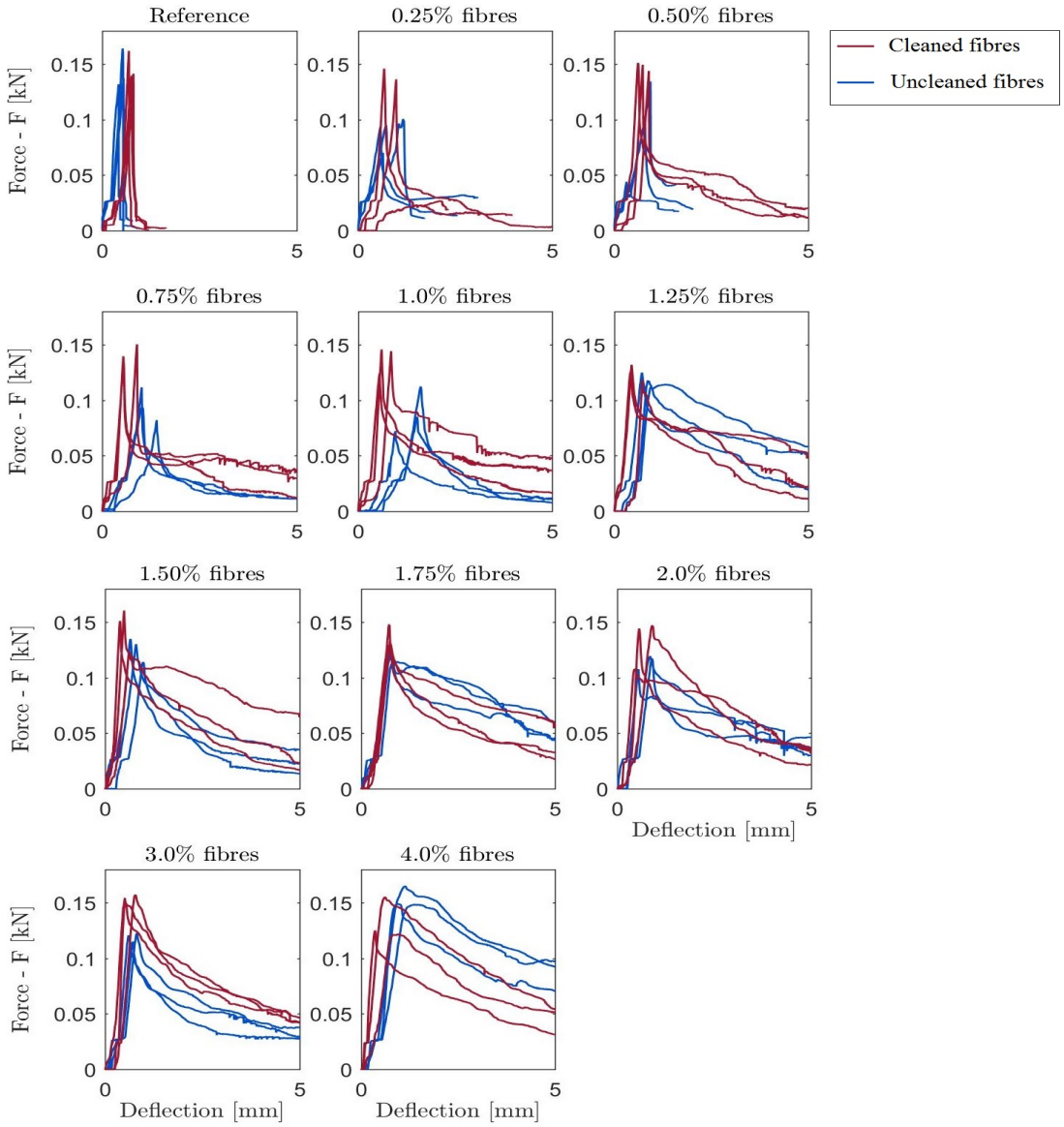

Figure 6.1: Deformation-load curves from bending tests for all specimens with unclean and clean fibres, respectively. The red curves illustrates the deformation-load curves for the cleaned fibres and the blue curves illustrates the deformation-load curves for the uncleaned fibres.

From Fig.(6.1) it is seen that the the reference specimens with 0% fibres have a completely brittle behaviour, with no indication of a plastic behaviour. With increased fibre content the behaviour becomes less brittle and the plastic area increases. It can also be seen that there is no second fracture strength in any of the tested elements. Furthermore the curves shows that the plasticity of the specimens containing cleaned fibres is larger than the specimens containing uncleaned fibres except in the case of 4% fibre content.

Bending strength					
Fibre concentration	Unclean fibres [kN]	Clean fibres [kN]	Difference (*1) Unclean [%]	Difference (*2) Clean [%]	Difference (*3) [%]
Reference 0 %	0.143	0.146	-	-	2.05
0.25 %	0.089	0.148	-37.76	1.36	39.86
0.50 %	0.093	0.148	-34.97	1.36	37.16
0.75 %	0.096	0.142	-32.87	-2.74	32.39
1.00 %	0.089	0.138	-37.76	-5.48	35.51
1.25 %	0.120	0.126	-16.08	-13.70	4.76
1.50 %	0.126	0.146	-11.89	0.00	13.70
1.75 %	0.119	0.152	-16.78	4.11	21.71
2.00 %	0.115	0.134	-19.58	-8.22	14.18
3.00 %	0.119	0.155	-16.78	6.16	23.23
4.00 %	0.157	0.134	9.79	-8.22	-17.16

Table 6.1: Mean bending strengths for prisms. (*1) - Difference between bending strength of reference and varying fibre concentration for unclean fibres. (*2) - Difference between bending strength of reference and varying fibre concentration for clean fibres. (*3) Difference between bending strength of clean fibres and unclean fibres for varying fibre concentration. Positive difference indicate increase in strength and negative difference indicate decrease in strength.

Tab.(6.1) shows that the fibres impact on the bending strength is not beneficial and that they in general have a negative effect, but it is seen that the uncleaned fibres have the largest negative impact. The highest bending strengths is obtained in the clean fibre specimens, which can be seen by comparing the uncleaned fibre results with the cleaned fibres results. However, it is seen on Fig.(6.2) that there is no clear tendency on the calculated differences.

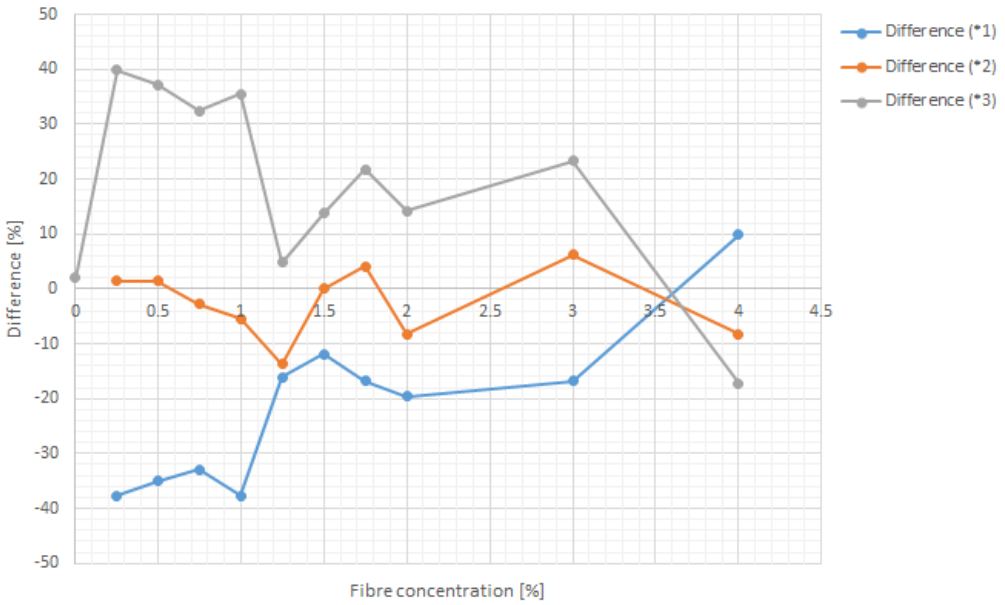

Figure 6.2: Differences in bending strengths. (*1) - Difference between bending strength of reference and varying fibre concentration for unclean fibres. (*2) - Difference between bending strength of reference and varying fibre concentration for clean fibres. (*3) Difference between bending strength of clean fibres and unclean fibres for varying fibre concentration. Positive difference indicate increase in strength and negative difference indicate decrease in strength.

6.1.1 Plasticity

The plastic area is considered to begin from the first fracture to 10.5 times the deflection at first fracture in accordance to [5], see Fig.(6.3).

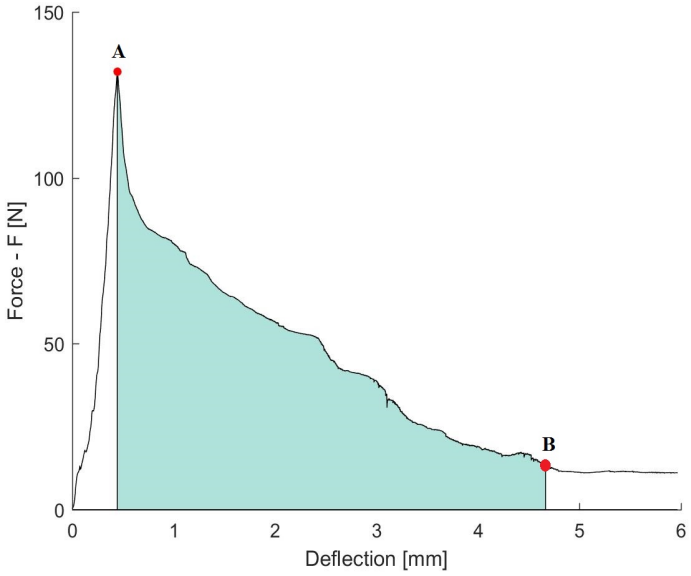

Figure 6.3: Representative bending deformation-load curve of a fibre reinforced clay beam. The ultimate bending strength is shown with a red point and the plastic area (energy absortion capability) under the curve is marked with a blue/green colour. The displayed representative curve has a fibre concentration of 1.25% clean fibres.

Toughness					
Fibre concentration	Unclean fibres [10^{-3} Nm]	Clean fibres [10^{-3} Nm]	Difference (*1) Unclean [10^3%]	Difference (*2) Clean [10^3%]	Difference (*3) [%]
Reference 0 %	3.00	10.80	-	-	72.22
0.25 %	44.94	79.63	1.398	0.637	43.56
0.50 %	33.19	175.7	1.006	1.527	81.11
0.75 %	78.90	218.7	2.530	1.925	63.92
1.00 %	90.02	279.7	2.900	2.490	67.82
1.25 %	410.6	282.9	13.586	2.519	-45.14
1.50 %	240.3	329.3	7.910	2.949	27.03
1.75 %	439.6	351.2	14.553	3.152	-25.17
2.00 %	322.2	305.8	10.640	2.731	-5.36
3.00 %	267.1	379.2	8.803	3.411	29.56
4.00 %	733.5	391.7	24.350	3.527	-87.26

Table 6.2: Mean bending toughness for fibre reinforced clay beams. (*1) - Difference between toughness of reference and varying fibre concentration for unclean fibres. (*2) - Difference between toughness of reference and varying fibre concentration for clean fibres. (*3) Difference between toughness of unclean fibres and clean fibres for varying fibre concentration. Positive difference indicate increase in strength and negative difference indicate decrease in strength.

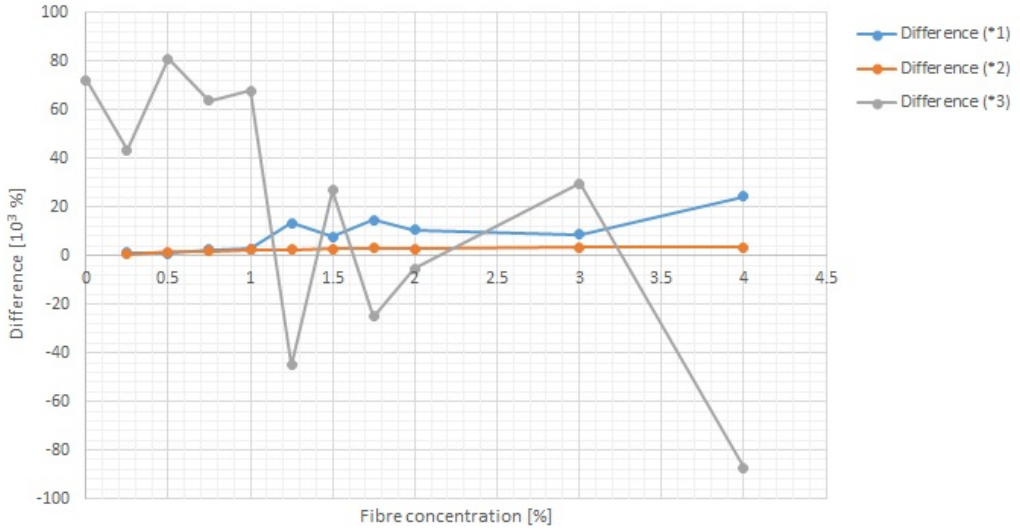

Figure 6.4: Differences in toughness in bending tests. (*1) - Difference between toughness of reference and varying fibre concentration for unclean fibres. (*2) - Difference between toughness of reference and varying fibre concentration for clean fibres. (*3) Difference between toughness of unclean fibres and clean fibres for varying fibre concentration. Positive difference indicate increase in strength and negative difference indicate decrease in strength.

From Tab.(6.2) and Fig.(6.4) it can be seen that there is a major increase in the energy absorption capability when increasing the fibre content i.e by increasing the fibre content from 0.25% to 0.50% the toughness is increased with 1006.0% for uncleaned fibres.. Furthermore the specimens with cleaned fibres has a larger toughness than the uncleaned fibres up to a fibre content of 1.25%, at this fibre content the impact of the impurities in the uncleaned fibres is less distinct and varies a lot.
During the tests it was observed that there was no crack growth in the reference specimens, since the specimens at the first crack completely split as a result of the low ductility of the material. Increasing the fibre content in the specimens resulted in a less brittle fracture concerning the separation, since the specimens cracks but do not separate in two half, which confirms the increased toughness.

6.2 Compression test

From the compressive tests one parameter is investigated, namely the compressive strength.

The figure below illustrates the compressive strength for each tested cylinder specimen dependant on the fibre content. It should be mentioned that during the tests of the specimens one reference specimen was defect as a result of a incorrect machine setting and for this reason the specimen is not included in the following.

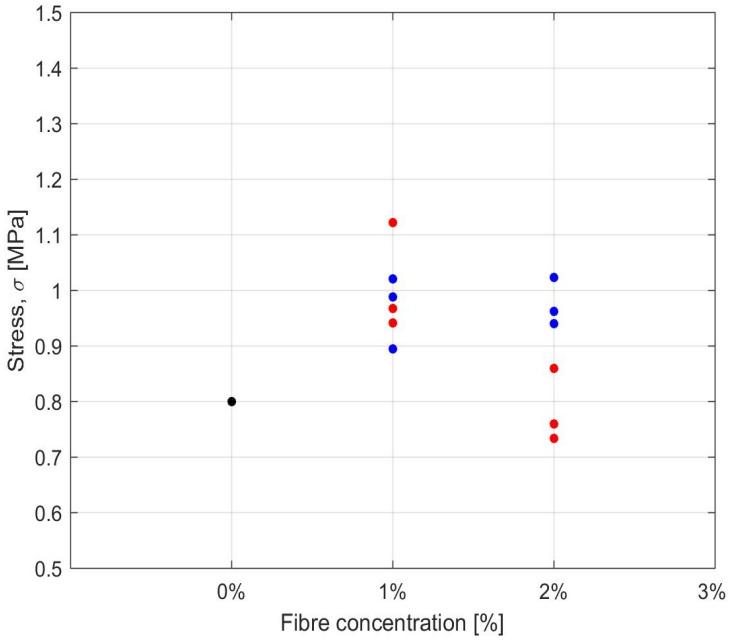

Figure 6.5: Compressive strength of cleaned and uncleaned fibre specimens dependant on fibre concentration. Black points - References, Blue points - Uncleaned fibres, Red points - Cleaned fibres.

The standard deviation of all the compressive strengths of the cylinder specimens is $111.88 \cdot 10^{-3}$ MPa, which only is 1/7 of the smallest compressive strength obtained. This indicates that the fibres' impact on the compressive strength is not significant, whether the fibres are cleaned or not, see Fig.(6.5).

Compressive strength						
		Fibre concentration			**Difference(*)**	
	No.	0% [10^{-3} MPa]	1% [10^{-3} MPa]	2% [10^{-3} MPa]	1% [%]	2% [%]
Unclean fibres	**1**	799.61	893.8	1022.3	11.77	27.84
	2	799.70	988.1	939.3	23.57	17.46
	3	-	1020.3	961.8	27.59	20.28
	Mean	799.66	967.4	974.5	20.98	21.86
Clean fibres	**1**	799.61	1121.6	732.5	40.26	-8.39
	2	799.70	967.5	759.6	20.99	-5.01
	3	-	941.3	859.5	17.71	7.48
	Mean	799.66	1010.1	783.9	26.32	-1.97

Table 6.3: Compressive strength for each cylinder specimen with 1% and 2% unclean and clean fibres and corresponding mean compressive strengths. Difference(*) between compressive strength of specimens with fibres (clean and uncleaned) and mean compressive strength of the references. Positive difference indicate increase in strength and negative difference indicate decrease in strength

From Tab.(6.3) it is seen that the compressive strength for the uncleaned fibres is increased compared with the reference without fibres from approximately 11% to 27%. Whereas the compressive strengths for the cleaned fibre specimens are increased for 1% fibre content, but is generally decreased for 2% fibre content, which indicates that the fibre content in the overall has not a major impact on the compressive strength.

7 Discussion

From the bending tests it was observed that the plastic behaviour of the specimens were increased, but no second fracture point was detected. This is needed in order to use the material as a reliable structural material. However the ductility of the material is increased with increased fibre content, which indicates that a further development and investigation of the material can be done in order to look further into the possibilities of an appropriate building material. The gravel could be investigated further in accordance to the clay content of the gravel and see if the clay should be rinsed out or if the clay have beneficial properties to the cohesiveness, brittleness, ductility, etc.

The results showed that the bending strength was significantly small, compared with other construction materials as concrete (10MPa - 35MPa) or bricks (0.17 MPa - 0.31 MPa). The same applies to the compressive strength. This is as expected, since the material was very brittle and had a low cohesiveness. There can be various reasons for the low strengths, one could be that the material was quit unworkable during the moulding, which could have resulted in air gabs in the specimens, leading to weaker strengths.

Furthermore, the workability in general was low, which may have resulted in lower strengths, ductility and cohesiveness. A reason for the pour workability could be the proportions of the mixtures. The mixtures had low water contents, in order to obtain higher strengths and less shrinkage, but this lowered the workability, which may have reduced the strength and therefore, may have had the opposite effect than desired.

8 Conclusion

The main objective of this project was to investigate the effect of adding polyethylene fibres to a clay mixture and to see the impact of the impurities in the fibres on the strength and the ductility.
From bending tests it was confirmed that the effect of the plastic fibres in a series of clay/gravel beam specimens was beneficial of both strength and ductility and showed a potential of further development towards a reliable building material.
The impact of the fibres in a compression test revealed on the other hand that there was no significant effect by adding the plastic fibres and therefore, it would be an economical disadvantage to use the plastic fibres in compression elements.

From the results it was also observed that the impact from the impurities in the fibres was large. This was especially seen for the bending tests, were the strengths was significantly higher for the cleaned fibres except for a fibre content of 4%, whereas the impurities' impact on the toughness showed to be non beneficial up to a fibre content of 1.25%, but appeared to have a positive impact on the specimens with higher fibre contents than 1.25%. This result implies that the impurities have properties which leads to a higher ductility when using a high fibre content and therefore the impurities may not be a disadvantage, when designing a structure, where a high plasticity is wanted. For the compression test there was no clear impact of the impurities, and for this reason there is no need for cleaning the fibres or in general to use fibres when designing a compression element with these materials.

It can be concluded that the reinforced plastic fibre clay elements has a potential as a zerowaste construction material, but further investigations have to be made in order to have a reliable building material with sufficient strengths and ductility.

References

[1] $http://snm.ku.dk/SNMnyheder/alle_nyheder/2016/2016.4/groenlandsk-mudder-skal-sikre-verdens-foedevareforsyning/$

[2] www.geolex.dk

[3] DS/EN 12390-3-2009, 2nd edition.

[4] DS/EN 1992-1-1.

[5] ASTM intenational, Designation: C 1018 – 97.

[6] B. C. Jensen, *Beton konstruktioner efter DS/EN 1992-1-1*, 2. udgave, 2012, Nyt Teknisk Forlag.

A Appendix

A.1 Mix designs for bending specimens

Mix design with unclean fibres						
Fibre concentration		Clay	Gravel	Fibre	Water	Total
0%	**Measured mass** [g]	1125.03	1125.08	0.00	250.78	2500.89
	Weight-percentage[%]	44.99	44.99	0.00	10.03	100.0
0.25%	**Measured mass** [g]	1125.02	1125.19	6.30	250.43	2506.82
	Weight-percentage[%]	44.88	44.88	0.25	10.00	100.0
0.50%	**Measured mass** [g]	1125.03	1125.02	12.56	250.17	2512.95
	Weight-percentage[%]	44.77	44.78	0.50	10.00	100.0
0.75%	**Measured mass**[g]	1125.06	1125.08	18.89	250.17	2519.14
	Weight-percentage[%]	44.66	44.66	0.75	10.00	100.0
1.00%	**Measured mass** [g]	1125.00	1125.06	25.25	250.73	2526.04
	Weight-percentage[%]	44.54	44.54	1.00	10.00	100.0
1.25%	**Measured mass** [g]	1125.12	1124.94	31.68	253.78	2535.52
	Weight-percentage[%]	44.37	44.37	1.25	10.01	100.0
1.50%	**Measured mass** [g]	1125.00	1125.14	38.06	254.36	2542.56
	Weight-percentage[%]	44.25	44.25	1.50	10.00	100.0
1.75%	**Measured mass** [g]	1125.01	1125.11	44.53	255.15	2549.8
	Weight-percentage[%]	44.12	44.13	1.75	10.01	100.0
2.00%	**Measured mass** [g]	1125.18	1125.15	51.05	255.73	2557.11
	Weight-percentage[%]	44.00	44.00	2.00	10.00	100.0
3.00%	**Measured mass** [g]	1124.98	1125.15	77.27	258.90	2586.30
	Weight-percentage[%]	43.50	43.50	3.00	10.01	100.0
4.00%	**Measured mass** [g]	1125.19	1124.96	104.03	261.51	2615.69
	Weight-percentage[%]	43.02	43.01	4.00	10.00	100.0

Table A.1: Mix design of the rectangular specimens with unclean fibres.

Mix design with clean fibres						
Fibre concentration		Clay	Gravel	Fibre	Water	Total
0%	**Measured mass** [g]	1124.98	1125	0.00	250.00	2500.01
	Weight-percentage[%]	45.00	45.00	0.00	10.00	100.0
0.25%	**Measured mass** [g]	1125.04	1125.19	6.27	250.68	2506.99
	Weight-percentage[%]	44.88	44.87	0.25	10.00	100.0
0.50%	**Measured mass** [g]	1125.03	1125.01	12.56	251.42	2514.02
	Weight-percentage[%]	44.75	44.75	0.50	10.00	100.0
0.75%	**Measured mass**[g]	1125.05	1125.01	18.89	252.08	2521.03
	Weight-percentage[%]	44.63	44.63	0.75	10.00	100.0
1.00%	**Measured mass** [g]	1125.06	1125.05	25.26	252.82	2528.19
	Weight-percentage[%]	44.50	44.50	1.00	10.00	100.0
1.25%	**Measured mass** [g]	1125.11	1125.04	31.64	253.66	2535.45
	Weight-percentage[%]	49.31	44.37	1.25	10.00	100.0
1.50%	**Measured mass** [g]	1125.00	1125.02	38.07	254.19	2542.28
	Weight-percentage[%]	44.25	44.25	1.50	10.00	100.0
1.75%	**Measured mass** [g]	1125.04	1125.03	44.52	254.95	2549.54
	Weight-percentage[%]	44.13	44.13	1.75	10.01	100.0
2.00%	**Measured mass** [g]	1124.98	1125.00	51.00	255.67	2556.65
	Weight-percentage[%]	44.00	44.00	2.00	10.00	100.0
3.00%	**Measured mass** [g]	1125.05	1125.06	77.26	258.61	2585.98
	Weight-percentage[%]	43.51	43.51	3.00	10.01	100.0
4.00%	**Measured mass** [g]	1125.1	1125.03	104.00	261.94	2616.07
	Weight-percentage[%]	43.01	43.00	4.00	10.01	100.0

Table A.2: Mix design of the rectangular specimens with clean fibres.

A.2 Mix design for compression specimens

Mix design with unclean fibres						
Fibre concentration		Clay	Gravel	Fibre	Water	Total
0%	**Measured mass** [g]	1125.07	1125.05	0.00	250.63	2500.75
	Weight-percentage[%]	44.99	44.99	0.00	10.02	100.0
1.00%	**Measured mass** [g]	1125.02	1125.06	25.25	252.77	2528.10
	Weight-percentage[%]	44.50	44.50	1.00	10.00	100.0
2.00%	**Measured mass** [g]	1125.02	1125.01	51.01	255.70	2556.74
	Weight-percentage[%]	44.00	44.00	2.00	10.00	100.0

Table A.3: Mix design of the cylinder specimens with unclean fibres.

Mix design with unclean fibres						
Fibre concentration		Clay	Gravel	Fibre	Water	Total
0%	**Measured mass** [g]	1125.07	1125.05	0.00	250.63	2500.75
	Weight-percentage[%]	44.99	44.99	0.00	10.02	100.0
1.00%	**Measured mass** [g]	1125.06	1125.03	25.25	252.81	2528.15
	Weight-percentage[%]	44.50	44.50	1.00	10.00	100.0
2.00%	**Measured mass** [g]	1125.08	1125.04	51.00	255.66	2556.78
	Weight-percentage[%]	44.00	44.00	2.00	10.00	100.0

Table A.4: Mix design of the cylinder specimens with clean fibres.

A.3 Drying time for cylinder specimens

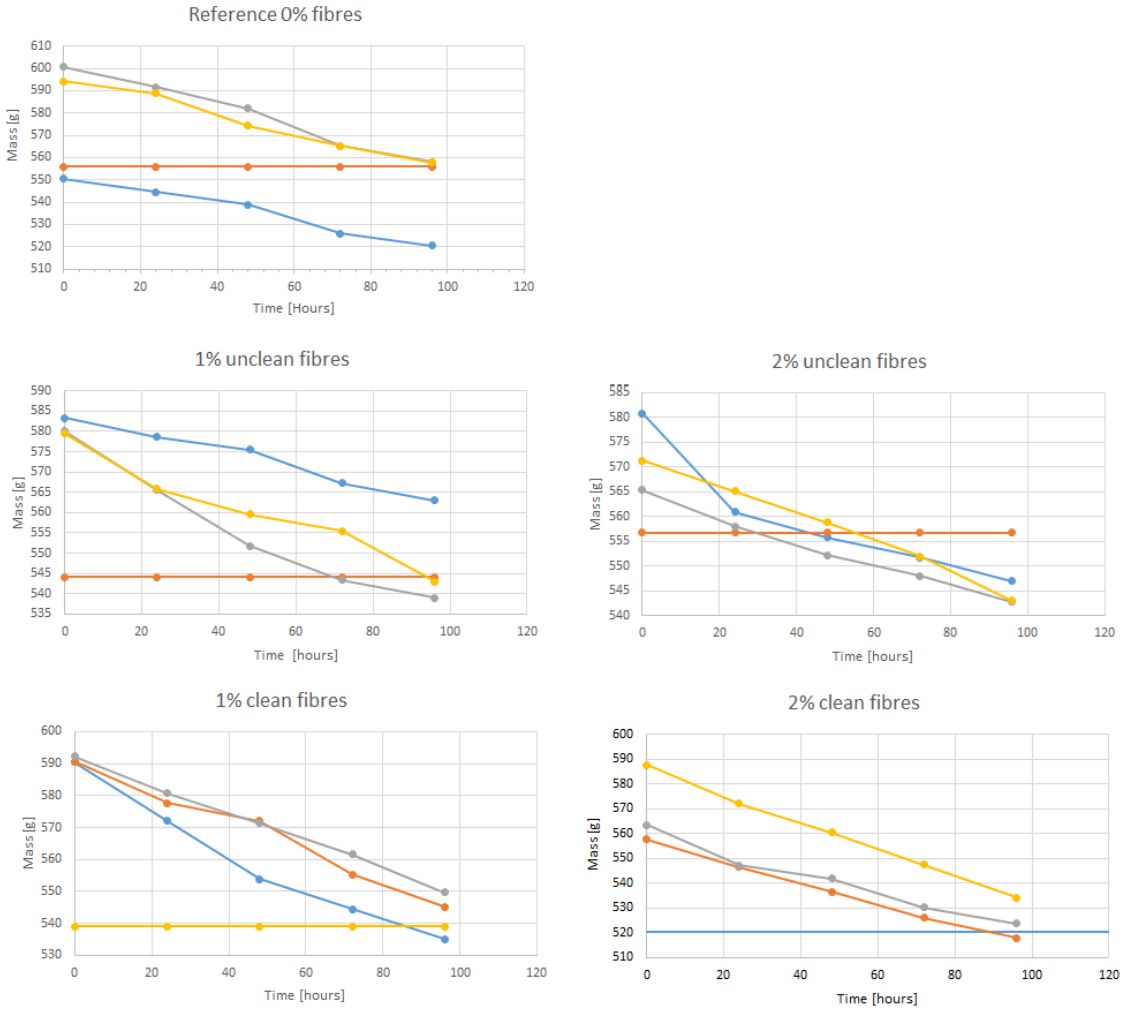

Figure A.1: Estimation of drying time and mass for the cylinder specimens relative to the rectangular specimens.

B Appendix

B.1 Fracture shapes

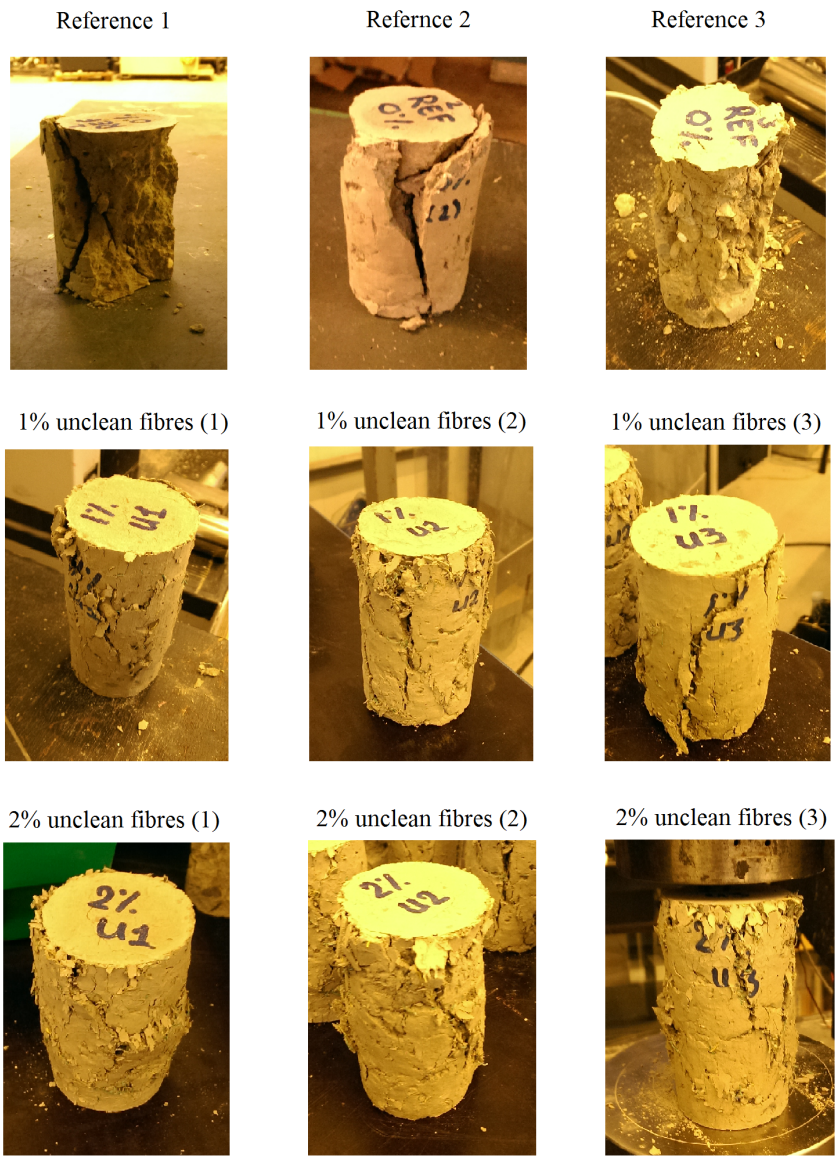

Figure B.1: Fracture shapes for reference and unclean fibre specimens obtained from compression test.

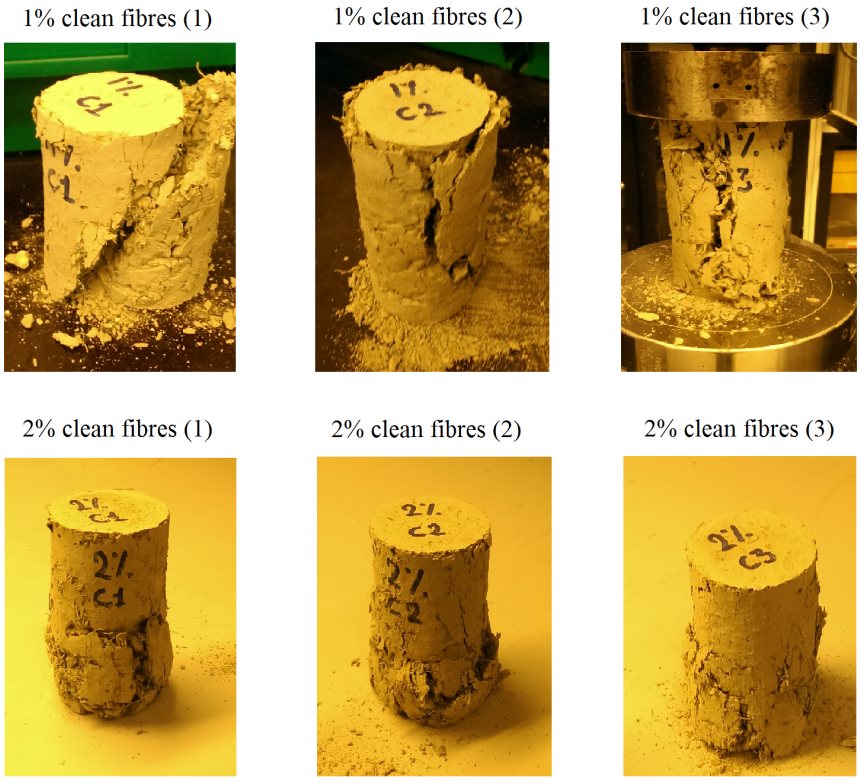

Figure B.2: Fracture shapes for clean fibre specimens obtained from compression test.