



# **Improvement of Concrete Structures Utilising Glass and Plastic Fibres as a Reinforcement**

**3<sup>rd</sup> Year Project (2017/2018)**

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## ABSTRACT

This project will study the possibility of reinforcing concrete structures using various types of fibres. It is well known that concrete is a brittle material that is strong in compression but weak in tension. For this reason, it would be advantageous to reinforced concrete using fibres made of glass and plastic. This will provide a mean to improve the bending and tensile properties as well as increase the toughness of concrete. This will also improve the thermal insulation of concrete since such fibres have a lower thermal conductivity when compared to concrete. In the current project, samples made of concrete were mixed with glass and plastic fibres. These were subjected to flexural testing in order to compare the performance with plain samples. The volume fractions of fibres as well as type of testing were based on literature studies as well as the British Standard (BS EN 196-1:2005). This study was also validated using Finite Element Analysis (FEA) in order to simulate the performance and confirm the results.

***Keywords:*** Concrete, Glass and Plastic Fibres, Flexural Testing, Composite Materials, Volume Fractions.

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# **1. INTRODUCTION TO THE PROJECT**

## **1.1 Background**

This project will look at adding fibres to concrete structures in an effort to reduce the damaging effects of impact loads. It is very well known that concrete structures suffer from brittleness and complete demolition when subjected to sudden loading conditions (Kotsovos, 1984). Concrete structures can be reinforced by adding fibres made of various materials in order to improve the strength of such structures and reduce their brittleness when it comes to ‘crash’ or impact conditions (FRC, 2017). Moreover, another goal is to help with recycling of such materials and get advantage of their use rather than disposing them into landfills. This means concrete can become less brittle when new additives such as fibres are added to the structure. This will also provide lighter structures since such fibres will occupy a certain volume and this would be an added advantage. In other words, reinforced concrete will be treated as a composite material with the cement being the matrix and the fibres being the reinforcing medium. This means that fibres will improve the bonding between the constituents as well as provide an additional ductility to the mixture.

## **1.2 Aims of the Project**

This project will investigate the effect of adding fibres to concrete structures in terms of mechanical properties and performance. This will require building up samples made of various volume fractions of fibres and for a varying amount of cure. In other words, three variables will be investigated, namely: volume fractions of fibres, time of curing and various types of fibres (glass and plastic). A relationship will be obtained by the flexural strength and the time of curing, fibre content and fibre material. The results shall be compared with plain samples made of the same mixture as well as with literature studies. Moreover, this will be backed up by FEA in order to check the performance of concrete. In summary, the project will involve the following aspects:

- Look at the various methods of concrete and reinforcement.
- The properties of composite materials such as reinforced concrete.

- The possibility of adding fibres to concrete and the effects of this addition.
- The effect of adding fibres on the strength and ductility of the reinforced concrete.
- To research previous studies carried out on the subject to obtain information on mix design, sample sizes, volume fractions, etc.
- To find the relevant standards for testing the concrete samples under different loading conditions
- The plan for testing include:
  - Adding selected fibres to concrete samples, e.g. glass and plastics.
  - Test concrete samples under bend loading, i.e. flexural.
  - Test samples which do not contain any type of fibres, i.e. plain samples.
  - Compare the results and take images using the microscope to study the bonding behaviour between the fibres and the concrete matrix.

### **1.3 Objectives of the Project**

This project aims at helping at recycling the various materials by converting these to fibres and mixes them with concrete. This will save the environment as well as provide a mean to strengthen concrete structures. Moreover, the reinforced concrete will have more ductility and less brittleness especially under the action of impact loading such as earthquakes and accidents by cars, etc. In addition to the above, the weight of the structure will be improved and will become lighter especially when used in high buildings. This will also reduce the amount of cement used and therefore reduce the overall cost of structures. Such materials can also act as barrier to heat transfer, i.e. insulation. This will be very beneficial especially when insulation is required in such structures.

### **1.4 Justification of the Project**

The current project has more than an advantages and this includes:

- Concrete structures are considered brittle when subjected to impact loading conditions.
- This means the addition of fibres might improve the properties of concrete and make them less brittle.

- The addition of plastic and glass fibres reduces the amount of waste in landfills.
- The concrete can become lighter in weight when mixed with fibres.
- The thermal properties of concrete might improve in terms of thermal insulation when mixed with fibres.
- The cost of concrete when mixed with plastics might also decrease which is beneficial.

## 1.5 The Project Plan

This project will be completed within 6 months from October 2017 till April 2018. The project will involve literature review of the various studies on the same topic as well as providing a new technique for adding concrete structures. All the work will be completed in the workshop alongside testing the samples in the lab. The preliminary plan for the project provides a rough estimate of the tasks and deliverables that have to be met during the project.

| Tasks                                                               | Year 2017/2018 |                            |        |               |        |        |        |
|---------------------------------------------------------------------|----------------|----------------------------|--------|---------------|--------|--------|--------|
|                                                                     | Oct-18         | Nov-18                     | Dec-18 | Jan-18        | Feb-18 | Mar-18 | Apr-18 |
| Proposal writing and submission                                     | ■              |                            |        |               |        |        |        |
| Study composite and concrete materials and their manufacture        |                | ■                          |        |               |        |        |        |
| Study the factors that affect the mechanical properties of concrete |                | ■                          |        |               |        |        |        |
| Build the samples and prepare the machines for testing              |                |                            | ■      |               |        |        |        |
| ----- BREAK (Christmas Holidays) -----                              |                |                            | ■      | ■             |        |        |        |
| Testing of concrete materials - Flexural testing                    |                |                            |        | ■             | ■      |        |        |
| Analysis of Results, Images and Curves                              |                |                            |        |               |        | ■      |        |
| Discussion and Conclusions of the project                           |                |                            |        |               |        |        | ■      |
| Writing and Submitting Final Report                                 |                |                            |        |               |        |        | ■      |
|                                                                     |                |                            |        |               |        |        |        |
|                                                                     |                | ■ The duration of the task |        | ■ Contingency |        |        |        |
|                                                                     |                | ■ Deadline of Deliverables |        |               |        |        |        |

## 1.6 The Emergency Plan and Risk Assessment

There might be several issues that might be encountered during the project and these need to be mitigated as follows:

| <b>Risk</b>                                          | <b>Consequences</b>                            | <b>Mitigation</b>                                                                                                                              |
|------------------------------------------------------|------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| Materials expensive                                  | These cannot be obtained and thus, no testing. | Sufficient money was secured at the beginning of the project                                                                                   |
| Material not available                               | Samples cannot be built and tested.            | Material should be ordered early and more than a supplier secured. Moreover, alternative materials should be order to complete the project.    |
| Difficulty in building up the samples                | Samples cannot be built and tested.            | Training should be given prior to start.                                                                                                       |
| Machines are busy or broken                          | No testing will be carried out                 | Arrange with workshop as well as other students to find free slots                                                                             |
| Wrong percentages of concrete mix or fibre fractions | No samples will be built up                    | A new plan should be in place in order to repeat the calculations and more time to build up the samples                                        |
| Results are not as expected                          | Wrong representation of the actual behaviour   | Repeat tests should be carried out and this requires additional samples to be planned during manufacturing                                     |
| Duration of the project is short                     | The project will not be completed              | The number of tests has to be reduced and weekends might be needed to finish testing. This has to be discussed immediately with the supervisor |

### **1.7 The Budget and Resources**

The project is fully funded by the University of Wales Trinity Saint David. The materials will be ordered from external suppliers while building up the samples and testing will be completed in-house. The university has the ownership of the outcomes of the project and any publications out of the project have to be discussed with the department.

## 2. LITERATURE AND BACKGROUND STUDIES

### 2.1 Composite Materials

Composite materials are hybrid materials that are made of several constituents such as fibres (the reinforcement) and a gluing material (the matrix). The fibres provide the strength to the composite materials whereas the matrix holds the fibres together. The manufacturing of such materials is more complicated as it needs a high consideration of mixing the constituents at the right percentages. The matrix is normally weaker than the fibres and thus composite materials provide a compromise between the two constituents. The matrix can be any material that has the capability of bonding the constituents together such as resin or cement. The additional advantages of the matrix are that it distributes the load on the fibres and hence provides a mean to maintain the integrity of the structures. The reinforcing material can be fibres made of glass, carbon, metal or plastic or can be in the form of reinforcing bars (re-bars) in concrete structures. The reinforcing medium can be long and mounted along a specific axis or can be short of random orientation relative to the applied load. In concrete structures, the re-bars are normally aligned in a certain direction to improve the tensile properties of the concrete structures. Whereas in carbon fibre reinforced plastics (CFRPs), the fibres can either be aligned in a certain direction or randomly distributed. This makes the material either isotropic (i.e. having similar strength in all directions) or anisotropic (i.e. stronger in one direction and weaker in the other), (Kostopoulos, 2002), (Froyen, 1994), (Gilliot, 2012). An illustration of composite structures made of CFRPs and reinforced concrete are shown in Figure 1.

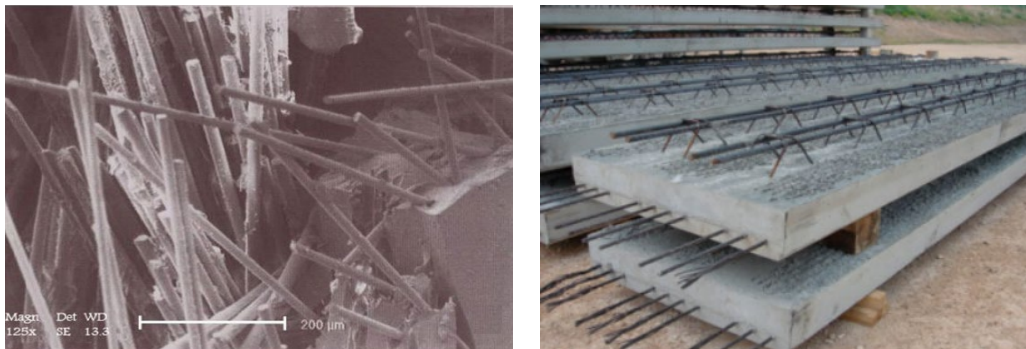


**Figure 1: Composite structures made of carbon fibres (left) and steel reinforced (right).**

## 2.2 The Properties of Composite Materials

In general, composite materials have become very attractive for engineering applications due to the various properties provided. The existence of fibres within the matrix provides a mean to prevent or slow down crack propagations through the structures. In the case of concrete, the fibres help to hold the parts of concrete together when subjected to cracking due to external loads. Moreover, the light density of fibres provides a structure of a lighter weight since the fibres occupy a certain volume of the structure and hence reduce the overall density of the material. The fibres provide stiffness and improve the toughness properties and this is desirable (Sinmazçelik, 2011). The orientation of the fibres within the matrix plays a key role in controlling the properties of the structure. The alignment of the steel bars, for instance, in concrete structures is done purposely in order to improve the tensile strength of the concrete in a specific direction that is subjected to excessive loadings. This is a very interesting feature of composite structures where the properties can be tailored according to the required application. The unidirectional alignment of fibres is beneficial when the fibres are aligned parallel to the tensile stress. However, the cost and time of manufacture can be reduced when randomly short fibres are employed in the structure (Fibre\_Orientation, 2015). The various arrangements of fibres are summarised in Figure 2.

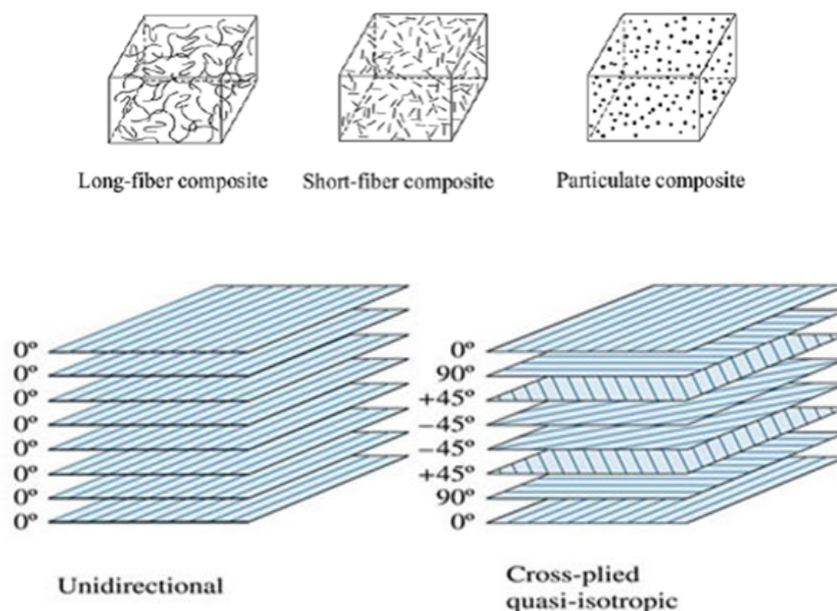


Figure 2: The various arrangements of fibres in composite materials.

## 2.3 The Influence of Fibres

There are several factors that can influence the performance of the composite materials based on the properties of the fibres. The geometry of the fibres (length and diameter), fibre content and the binding between the fibres and the matrix can have a direct impact on the mechanical behaviour of the structure. The aspect ratio of the fibre is defined as the length divided by the diameter of the fibre, i.e. termed as  $(l/d)$ . The aspect ratio affects the properties of the fibres and hence the overall structure. The diameter of the fibres normally ranges between 10 and 150  $\mu\text{m}$ . When the aspect ratio is high, i.e. small diameter or long fibre, the strength of the composite material is improved. This is due to the fact that fibres can fail due to cracks on their surfaces. This means that when the diameter is small, less surface area exists and hence the possibility of surface cracking of the fibre is reduced. The longer fibres are preferred since the middle portion of the fibre carries most of the load when compared to the ends and thus longer fibres provide better strength (Bagherpour, 2012). The effect of fibre length, for instance, is summarised in Figure 3.

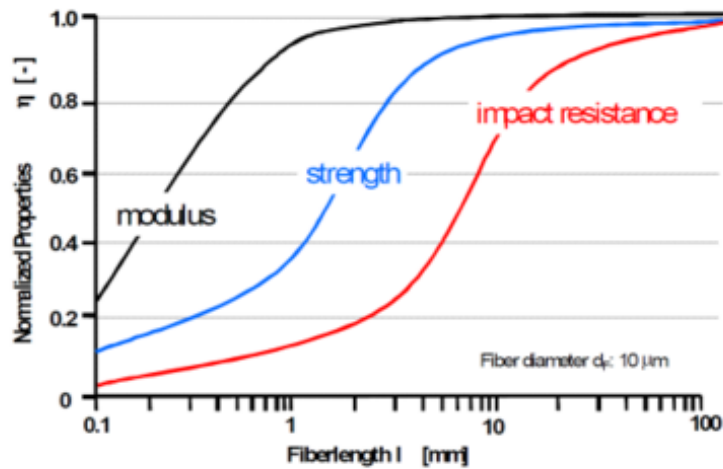


Figure 3: The influence of fibre length on the mechanical properties of composites (Fibres\_length, 2015).

## 2.4 The Reinforced Concrete Structure

### 2.4.1. Bars Reinforced Concrete

Concrete is defined as the mixture of cement, water and aggregates at certain percentages. The aggregates can be fine, i.e. sand, or coarse, i.e. gravel. This mixture provides a composite material where all the constituents are held by the cement paste, i.e. the matrix. On the other

hand, the ‘Mortar’ is defined as the same mixture of concrete but only without the gravel. This means that it contains cement, water and sand only without and coarse gravel. The concrete has the properties of excellent compressive strength with significantly weak tensile strength (one-tenth of the compressive strength). In order to overcome such deficiency, concrete is normally reinforced using steel reinforcing bars, i.e. re-bars, in order to increase the tensile strength of the structure. While under compression, the gravel carry most of the compressive loads since they are extremely difficult to be compressed and hence provide excellent properties. In tension, the steel re-bars provide the strength to resist any cracking of fracture. This composite material that is made of reinforced concrete provides a method for most recent structural engineering applications (Han, 2013), Figure 4.



**Figure 4: The phenomenon of concrete and the reinforcement of concrete by steel re-bars.**

#### *2.4.2. Fibre Reinforced Concrete*

On the other hand, a new reinforcing method has started to emerge using fibres to reinforce the concrete structure. This type of steel is termed as Fibre Reinforced Concrete (FRC) which contains cement, water, aggregates alongside the fibres that occupy a certain volume fraction. This mixture normally contains short and randomly distributed fibres made of several materials such as glass, carbon, steel or even plastic. These fibres can vary according to their length, diameter, shape, volume fractions and densities in order to strengthen the concrete mixture. Once fibres are added to the mixture, the workability of the concrete is changed and hence the amount of water added to the mixture might be modified in order to make the mixture homogeneous and workable, i.e. easy to mix (FRC, 2018). The volume fraction of

the fibres is very important since high volumes might result in ‘balling’, i.e. tangling of fibres to make balls, which results in inhomogeneous distribution amongst the matrix (Balling\_Concrete, 2018).

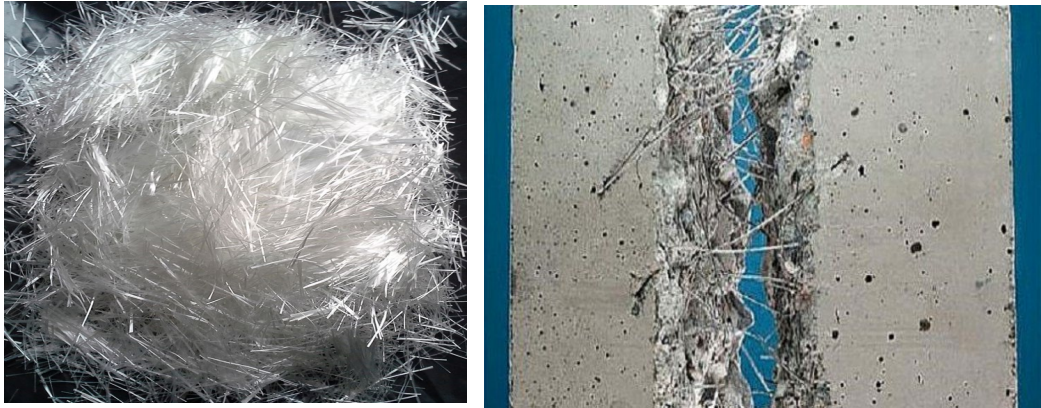


Figure 5: The short fibres (left) and fibre reinforced concrete (right).

#### 2.4.3. Distribution of Fibres

It is important to ensure a homogeneous distribution of the fibres within the concrete mixture to avoid balling of the fibres, segregation and difficulty of mixing. In this regard, increasing the aspect ratio, volume fraction and size and quantity of aggregates increase the possibility of balling. The mixing process should start with mixing the fibres with the mixture before water is added, Figure 6. Moreover, while mixing in a mixer, it is important to add the fibres gradually to help in a better distribution rather than adding the fibres at once to the mixture (FRC, 2018).



Figure 6: The mixing process of fibres with the concrete mixture.

#### 2.4.4. Fibre Properties and Geometry

Generally speaking, short fibres are termed as ‘micro’ fibres whereas longer fibres are called ‘macro’ fibres’. The typical length of micro fibres is below 1.5 inches (38mm) whereas macro fibres are longer than 38mm (Construction, 2018). The short fibres are helpful to resist short cracks whereas long fibres are beneficial in stopping long cracks. In other words, when the reinforced concrete is under tensile loading, it is expected that micro cracks will start to initiate within the mixture. The existence of short fibres will help to slow down the propagation of these short cracks. However, while the load is being applied, the cracks become progressively larger and the short fibres can no longer stop such cracks. At this point, the macro cracks take over to try and slow down the long cracks. This means mixing short and long fibres might be helpful from this point of view during cracking of concrete structures, Figure 7, (Hybrid\_Reinforcement, 2018).

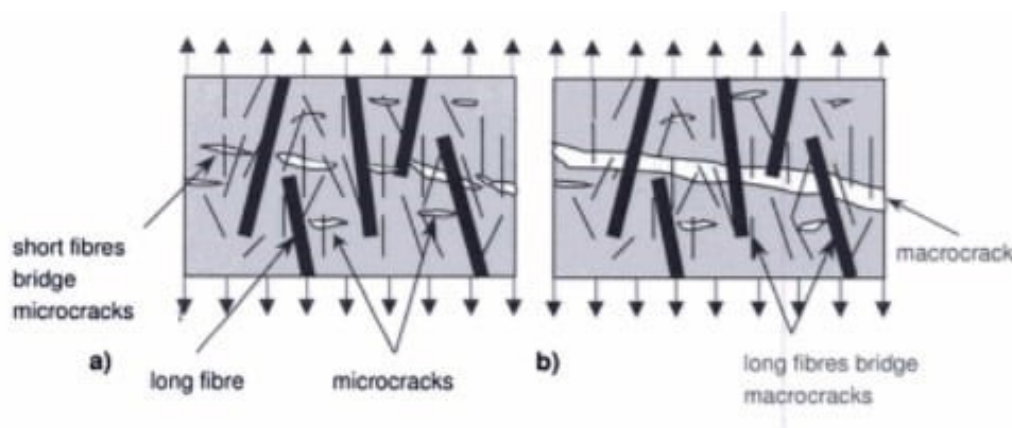


Figure 7: The role of short and long reinforcing fibres in concrete mixtures.

There is always a possibility of fibre failure while in the concrete mixture. In this regard, the fibres might fracture when under loading conditions and they might sometimes debond from the concrete mixture due to the loss of adhesion. The matrix of concrete might also be subjected to micro and macro cracks and this lead eventually to failure of the structure. If the fracture of the fibre takes place within the concrete matrix and not across the crack propagation path, they can still provide some ‘bridging’ and this slows down the propagation of cracks, Figure 8, (Zastrau, 2002).

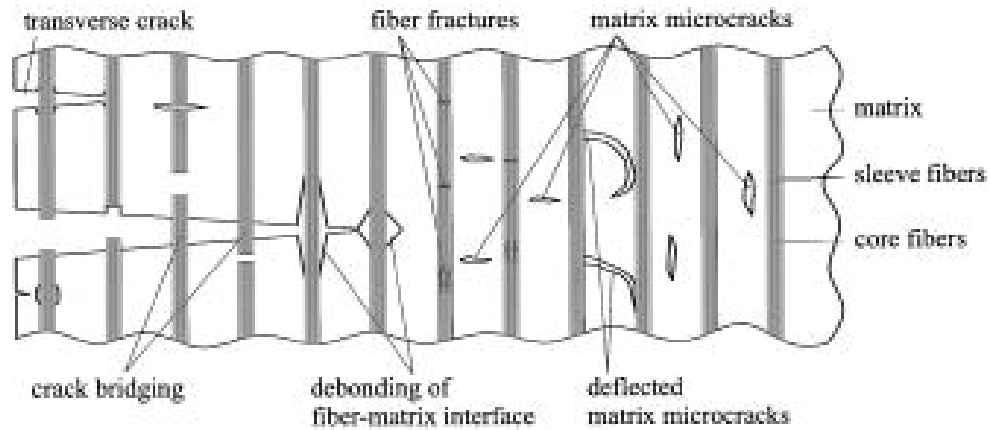


Figure 8: The types of failures expected in fibre reinforced structures.

#### 2.4.5. Fibre Sizes, Geometry and Volume Fractions

Depending on the type of fibres, the size and volume fractions might vary from one type to another. A study by Yin et al. (Yin, 2015) used macro fibres of 30-60mm in length and 0.6-1.0mm<sup>2</sup> made of plastics (polypropylene, polyethylene and polyethylene terephthalate, PET). This study has used several shapes of the fibres such as crimped, twist, straight and hooked ends fibres. On the other hand, another study by Saidani et al. (Saidani, 2016) used fibres of 50 mm ( $\pm 10\%$ ) length and diameter of 1.0 mm ( $\pm 10\%$ ). These fibres were made of steel and polypropylene with hooked and twisted shapes. In a separate study by Holschemacher et al. (Holschemacher, 2010), steel fibres of 50mm length and 1.0mm diameter with hooked and straight configurations. The shape of the fibres proved to provide additional strength through ‘gripping’ action with the gravel within the concrete mixture which is favourable, Figure 9, (Hooked\_Fibres, 2018).

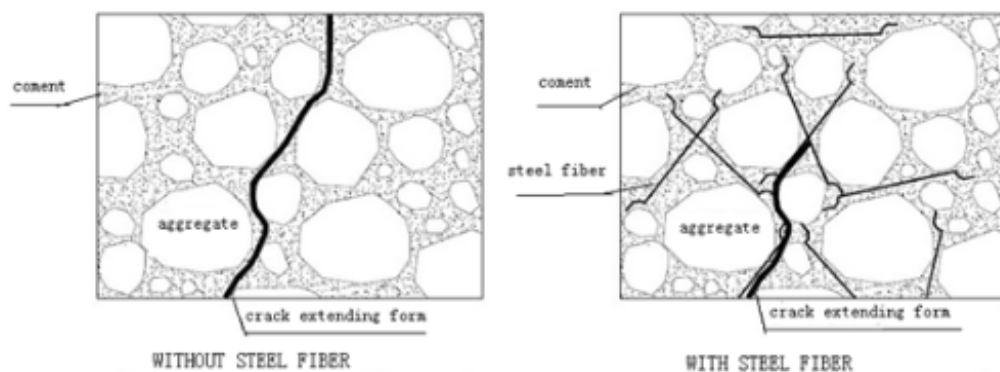


Figure 9: The role of hooked fibres on the performance of concrete mixtures.

In terms of volume fractions, several studies have used varying fractions of fibres and these are summarised as follows:

- Fibre content of 0.4%, 0.75% and 1.25% by volume (Pesic, 2016).
- Fibre content of 1%, 2%, and 4% by volume (Saidani, 2016).
- Fibre content of 0.5%, 1% and 2% by volume (Sofi, 2015).
- Fibre content of 0% and 2% by volume (Tassew, 2014).

The various shapes of fibres that have been used in the previous studies are summarised in. Each type of these shapes provides certain features and this is important during the design stage in order to decide on the required properties.

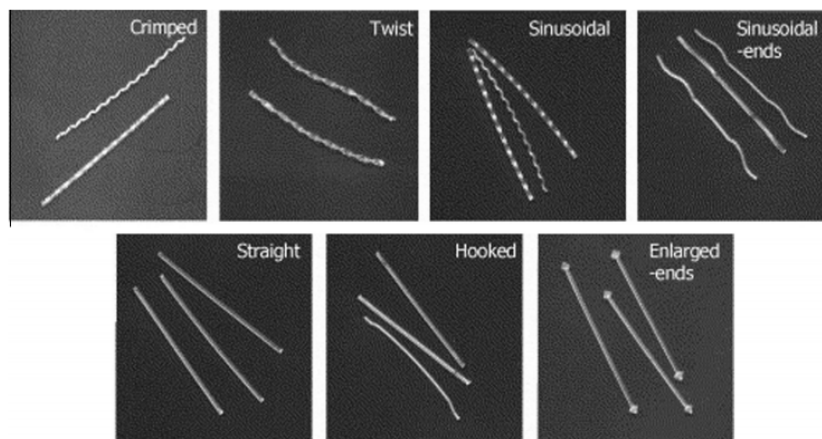


Figure 10: The various shapes of fibres for concrete reinforcement.

### 3. EXPERIMENTAL WORK

The current chapter will discuss the various methods for sample preparations, testing matrix and testing methods. The material that has been used in the current project will also be presented and discussed.

#### 3.1 The Materials and Test Matrix

The samples in the current project were manufactured of cement, water, sand and fibres (glass and Polypropylene plastic). The utilised fractions of each constituent will be discussed in the following sections of this chapter. The test matrix examined in the current testing program is shown in Table 1. The percentages of fibres used were 2.5 and 5% (by weight) and this fills the gap in the knowledge when compared to the percentages available in the literature. Moreover, in terms of curing, the chosen periods were 2 and 4 weeks and this provides another way of comparing the results. In other words, three variables will be investigated:

- 1) The reinforcement material
- 2) The curing time
- 3) The volume fractions (by weight)

**Table 1: The test matrix of the current project.**

| Reinforcement        | Percentage | Curing Time |         |
|----------------------|------------|-------------|---------|
|                      |            | 2 weeks     | 4 weeks |
| No Reinforcement     | 0%         | 2           | 2       |
| Glass Fibres         | 2.5%       | 2           | 2       |
|                      | 5%         | 2           | 2       |
| Polypropylene Fibres | 2.5%       | 2           | 2       |
|                      | 5%         | 2           | 2       |

### 3.2 The Mix Design

The British Standard (BS\_EN\_196-1, 2005) has been used in designing the mixture of the samples in the current project. In this respect, the recommended samples size in the same standard is 160x40x40mm and this has been followed in the current project. The amount of constituents recommended is as follows:

- 1) For three samples of 160x40x40mm, the amounts are: 450g (cement), 1350g (sand) and 225g (water).
- 2) The fibres were taken as a percentage of the cement as the fibres will replace a certain amount of the cement. For instance, the 5% fibres means:

$$\text{Fibres (weight)} = 0.05 * 450 = 22.5\text{g}$$

And the 2.5% fibres mean:

$$\text{Fibres (weight)} = 0.025 * 450 = 11.25\text{g}$$



Figure 11: The various constituents of the samples.

3) The mixing steps are as follows:

- Put water
- Put half the fibres
- Switch the vibrator on
- Put cement during 30 seconds
- Mix for 30 seconds
- Put the other half of fibres
- Put the sand during 30 seconds
- Mix slow for 1 minute
- Mix fast for 1 minute

The above constituents are then placed in the mould which contains 3 cavities of 160x40x40mm, Figure 12. This will provide 3 samples for flexural testing as will be discussed later in the next section.



Figure 12: The mould that has been used to prepare the samples.

After 24 hours, the samples are demoulded and placed in a water tank. This process is necessary to avoid cracking of the samples during the curing period. In other words, since the cement reaction is exothermic, it is expected that heat will be generated and this causes the water in the mixture to vaporise. If this happens, cracking will happen due to shrinkage and

the samples will be significantly weak. In order to avoid that, the samples are placed in a water tank in order to keep the amount of water in the samples at the allowable limit (Nahata, 2014). The samples can then be taken out of the tank after the defined curing period (2 or 4 weeks) ready for testing.



**Figure 13: The samples in the water tank after 24 hours of moulding.**

### **3.3 The Mechanical Testing**

After the curing time, the samples were then tested under flexural testing. For this purpose, the 3-point flexural testing machine has been employed. The sample was placed on two supports while a concentrated load is applied at the middle of the specimen. This allows the measurement of deflection as a function of load. Moreover, this can provide information on the strain along the beam as a function of the applied load (BS\_EN\_196-1, 2005). This can also provide information on the flexural, i.e. bending, strength of the samples utilised in the project as a function of curing time and reinforcing material. This will form the basis for the comparative study that will be carried out in the current project. An illustration of the employed flexural testing device is shown in Figure 14.



Figure 14: The flexural testing machine employed in the current project.

## 4. RESULTS AND DISCUSSION

### 4.1 The Plain (No Fibre) Samples

The results of the concrete samples which contained no fibres are shown in. It can be seen that the 3-week sample has shown a higher strength when compared with the 2-week sample. This is due to the fact that the longer the curing time the better the mechanical properties as discussed earlier in some literature studies (Zemajtis, 2018). The 3-week sample achieved a strength of around 3.2kN when compared to the 2-week sample which achieved only 2.3kN.

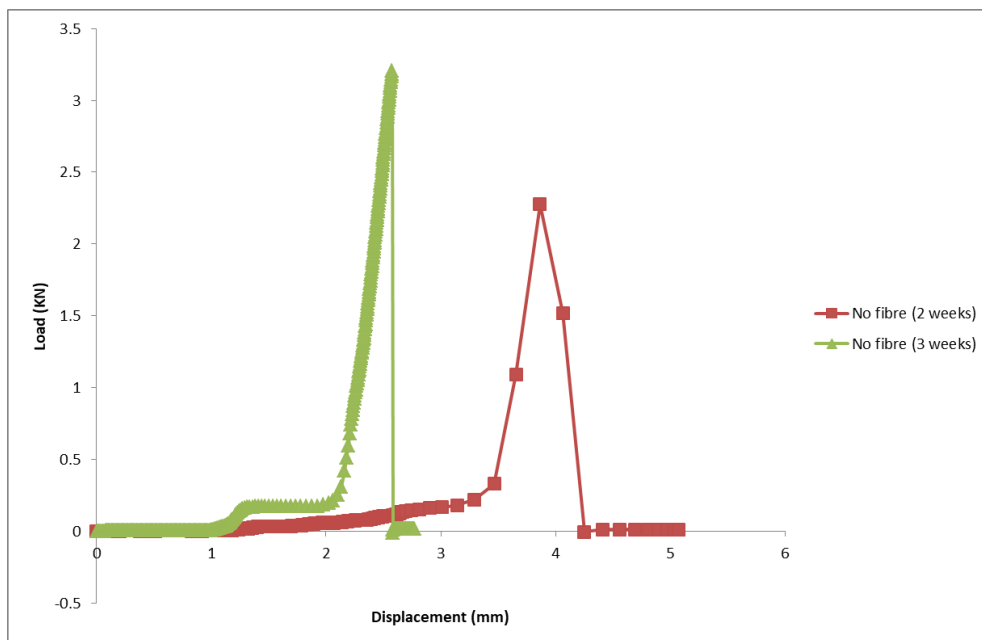


Figure 15: The results of the samples with no fibres after 2 and 3 weeks curing.

### 4.2 The Polypropylene Fibre Samples

The results of the 2 and 3-week samples (2.5%) are shown in Figure 16. It can be seen that the strength of the concrete has dropped when compared with the samples which contained no fibres. The range of strength was between 1.3 and 1.5kN for the 2-week samples. However, it can also be seen that the 3-week sample has achieved even a lower strength (only 0.85kN) which makes the situation worse. Overall, it can be seen that the fibres at 2.5% by weight cured for 2 and 3 weeks caused the strength to significantly decrease.

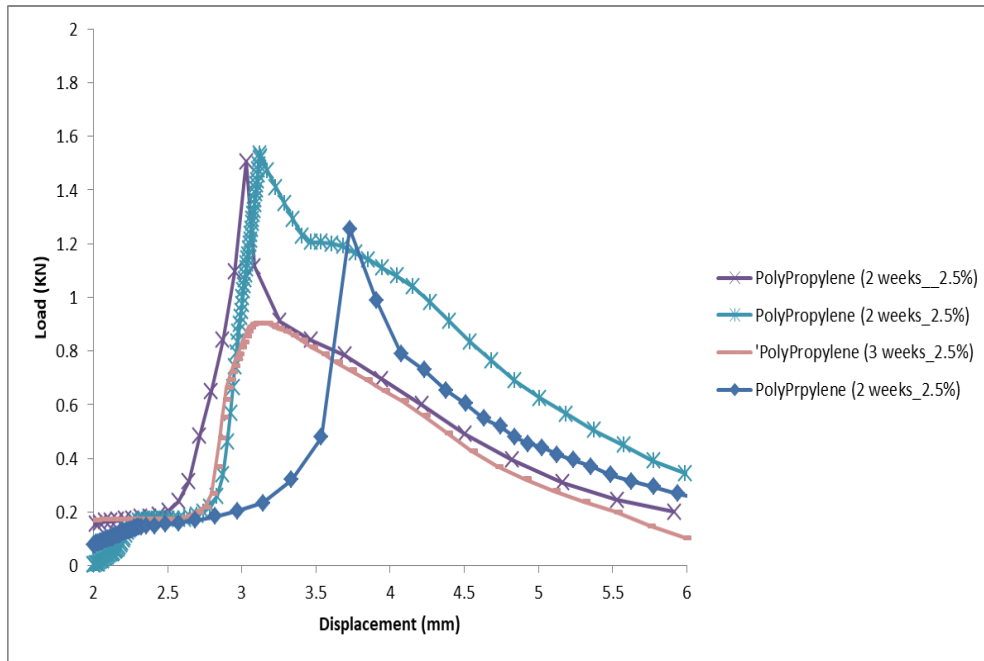


Figure 16: The results of the samples with 2.5% Polypropylene fibres after 2 and 3 weeks curing.

On the other hand, the results of the 2 and 3-week samples (5%) are shown in Figure 17. It can be seen the strength has a bit improved when compared to the 2.5% samples. The 3-week samples have slightly provided a better performance than the 2-week samples; however, the improvement is very minimal. When compared to the no fibre samples, it can be seen that the performance is much lower as indicated previously by the 2.5% samples. In order to justify this effect of increasing the volume fraction of the fibres on the flexural strength, literature studies have demonstrated that the use of fibers in cement-based materials may considerably enhance the toughness, impact resistance, durability and reduce the cracking in concrete. The main weaknesses of incorporating the fibers are the loss of workability and the increased difficulty of casting. This status may lead to an insufficient workability and high volumes of entrapped air in mortar, which cause reduction in its strength and durability. This effect can clearly be seen when high volume fractions (above 1.5%) of the fibres are used in the concrete (Alsadey, 2016). This explains the behaviour of the fibre-containing samples when compared to the plain samples. Another study has also confirmed that above 3% of propylene fibre volume fraction, the flexural properties decrease as it is the case in the current results (Kalwane, 2016).

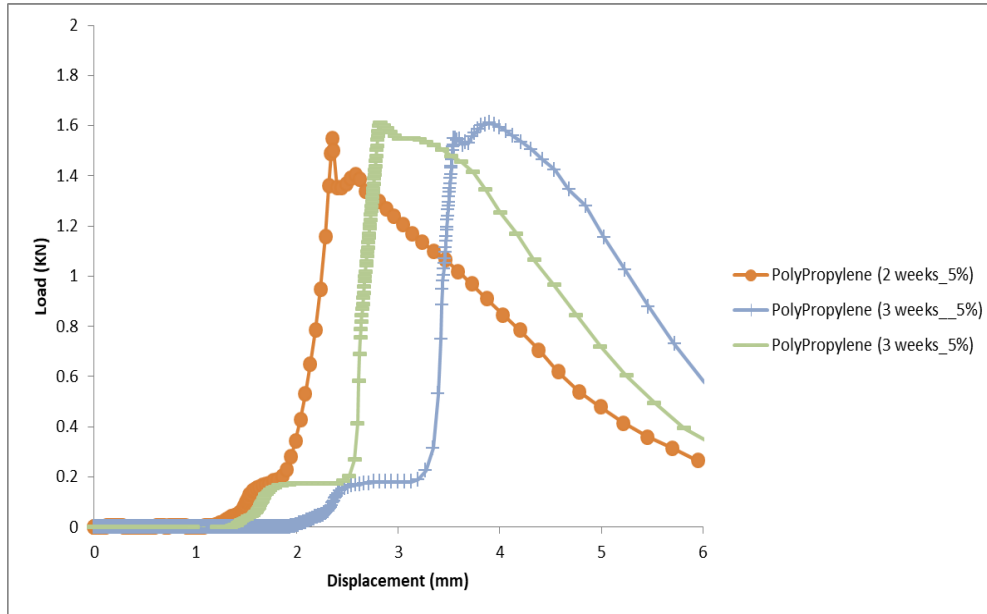


Figure 17: The results of the samples with 5% Polypropylene fibres after 2 and 3 weeks curing.

### 4.3 The Glass Fibre Samples

The results of the 2 and 3-week samples at 2.5% glass fibre content are shown in Figure 18. It can be seen that the strength for the glass fibre samples is higher than that achieved for the polypropylene samples under the same conditions. Indeed, the strength was comparable to that of the plain samples which means that the addition of the glass fibres does not lead to deterioration of properties as it is the case with the polypropylene samples. On the other hand, the curing for 2 weeks provided slightly weaker samples when compared to the 3-week samples. Despite the fact that the increase in strength is not significant, this slight increase means that the increase in curing time leads to a better performance. On the contrary, a better performance is obtained when 5% glass fibre content was included in the concrete. In this regard, the overall level of strength is better than that for the 2.5% samples. Moreover, it can be seen that the increase in curing time has provided a higher strength level when comparing the 2 and 3-week samples. This means that the increase of the glass fibre fraction leads to improved properties. However, this is still below that for the plain samples. In some literature studies in glass fibres, it has been shown that there might be a threshold of volume fraction within the concrete above which deterioration of properties might takes place. The strength is therefore dependent on the fibre content and this reflects on the overall results obtained in this project (CEP\_Engineering, 2018), (Ahangar, 2014).

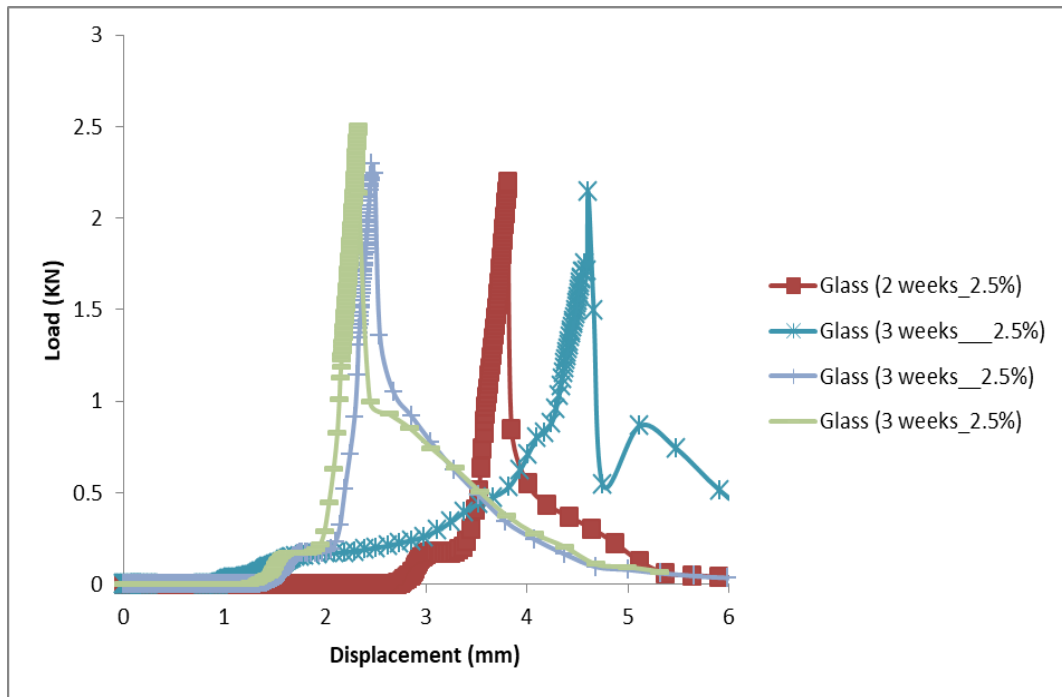


Figure 18: The results of the samples with 2.5% glass fibres after 2 and 3 weeks curing.

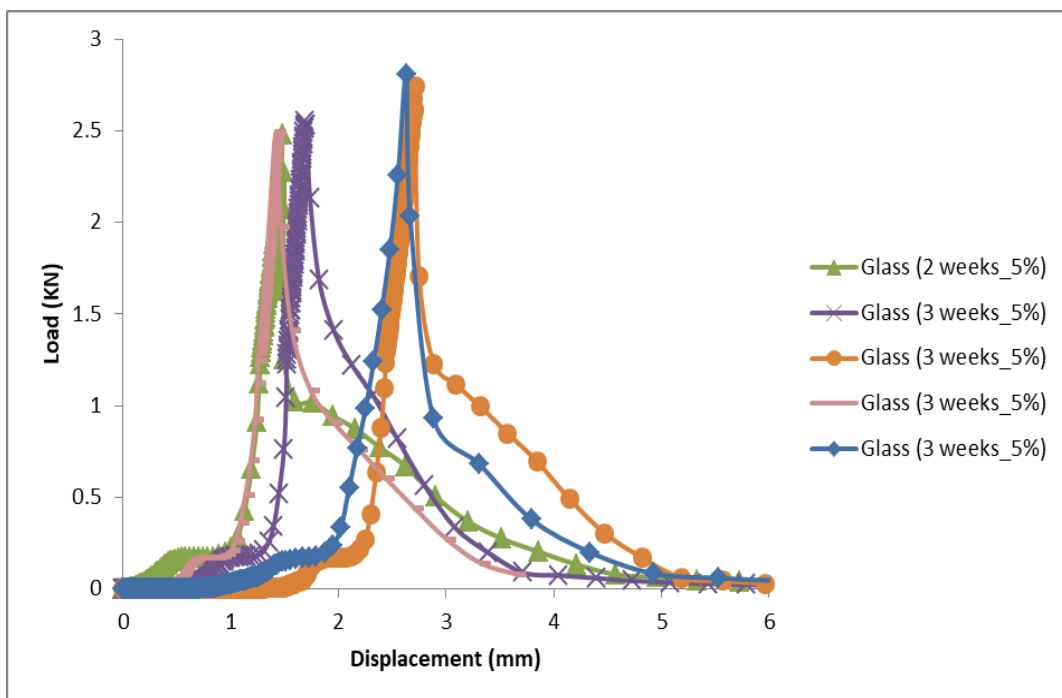


Figure 19: The results of the samples with 5% glass fibres after 2 and 3 weeks curing.

#### 4.4 The Increase in Fibre Content

In the current experiment, the first trial has involved mixing 10% of fibres with the concrete mixture. It has been observed that the mixture was inhomogeneous and that the workability of the concrete has significantly dropped. Moreover, it has been observed that the amount of fibres was significantly high when compared to the other constituents. This has caused the amount of water to quickly disappear due to the absorption of the water by the fibres. Some studies mentioned that the increase in fibre content above certain limit affects the workability as well as the mechanical properties of the concrete (Murugan, 2017). This means that the amount of fibre should be optimised in order to avoid such damaging effects. Moreover, this amount of fibre content should be avoided in any future studies working on fibre-reinforced concrete. This also means that the mix design is very crucial in order to obtain the desired properties of the concrete mixture.



Figure 20: The 10% fibre content (left) and the 2.5% fibre content (right).

#### 4.5 Microscopic Studies

In order to confirm the uniformity and bonding of the fibres within the concrete matrix, the optical microscope has been used. The obtained images in Figure 21 show that the fibres are uniformly distributed and strongly bonded to the mixture. This is interesting as such fibres could have been concentrated in a certain region within the sample. However, these images confirm the uniform distribution which is desirable in such concrete mixture in order to obtain the required properties.

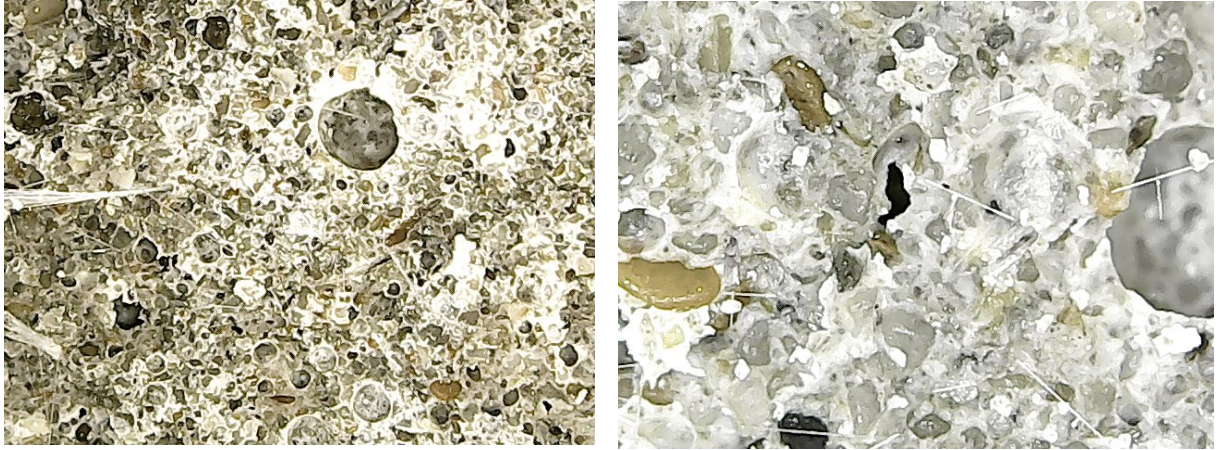


Figure 21: Microscopic studies of the reinforced concrete samples.

## **5. FINITE ELEMENT (FE) ANALYSIS**

The current chapter will discuss the application of finite element analysis (FEA) on fibre reinforced concrete (FRC). In this regard, two types of fibre were considered: glass and plastic fibres. These fibres have been added to the concrete mixture at various percentages in order to study the improvement in the mechanical properties of the concrete. The stress intensity in the mixture as well as the deformation of the concrete under these conditions were studied. The ANSYS software package has been utilised in this and the results will be used to construct the basis for comparisons.

### **5.1 The Current Work**

In the current work, only plastic (Polypropylene, PP) and glass fibres were considered in the analysis. These fibres were obtained from external suppliers and added to the mixtures as follows:

- 1) Glass fibres: 5% by weight.
- 2) Glass fibres: 2.5% by weight.
- 3) PP fibres: 5% by weight.
- 4) PP fibres: 2.5 by weight.
- 5) Plain samples: 0% fibres.

### **5.2 Research Strategy**

For this purpose, it is important to look for literature studies that have investigated fibre reinforced concrete using propylene and glass fibres. In this regard, it would be very beneficial to look for studies which have included the same percentage of fibres as those used in the current project, i.e. 2.5 and 5% by weight. However, if this is not possible, it is advisable to look for studies which have included close amount of fibre fractions and the required fractions can be obtained by extrapolation or interpolation using various studies. Moreover, in order to build the FE model, it would be very helpful to obtain the mechanical properties of the reinforced concrete such as tensile, compressive and flexural properties.

### 5.3 Sample Sizes

The sample size was taken as 160x40x40mm as this is similar to the samples produced in the current 3rd year project and examined by literature studies (Uchida & al., 2010) under flexural conditions, Figure 22.

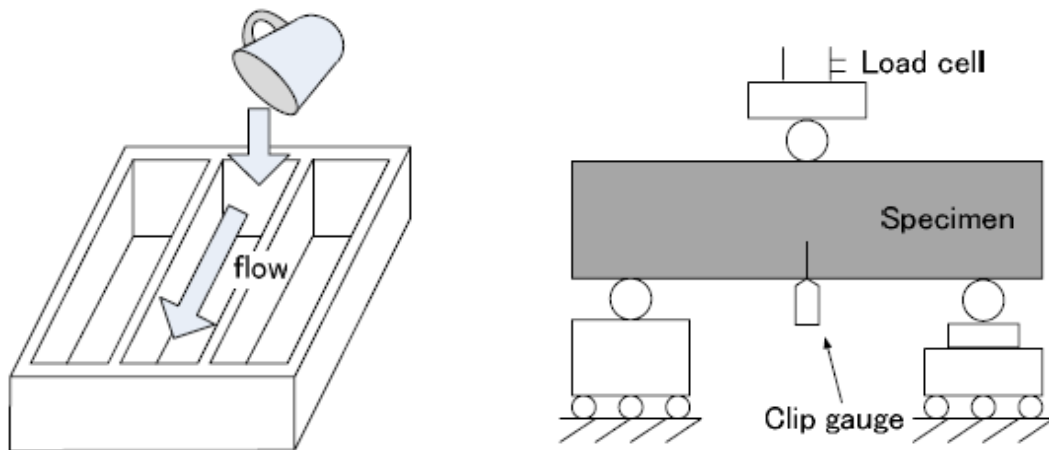


Figure 22: The casting process to produce 160x40x40mm samples (left) and flexural testing (right).

### 5.4 Literature Studies

These literature studies will provide information on the required mechanical properties. In this respect, studies of glass and polypropylene fibre reinforced concrete were considered.

#### 0% Fibre Concrete Properties (Unreinforced)

The compressive, tensile and flexural strength of concrete based on 0% fibre content are shown in Table 2. These properties were obtained from literature studies (Kiran & Rao, 2015; Qureshi & Ahmed, 2013).

**Table 2: The mechanical properties of concrete with 0% fibre additions (Kiran & Rao, 2015; Qureshi & Ahmed, 2013).**

| S.No | Age (days) | Split tensile Strength(N/mm <sup>2</sup> ) |
|------|------------|--------------------------------------------|
| 1    | 1          | 1.62                                       |
| 2    | 3          | 2.04                                       |
| 3    | 7          | 2.86                                       |
| 4    | 28         | 3.77                                       |
| 5    | 56         | 4.37                                       |

| S.No. | Age (days) | Compressive Strength (N/mm <sup>2</sup> ) |
|-------|------------|-------------------------------------------|
| 1     | 1          | 10.73                                     |
| 2     | 3          | 16.83                                     |
| 3     | 7          | 21.60                                     |
| 4     | 28         | 39.00                                     |
| 5     | 56         | 43.87                                     |

| S.No | Age (days) | Flexural strength (N/mm <sup>2</sup> ) |
|------|------------|----------------------------------------|
| 1    | 1          | 2.48                                   |
| 2    | 3          | 4.37                                   |
| 3    | 7          | 4.68                                   |
| 4    | 28         | 6.61                                   |
| 5    | 56         | 7.57                                   |

### 2.5 % Glass Fibre Reinforced Concrete Properties

The compressive and flexural strength of concrete based on 2.5% fibre content were considered as shown Figure 23. These properties were obtained from literature studies (Qureshi & Ahmed, 2013). However, no tensile properties were found in the literature and therefore the tensile properties were estimated based on the 0% and 5% properties.

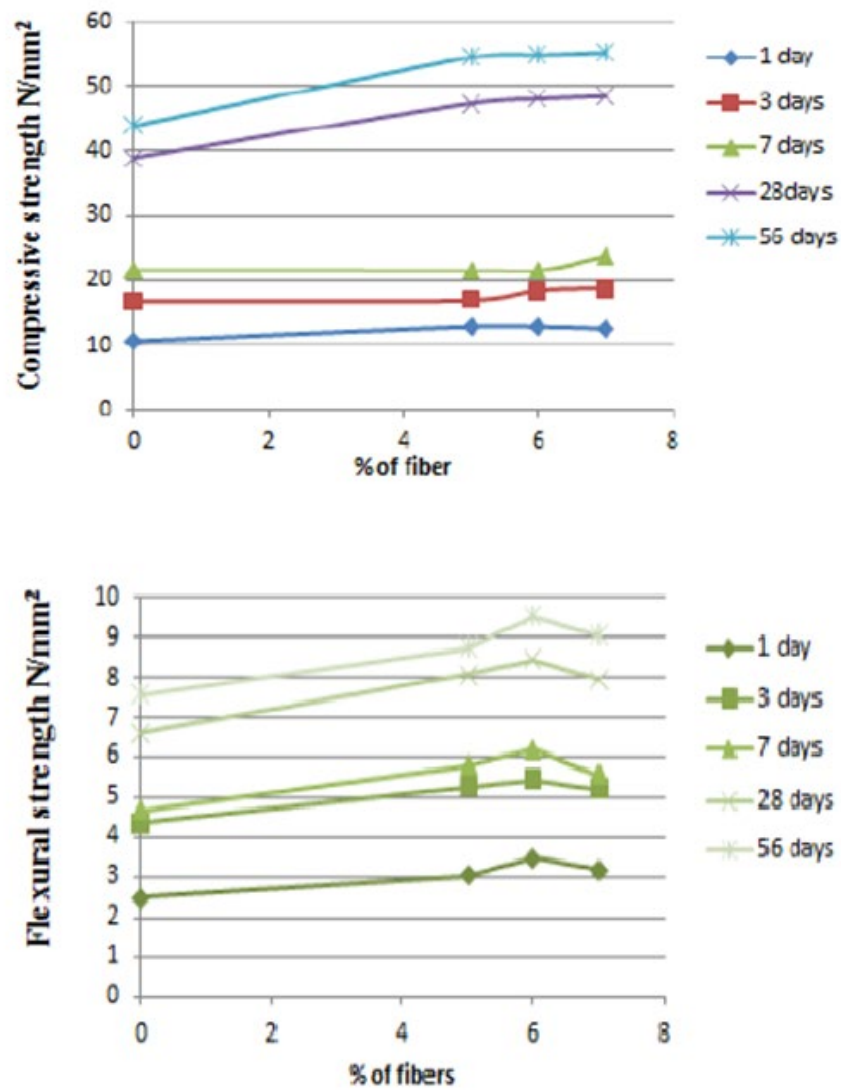


Figure 23: The mechanical properties of concrete with 2.5% fibre additions

### 5% Glass Fibre Reinforced Concrete Properties

The compressive, tensile and flexural strength of concrete based on 5% fibre content are shown in Table 3. These properties were obtained from literature studies (Kiran & Rao, 2015).

Table 3: The mechanical properties of concrete with 5% fibre additions (Kiran & Rao, 2015).

| S.No. | Age(days) | Compressivestrength (N/mm <sup>2</sup> ) |
|-------|-----------|------------------------------------------|
| 1     | 1         | 12.87                                    |
| 2     | 3         | 17.00                                    |
| 3     | 7         | 21.53                                    |
| 4     | 28        | 47.27                                    |
| 5     | 56        | 54.40                                    |

| S.No | Age (days) | Flexural strength (N/mm <sup>2</sup> ) |
|------|------------|----------------------------------------|
| 1    | 1          | 3.03                                   |
| 2    | 3          | 5.27                                   |
| 3    | 7          | 5.81                                   |
| 4    | 28         | 8.07                                   |
| 5    | 56         | 8.76                                   |

| S.No | Age (days) | Split tensile strength (N/mm <sup>2</sup> ) |
|------|------------|---------------------------------------------|
| 1    | 1          | 1.90                                        |
| 2    | 3          | 2.80                                        |
| 3    | 7          | 3.34                                        |
| 4    | 28         | 4.50                                        |
| 5    | 56         | 5.16                                        |

### 2.5% Polypropylene Fibre Reinforced Concrete Properties

The properties of 2.5% polypropylene fibre addition were not available in the literature. For this reason, the properties at 2% additions were found and considered. This will allow a rough estimation of the properties at 2.5% which is acceptable. The compressive, tensile and flexural strength of concrete based on 2.0% fibre content are shown in Table 4. These properties were obtained from literature studies (Dharan & Lal, 2016).

**Table 4: The mechanical properties of concrete with 2.0% fibre additions (Dharan & Lal, 2016).**

| S.No | % of fibers | 28days Flexural strength (N/mm <sup>2</sup> ) |
|------|-------------|-----------------------------------------------|
| 1    | 0           | 4.34                                          |
| 2    | 0.5         | 5.21                                          |
| 3    | 1           | 5.48                                          |
| 4    | 1.5         | 5.71                                          |
| 5    | 2           | 4.82                                          |

| S.No | % of fibers | 7days Compressive strength (N/mm <sup>2</sup> ) | 28days compressive strength (N/mm <sup>2</sup> ) |
|------|-------------|-------------------------------------------------|--------------------------------------------------|
| 1    | 0           | 25.20                                           | 38.50                                            |
| 2    | 0.5         | 27.90                                           | 42.14                                            |
| 3    | 1           | 28.83                                           | 44.61                                            |
| 4    | 1.5         | 29.91                                           | 46.00                                            |
| 5    | 2           | 27.12                                           | 41.72                                            |

| S.No | % of fibers | 28days Split tensile strength (N/mm <sup>2</sup> ) |
|------|-------------|----------------------------------------------------|
| 1    | 0           | 3.42                                               |
| 2    | 0.5         | 3.86                                               |
| 3    | 1           | 3.98                                               |
| 4    | 1.5         | 4.38                                               |
| 5    | 2           | 3.66                                               |

### 5% Polypropylene Fibre Reinforced Concrete Properties

The compressive, tensile and flexural strength of concrete based on 5% fibre content was not available in the literature with the maximum additions to only 2% (Dharan & Lal, 2016). For this reason, the properties at 5% fibre addition will be estimated based on the other percentages of polypropylene additions.

### **5.5 Summary of the Literature Studies**

The below table shows an overall comparison of the effect of fibre content on the overall mechanical properties obtained from the previous studies. These values are based at 7 and 14 days (wherever applicable).

1. No fibre additions (i.e. Pure Concrete):

**Table 5: The mechanical properties of 0% fibre addition.**

| 0% fibre                              | Property         |                      |                   |
|---------------------------------------|------------------|----------------------|-------------------|
|                                       | Tensile Strength | Compressive Strength | Flexural Strength |
| 7days                                 | 2.86 MPa         | 21.6 MPa             | 4.68 MPa          |
| 14 days (as 14 days is not available) | 3.77 MPa         | 39.0 MPa             | 6.61 MPa          |

## 2. Glass fibre additions:

**Table 6: The mechanical properties of 2.5% glass fibre addition.**

| 2.5% glass fibre                      | Property         |                      |                   |
|---------------------------------------|------------------|----------------------|-------------------|
|                                       | Tensile Strength | Compressive Strength | Flexural Strength |
| 7days                                 | 3.1 MPa*         | 21.8 MPa             | 5.6 MPa           |
| 28 days (as 14 days is not available) | 4.14 MPa*        | 43.2 MPa             | 7.5 MPa           |

\* These values were estimated as they are not available in the literature.

**Table 7: The mechanical properties of 5% glass fibre addition.**

| 5% glass fibre                        | Property         |                      |                   |
|---------------------------------------|------------------|----------------------|-------------------|
|                                       | Tensile Strength | Compressive Strength | Flexural Strength |
| 7days                                 | 3.34 MPa         | 22.3 MPa             | 5.81 MPa          |
| 28 days (as 14 days is not available) | 4.5 MPa          | 47.27 MPa            | 8.07 MPa          |

## 3. Polypropylene fibre additions:

**Table 8: The mechanical properties of 2% Polypropylene fibre addition.**

| 2%* polypropylene fibre               | Property         |                      |                   |
|---------------------------------------|------------------|----------------------|-------------------|
|                                       | Tensile Strength | Compressive Strength | Flexural Strength |
| 7days                                 | 2.97 MPa         | 29.2 MPa             | 4.51 MPa          |
| 28 days (as 14 days is not available) | 3.82 MPa         | 41.3 MPa             | 6.72 MPa          |

\* The 2.5% was not available in the literature. Therefore, these values were considered and the 2.5% estimated.

**Table 9: The mechanical properties of 5% Polypropylene fibre addition.**

| 5% polypropylene fibre                | Property         |                      |                   |
|---------------------------------------|------------------|----------------------|-------------------|
|                                       | Tensile Strength | Compressive Strength | Flexural Strength |
| 7days                                 | 3.31 MPa*        | 30.8 MPa*            | 5.3 MPa*          |
| 28 days (as 14 days is not available) | 4.1 MPa*         | 42.3 MPa*            | 7.1 MPa*          |

\* The 5% was not available in the literature. Therefore, these values were all estimated based on previous data.

## 5.6 The FE Modelling Results

The FE modelling was based on 3-point bending, i.e. flexural properties using ANSYS modelling. This option was obtained by building up the sample with the required dimensions of 160x40x40mm. The sample was then subjected to a concentrated load at the centre to simulate the actual tests in the lab, Figure 24.

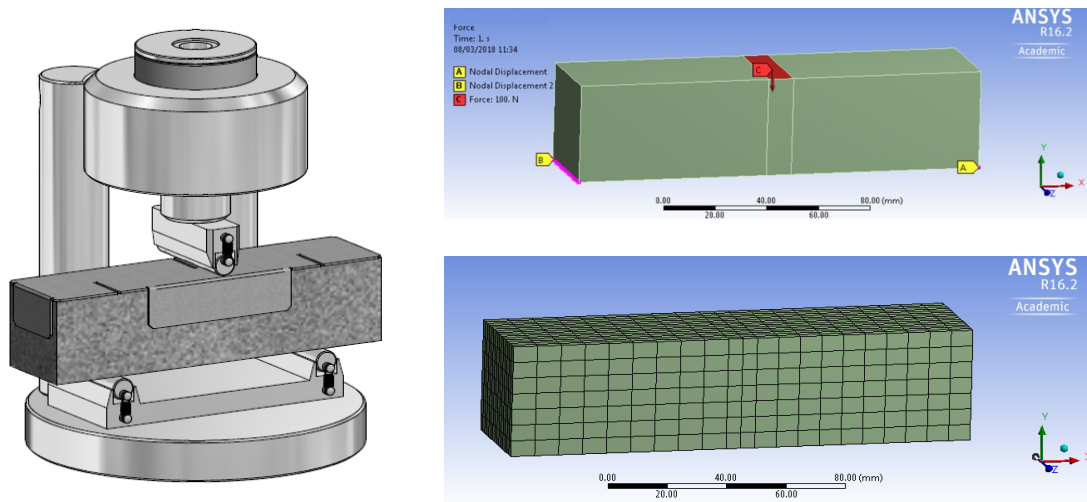


Figure 24: The principle of flexural testing (left) and the samples built using ANSYS.

In ANSYS, the fibre reinforced concrete material does not exist. For this reason, the properties that were obtained from the literature at the various fibre contents were used to build up a new material having such properties. In other words, the properties obtained from the literature studies were utilised to build up a model material and this data was considered as the input of the new material that has to be analysed. This method is the widely accepted method worldwide by researchers (ANSYS, 2009).

### The 0% Fibre Content

The results of the stress and deformation of the sample with 0% fibre content are shown in Figure 25. It can be seen that the worst case scenario in terms of stress is recorded at the bottom side of the sample where tension is encountered. However, this is less significant at the upper side where concrete behaves better. This means that the critical region is the bottom side of the sample as shown in Figure 25. In terms of displacement, it can also be seen that

the bottom side of the sample is subjected to the highest level of deflection and therefore elongation. Since concrete is very weak under tension, the expectation is that the sample will fail at the bottom at a stress of 5.36MPa with a total deformation of 0.036mm.

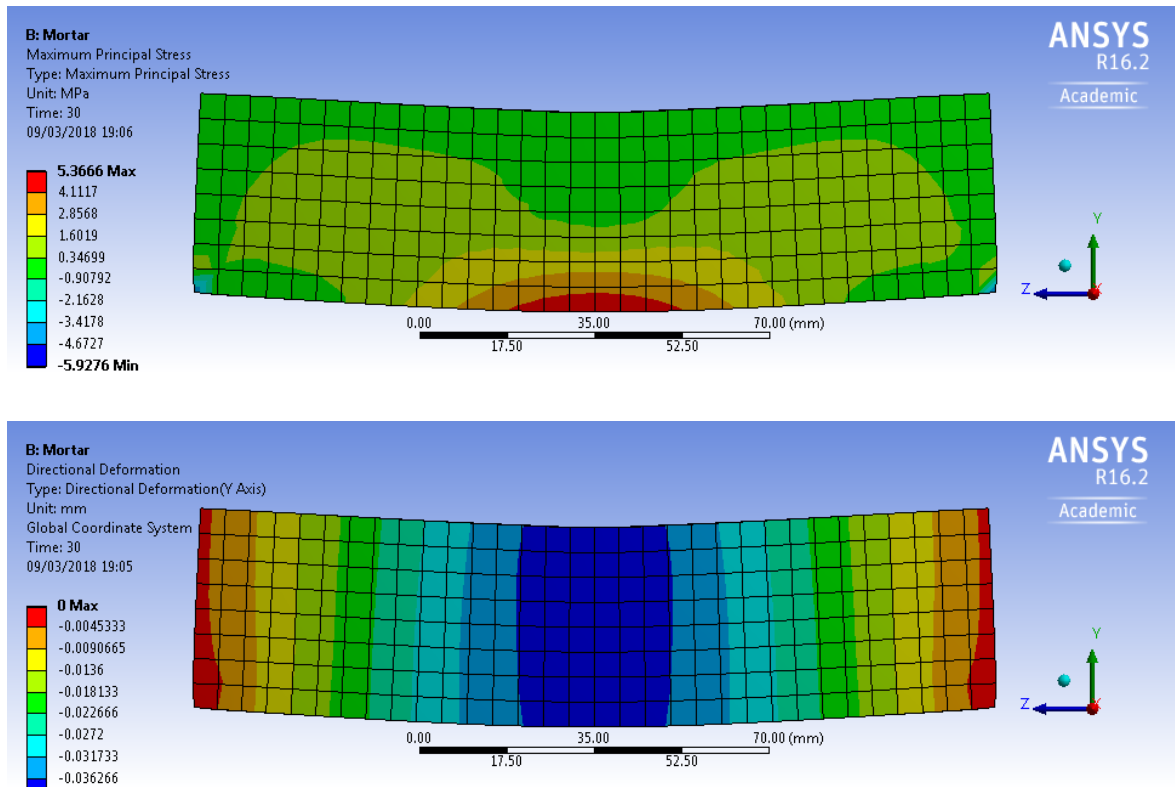


Figure 25: The stress distribution (top) and deformation (bottom) of the 0% fibre addition.

### The 2.5% Glass Fibre Content

The results of the stress and deformation of the sample with 2.5% glass fibre content are shown in Figure 26. It can be seen that the worst case scenario in terms of stress is recorded at the bottom side of the sample where tension is encountered. However, this is less significant at the upper side where concrete behaves better. This means that the critical region is the bottom side of the sample as shown in Figure 26. In terms of displacement, it can also be seen that the bottom side of the sample is subjected to the highest level of deflection and therefore elongation. Since concrete is very weak under tension, the expectation is that the sample will fail at the bottom at a stress of 5.73MPa with a total deformation of 0.004mm. In other words, the results shown in Figure 26 an improvement in the strength is observed.

However, the deformation is lower in this case, i.e. 0.0041mm, and this means that the sample has become stiffer.

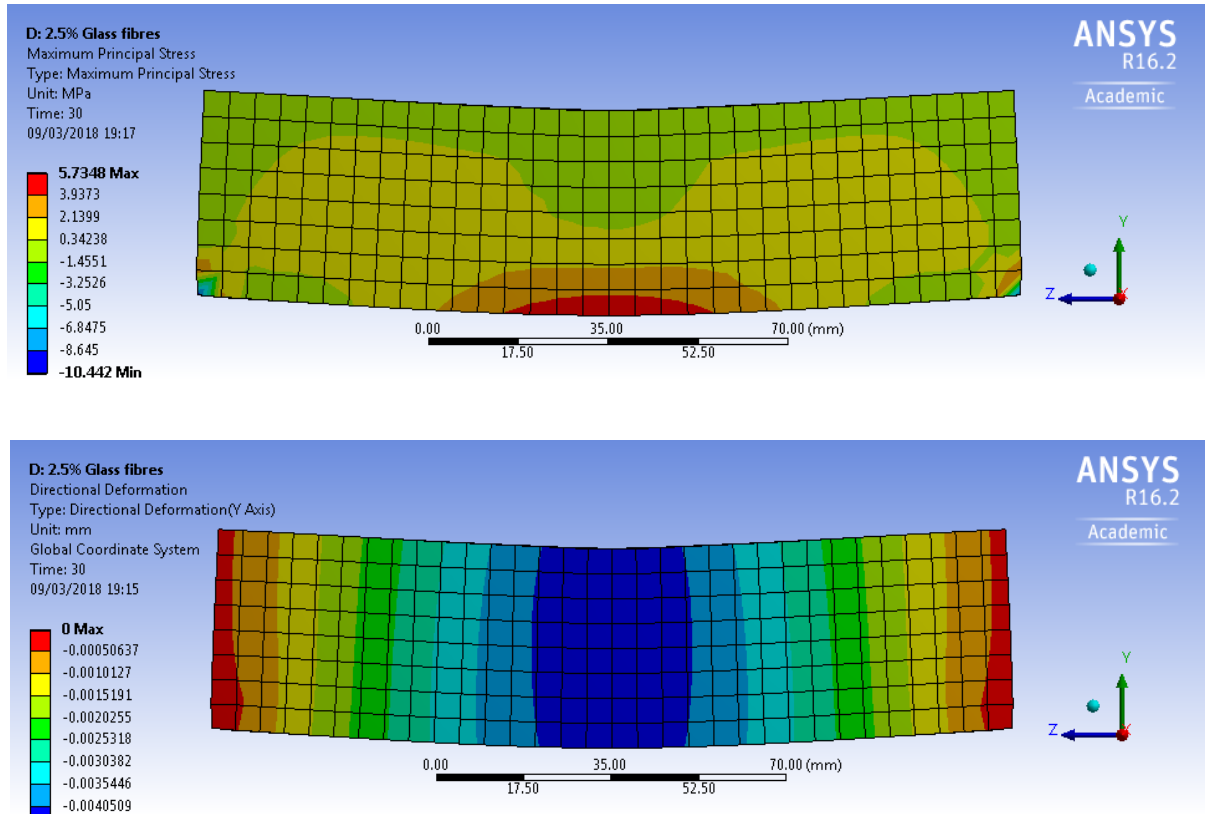


Figure 26: The stress distribution (top) and deformation (bottom) of the 2.5% glass fibre addition.

### The 5% Glass Fibre Content

The results of the stress and deformation of the sample with 5% glass fibre content are shown in Figure 27. It can be seen that the worst case scenario in terms of stress is recorded at the bottom side of the sample where tension is encountered. However, this is less significant at the upper side where concrete behaves better. This means that the critical region is the bottom side of the sample as shown in Figure 27. In terms of displacement, it can also be seen that the bottom side of the sample is subjected to the highest level of deflection and therefore elongation. Since concrete is very weak under tension, the expectation is that the sample will fail at the bottom at a stress of 5.92MPa with a total deformation of 0.003mm. This means

that the increase in glass fibre content has increased the strength of the concrete sample but reduced the deformation and this is a sign of increasing the stiffness which is desirable.

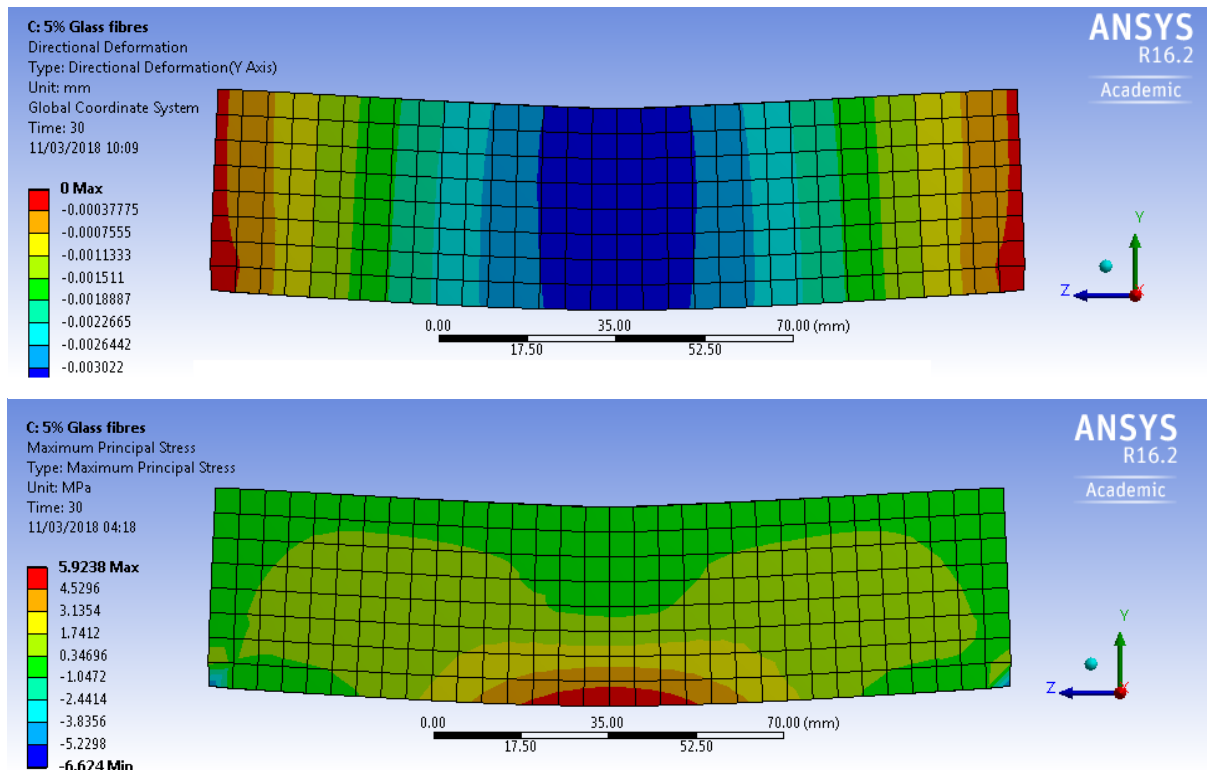


Figure 27: The stress distribution (top) and deformation (bottom) of the 5% glass fibre addition.

### The 2.5% Polypropylene Fibre Content

The results of the stress and deformation of the sample with 2.5% Polypropylene fibre content are shown in Figure 28. It can be seen that the worst case scenario in terms of stress is recorded at the bottom side of the sample where tension is encountered. However, this is less significant at the upper side where concrete behaves better. This means that the critical region is the bottom side of the sample as shown in Figure 28. In terms of displacement, it can also be seen that the bottom side of the sample is subjected to the highest level of deflection and therefore elongation. Since concrete is very weak under tension, the expectation is that the sample will fail at the bottom at a stress of 5.448MPa with a total deformation of 0.0048mm. This shows that there is an improvement in strength and stiffness when compared to pure concrete; however, the improvement is not as high as that achieved at 2.5% glass fibres. This is due to the fact that glass is stronger and stiffer than polypropylene.

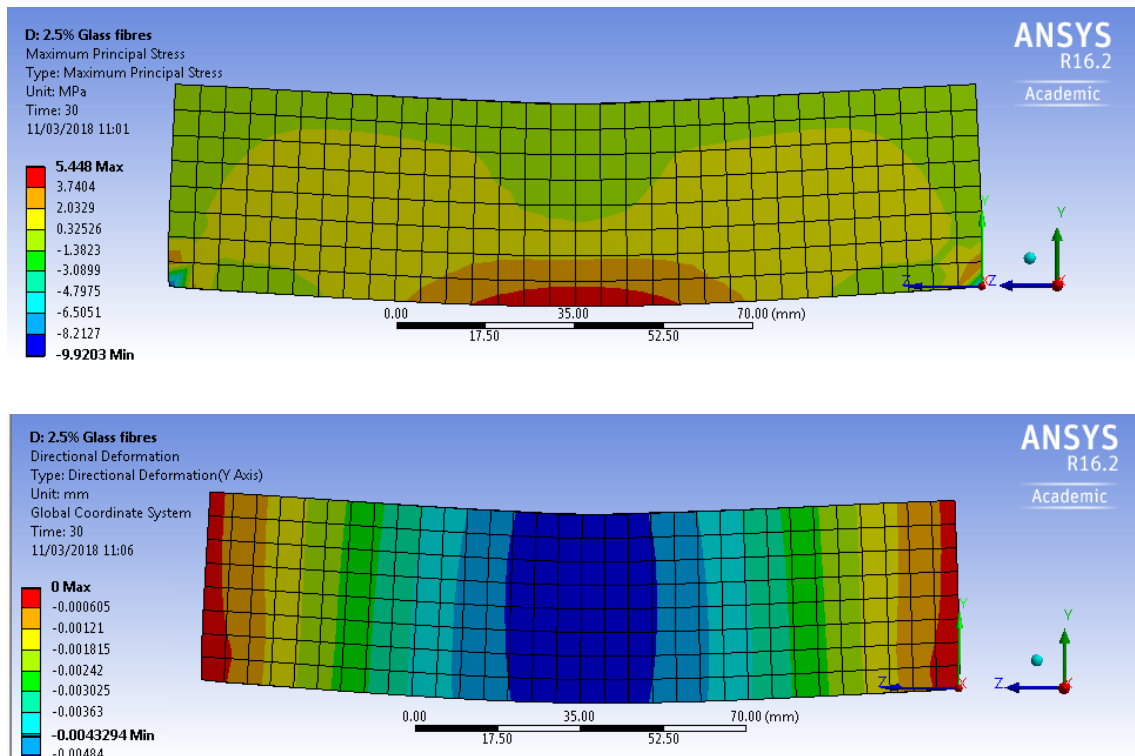


Figure 28: The stress distribution (top) and deformation (bottom) of the 2.5% polypropylene fibre addition.

### The 5% Polypropylene Fibre Content

The results of the stress and deformation of the sample with 5% Polypropylene fibre content are shown in Figure 29. It can be seen that the worst case scenario in terms of stress is recorded at the bottom side of the sample where tension is encountered. However, this is less significant at the upper side where concrete behaves better. This means that the critical region is the bottom side of the sample as shown in Figure 29. In terms of displacement, it can also be seen that the bottom side of the sample is subjected to the highest level of deflection and therefore elongation. Since concrete is very weak under tension, the expectation is that the sample will fail at the bottom at a stress of 5.84MPa with a total deformation of 0.0037mm which means that there is an improvement in strength and deformation when compared to the sample with no fibres and that with 2.5% polypropylene fibres. However, the improvement is not as high as that achieved at 2.5% glass fibres. This is due to the fact that glass is stronger and stiffer than polypropylene.

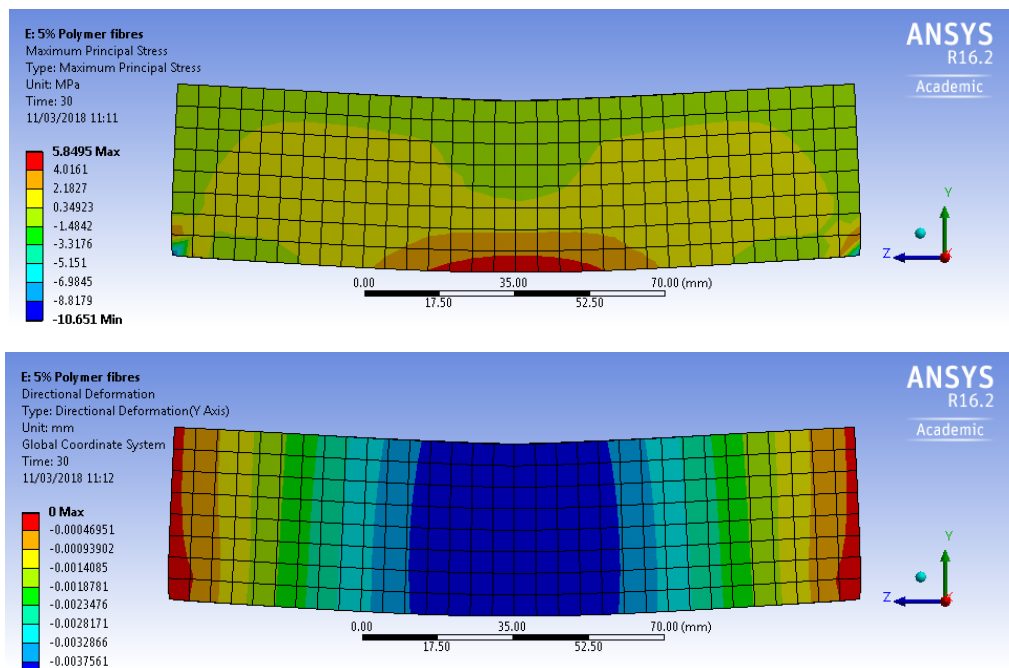


**Figure 29: The stress distribution (top) and deformation (bottom) of the 2.5% polypropylene fibre addition.**

## 5.7 Summary of the Modelling Results

The results obtained from FE modelling for the pure concrete, glass and polypropylene reinforced concrete are shown in Table 10 and Table 11. Overall, there is an improvement in the concrete properties when glass and polypropylene fibres are added. It can be seen that the strength has been improved as well as the stiffness which is observed through the lower deformation levels of the concrete. It can also be seen that the glass fibres provide better properties when compared to the polypropylene samples.

**Table 10: The FE modelling results of the pure concrete and the glass reinforced concrete.**

| Fibre content (%) | Mechanical Property  |                  |
|-------------------|----------------------|------------------|
|                   | Maximum Stress (MPa) | Deformation (mm) |
| 0                 | 5.36                 | 0.036            |
| 2.5               | 5.73                 | 0.004            |
| 5                 | 5.92                 | 0.003            |

**Table 11: The FE modelling results of the pure concrete and the polypropylene reinforced concrete.**

| Fibre content (%) | Mechanical Property  |                  |
|-------------------|----------------------|------------------|
|                   | Maximum Stress (MPa) | Deformation (mm) |
| 0                 | 5.36                 | 0.036            |
| 2.5               | 5.448                | 0.0048           |
| 5                 | 5.84                 | 0.0037           |

This means that there is an enhancement in properties of the concrete with the addition of fibres. The glass fibres provided the best results in terms of strength and stiffness. In this exercise, ANSYS has been employed and input data were collected from literature studies. This agrees with the experimental work carried out in the current project and this validates the utilised model.

## **6. CONCLUSIONS AND FUTURE RECOMMENDATION**

### **6.1 Conclusions**

- It was possible to mix the fibres with the concrete mixture at certain percentages. The mix design stage is very crucial to obtain a homogeneous mixture.
- The plain samples showed a higher strength when compared to the fibre-reinforced samples.
- Some literature studies mentioned that the existence of fibres above certain percentages might cause the strength to decrease due to the lower workability and loss of adhesion.
- The glass fibres were better than the polypropylene fibres in terms of strength. Moreover, the longer the curing time the better the obtained properties.

### **6.2 Future Recommendations**

- Optimisation studies are required in order to determine the threshold value of fibre volume fraction in concrete mixtures.
- More testing such as compressive and workability might be required in order to obtain a better understanding of the fibre-reinforced concrete.
- Other shapes of fibres such as twisted or hooked ends might provide new results in terms of strength of the concrete.
- Longer curing times might be necessary if possible to understand the relation between curing time and strength of concrete.

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