ICBBM EcoGRAFI

2nd International Conference on Bio-based Building Materials &
1st Conference on ECOlogical valorisation of GRAnular and FIbrous materials

June 21th - 23th 2017
Clermont-Ferrand, France

# USE OF NATURAL FIBRES TO ENHANCE TENSILE STRENGTH OF CONCRETE

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**Abstract**

This paper discusses the influence of natural fibres on density, compressive strength and flexural strength of fibre reinforced concrete specimens. Coir fibre extracted from coconut husk was added to high strength concrete to produced 36 test cubes and 36 beam samples. Tests carried out on cube and beam samples show that compressive strength of high strength concrete reduces with addition of coir fibres. The reduction is noticed varying with the change of fibre content and fibre length. Further, comparison between cubes and beams indicate variation in density of the concrete as well. The test results show that a reduction in flexural strength in most cases except for 2% coir fibre reinforced concrete, where a slight enhancement was noticed in flexural strength.

**Keywords:**

Compressive and flexural strength; coir fibres; unit weight; high strength concrete

## 1 INTRODUCTION

Concrete is a widely used composite construction material made of various proportions of coarse aggregates, fine aggregates, water and cement. Concrete is appreciated for its high compressive strength. Despite many advantages demonstrated by concrete, its weak tensile strength is a major disadvantage. Therefore, flexural members require steel reinforcement to provide tensile strength and to avoid cracks and failures. Steel reinforcement has been used traditionally to enhance tensile strength of concrete as steel reinforcement is appreciated for its compatibility with concrete for mechanical and thermal properties. However, steel reinforcement is expensive and less durable compared to concrete. Further, steel reinforcement is heavy and requires cover to protect it from extreme environmental conditions and fire.

If concrete structures can be constructed without steel reinforcement, they can be less expensive and more durable as there will not be any corrosion damages. Considering these advantages, there is a great interest to use corrosion resistant fibres to enhance the tensile strength of concrete in the form of fibre reinforced concrete. Carbon and glass fibres are being used to enhance the strength of plain concrete. The benefits of fibre reinforced concrete (FRC) encourage research community to investigate the use of natural fibres such as coconut (cocos nucifera) coir due to their sustainable nature.

In the recent past, there were studies on the use of natural fibres in concrete (Abhijeet, et al., 2014; Heidi, et al., 2011). Natural fibre reinforced concrete is prepared by adding various types of cellulose fibres to the concrete mixes. While the use of natural fibres help to enhance the tensile strength, they also facilitate to achieve the goal of sustainability as these fibres are natural and are available in abundant in the nature. Natural fibre cannot be depleted due to human use. Further, these fibres are light weight compared to steel and other fibres.

Due to their lightweight, cost effectiveness and sustainability, natural fibres can be an attractive choice in concrete structures if the flexural strength can be enhanced by adding natural fibres to concrete. This paper discusses the influence of coir fibres in self weight, compressive strength and flexural strength of high strength concrete. Due to its abundance in Sri Lanka, coir was selected for this study.

## 2 BACKGROUND

Concrete is considered as one of the major construction material in the building construction industry. Therefore, several studies have been carried out to establish properties of concrete. Since 1960s Fibre Reinforced Concrete (FRC) has been considered as an alternative to reinforced concrete in some application by considering enhanced tensile strength of FRC. There are mainly three types of fibres namely metallic fibres, mineral fibres and organic fibres. Even though addition of metallic and mineral fibres to concrete was successful, applications of those are limited due to its cost and processing constraints. Due to this constraint, in the recent past research studies have tried to improve the properties of plain concrete using natural fibres. Using natural fibres also helps towards sustainability goals as well. However, studies on natural fibre reinforced concrete did show some mixed results and leads to further investigation.

It can be noticed that the properties of any fibre reinforced concrete material is depending on two material characteristics. They are aspect ratio of fibres and percentage of added fibre. Previous studies on basalt fibre reinforced concrete showed that adding higher amount of fibre prevented catastrophic failure of concrete to some extent. The studies showed increase in concrete compressive strength when 0.5% fibres were added to concrete by the ratio of the weight of cement and the strength reduced as the fibre content increased to 1% and 1.5%. Researchers suspect this reduction was due to the increase of voids in the samples. Comparison of the results of the slump values show that slump values do decrease with the addition of fibres and with the increase of fibre- cement ratio. Therefore, use of super plasticizer to increase the workability of the concrete for the mix design was suggested.

Among the studies on coir fibre reinforced concrete, Agrawal [2014] have investigated grade 30 concrete with coir fibres having diameter range of 0.29mm to 0.83 mm added. The length of the fibres was in the range of 6mm to 24mm. The study showed a slight increase in flexural strength when fibres were added. This study also showed that flexural tensile strength reduced as the fibre-cement ratio exceeded 3%. The study concluded that the coir cannot replace steel as tensile strength enhancement was not sufficient to remove steel. Hence, the study suggested the use of coir fibres in non-structural components.

In fibre reinforced concrete interfacial bonding between concrete and fibre is very important towards achieving good mechanical properties. Cellulose fibres generally have poor interfacial bonding. Wettability is an important factor that affects bonding. Poor fibre wetting can lead to stress concentration due to interfacial defects [Chen P 2006, Pickering K.L 2015]. Previous studies have shown the effect of wettability towards flexural and tensile strength of composites [Wu XF 2006]. During the tensile loading stage of the composite material in order to fibre to be broken, fibres should have higher length than the critical length [ (Kelly & Tyson, 1965)].Therefore fibre length is also important factor which can affects the mechanical properties of the composites.

By processing the natural fibres with physical and chemical treatments wettability and interfacial strength of the fibres can be enhanced [ (Bénard, et al., 2007) (Sinha & Panigrahi, 2009) (Liu, et al., 2008)]. Alkali treatment is one of the popular natural fibre processing method. It exposes cellulose in the fibres by removing lignin, hemicellulose, pectin, fat and thereby increase the interfacial bonding. This also improves the cellulose structure of the natural fibres. Findings in some of the studies have shown improved fibre strength with the alkali treatment [ (Beckermann & Pickering, 2008) (Kabir, et al., 2012) (Bera, et al., 2010)].

Some of the recent studies have focused on using extrusion to disperse fibres inside composites. These studies have shown the possibility of obtaining favorable fibre orientation using extrusion method. However, with the addition of the aggregates, fibres tend to get disoriented. The results have shown improved interfacial strength, splitting strength, ductility and improved bonding with the composites [ (Khelifi, et al., 2016) (Lecompte, et al., 2015)].

Yalley and Kwan (Yalley & Kwan, 2005) investigated using coconut fibres as reinforcing material in fibre reinforced concrete. In this study, rigorous procedure was used to prepare the coir fibres. Coconut husks were soaked in water for one month and later placed in 10% concentration of sodium hydroxide (NaOH) for seven days before extraction. The fresh water was meant to remove pith particles whereas NaOH was used as a solvent for lignin and hemicellulose in the coir fibres. Due to the existence of lignin and hemicellulose in natural fibres it would cause to reduce the compressive strength of the natural fibre reinforced concrete. Studies carried out on the durability of natural fibres indicated that NaOH is a good solvent for hemicelluloses and lignin [ (Ramakrishna, 2005)]. Yalley and Kwan [2005] also studies Compressive Strength, Tensile Strength, and Torsion test of coir fibre reinforced concrete. The study has found that optimal fibre aspect ratio is to be 125 and optimum weight fraction to be 0.5%. As conclusions, it has stated that addition of coir fibres significantly improves properties of the concrete such as torsion, toughness, tensile strength and ability to resist cracking. But it is also stated that addition of coir fibres reduced the compressive strength of concrete due to difficulties in compaction. Therefore, this study also has stated that coir fibre reinforced concrete is unlikely to replace steel in the construction but it can be utilized up to some extent in lightly loaded structures. Paper also identifies two disadvantages of using natural fibres in cement based composites. They are high water absorption of natural fibre which causes unstable volume and low cohesion between fibre and matrix and natural fibres decomposes rapidly in the alkaline environment of cement and concrete [Yalley and Kwan, 2005].

A study by Mohr [2005] showed that the increase in fibre content contributed in properties such as flexural first crack and peak strength to increase. However, there is a disagreement on this as in many cases, the flexural properties increase with fibre content up to optimum fibre content and then reduce. Generally, most of the studies have found values between 6% to 20% to be the optimum fibre content.

## 3 MATERIAL AND TEST SETUP

All the test specimens used for this study were casted based on single mix proportion of concrete with three different aspect ratios and three different weight ratios of coir fibres.

### 3.1 Materials

Ordinary portland cement conforming to BS EN 197–1:2000 and water according to BS EN 1008 were used to prepare concrete mix. Uncrushed natural sand was used as fine aggregates and crushed coarse aggregates of both 20 mm and 10 mm were used as coarse aggregates. The workability of the concrete mix was enhanced by introducing superplasticizer as water reducer in all the mixes. This superplasticizer confirms to ASTM C494 Type A, F and G and BS EN 934-2 and based on polycarboxylate and modified phosphonate.

Coconut fibres with the length of 10 mm, 25 mm, 40 mm were used in this study. Fibre length was selected to comply ASTM C1609 standard as no relevant specifications found in eurocode. Coir fibre distributors in Sri Lanka category the fibres to several types based on the procedure of extraction. They are one tie fibre, two tie fibre, omat fibre and DI fibre. Out of these one tie fibres were used for this study. These fibres were soaked in water for a period of one month before the extraction of coconut fibres. As stated by Yalley and Kwan [2005], this procedure can remove the pith particles of the fibre.

These coir fibres were then subjected to a chemical treatment. Selected fibres were then placed in 7% concentration of sodium hydroxide (NaOH) for 48 hours. This act as a solvent for lignin and hemicellulose in the coir fibres. This process is expected to prevent any reduction in compressive strength in natural fibre reinforced concrete. Then the fibres were manually chopped into 10 mm, 25 mm and 40 mm sizes. Aspect ratio distribution of the selected fibres are shown in the Tab. 1. Fibres of the selected sizes were added to the moulds as randomly oriented fibres.

*Tab. 1 : Aspect ratio of the fibres*

| Fibre length | 10 mm | 25 mm | 40 mm |
|---|---|---|---|
| Aspect ratio | 30 | 74 | 118 |

By using the micrometer screw gauge the diameter of the fibres were measured. This was used to identify the average diameter of the coir fibres which were calculated to be 0.34 mm.

Density of the coir fibre materials was tested using a water replacement method. In this method, weight of the coir fibres was measured at first. Then fibres were put into a beaker and water was filled up to 800 ml level. After that fibres were removed from the beaker. With the removal of the fibres water level of the beaker was reduced. Then by using electronic fixed volume pipette water level was restored back to 800 ml level. Volume of water replaced were recorded by using the electronic pipette reading. By doing this test several times; average value of the volume of water replaced was recorded. **Error! Reference source not found.**Then the density of the coir fibres was calculated with the collected data. Recorded data from the study is shown in the Tab. 2.

*Tab. 2 : Density of coir fibres.*

| | |
|---|---|
| Weight of fibres | 16.32 g |
| Average Volume of water replaced | 24 ml |
| Density of Coir Fibres | 0.68 g/cm$^3$ |

Tensile strength of the coir fibres was measured by using the universal testing machine. This test was done on coir fibre bundles instead of single fibres. Collected data from the study is shown in Tab. 3. From the observed data, average tensile strength obtained from this study was 220 MPa. Some Literature sources [ (Rehsi, 1988) and (Agopyan, 1998)] suggested that the tensile strength of the coconut fibres ranges from 15 MPa to 220 MPa. Therefore, tensile strength obtained from this study is at the upper limit of the suggested value in literature.

*Tab. 3 : Tensile strength of coir fibres*

| | |
|---|---|
| Average Diameter of Coir Fibres | 0.34 mm |
| Average sectional area of coir fibres | 0.0908 mm$^2$ |
| Ultimate Tensile load for one fibre | 0.02 kN |
| Ultimate Tensile strength of coir fibres | 220 MPa |

### 3.2 Concrete Mix Design Details

Concrete mix design for this study was selected after reviewing the results of four trial mixes on four different mix designs. The selected is a Grade 60 (C50/60) mix design. Proportions of the materials which needs to be used for this design mixture is listed in Tab. 4. In all mix designs performed for the study; moisture correction was performed accordingly to minimize variation of water content.

*Tab. 4 : Proportions of the Mix Design for 1m$^3$ of concrete mixture.*

| | | | |
|---|---|---|---|
| Cement | 400 kg | Total Water | 175 kg |
| Total Aggregates | 1825 kg | Free Water | 170.12 kg |
| Fine Aggregates | 639 kg | Admixture (Superplasticizer) | 2.0 kg |
| Coarse Aggregates (20 mm) | 639 kg | w/b ratio | 0.4375 |
| Coarse Aggregates (10 mm) | 547 kg | a/b ratio | 4.5625 |

### 3.3 Specimen Preparation

Total of 36 test cubes and 36 prisms were casted in this study. Test cubes were used for the compression testing and prisms were used for the flexural strength test. All the specimens are based on single mix design and coir fibres were added based on the proportions described in the Tab. 5. Dimensions of the test cubes were 150 mm × 150 mm × 150 mm. Set of prisms with dimensions of 100 mm × 100 mm × 350 mm was also prepared based on details given in Tab. **5**. These samples were subjected to flexural strength test to determine the flexural strength of each mix. Since the aim of the study was to increase the tensile capacity of concrete; high fibre contents were proposed.

*Tab. 5 : Number of samples prepared.*

| Fibre Length \ Weight Fraction (Fibre / Cement) | 2% | 4% | 6% |
|---|---|---|---|
| 10 mm | 3 | 3 | 3 |
| 25 mm | 3 | 3 | 3 |
| 40 mm | 3 | 3 | 3 |

The concrete used for the study was mixed using drum mixer to avoid any inconsistency that could occur when using a hand mix. First cement and sand were mixed for about a minute in the drum mixer. Then the total water was added to the mix and a slurry was prepared by adding 0.5% admixture (Superplasticizer) by the weight of cement. After mixing for about 30 seconds, 20 mm and 10 mm coarse aggregates were added to the slurry. Then the mixing procedure was continued for another one minute. Later, fibres in the saturated surface dry condition were continuously added to the mix for 2-3 minutes while rotating the drum. Then the mixing procedure was continued for another 3 minutes. Each mix was used to prepare 3 test cubes and 3 prism specimens.

Compaction of the test cubes were done in accordance with the BS EN 14845. Compaction of the test cubes were done by using a tamping rod by applying 35 strokes per layer. But for the consolidation of prism specimen, external vibration technique used in accordance with ASTM C1609. Reason for this is to avoid any damage to the fibres when they are compacted.

## 4 RESULTS AND DISCUSSION

### 4.1 Strength of concrete

***Compressive strength test***

Compressive strength test was done using the compression testing machine. After 28 days of curing 3 test cube samples from each combination was tested and averaged for the final compressive strength. Firstly, samples of plain concrete were tested. Among the 36 cubes tested. 9 cubes were made of plain concrete of Grade 60 (C50/60) & 27 test cubes were made of coir fibre reinforced concrete. The obtained test values were used to calculate compressive stress.

Compression test was performed on the casted cube samples. From the obtained data, Fig. 1 is plotted. Compressive strength of plain concrete was 60.19 N/mm$^2$ as shown for 0% fibre content. Comparison of plain concrete strength with the concrete strength of fibre reinforced concrete show that a reduction in concrete strength with the increase of fibre content. Lowest compressive strength was obtained for 6%, 25 mm fibre added specimen. However, a comparison of fibre length in concrete mix outlines a slight increase in compressive strength as fibre length reduced for each fibre content as shown in Fig 1.

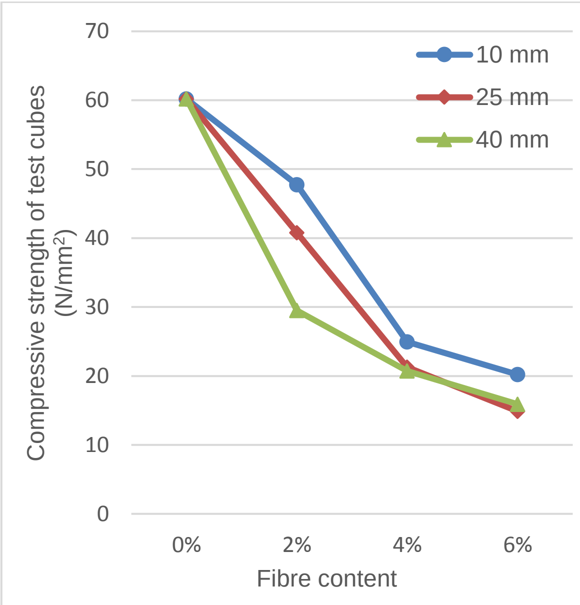


*Fig. 1 : Compressive Strength of Concrete vs Fibre content.*

***Flexural strength test***

Flexural test was carried out on the beam samples to investigate tensile strength of the fibre reinforced concrete. The test was performed using universal testing machine as shown in Fig. 2. Three beam specimen from each mix were tested after 28 days of curing and average flexural strength was estimated. A total of 36 beams were tested to study the influence of fibres in flexural strength including 9 specimen constructed using plain concrete of Grade 60 (C50/60) Then using the collected data flexural strength of each mix were determined.

*Fig. 2 : Testing Beam specimens for flexural strength.*

The test beams were subjected to a three-point flexural test as per the general guidelines given in the "ASTM C1609". The tests were carried out using load control method by loading the specimen at the rate of 0.015 kN/s. In addition to ultimate failure strength, load versus deflection behaviour also obtained from this study and plotted. Flexural Strength of these beams were then determined by using the peak load.

Results obtained from that test can be seen in Fig. 3. In comparison to the plain concrete only the 2% coir fibre added concrete mixes had higher flexural strength. As the coir content increased beyond 2%, the flexural strength further reduced. The lowest flexural strength was obtained for 4% amount 25 mm length fibre added specimen. An enhancement of 5.7% in flexural strength compared to plain concrete was obtained In the 2% - 40 mm fibre added mix and an 2.8% strength was noticed in 2% - 25 mm fibre added samples. However, the strength enhancement doesn't show any trends. Therefore, from the results of this test effect of coir fibre length to the flexural strength was not conclusively identified. In general, the enhancement obtained by applying the coir fibres to the plain concrete is minimal. In comparison to other studies which added coir fibres to plain concrete enhancement obtained is significantly lower [Yalley and Kwan, 2005]. In most of these studies coir fibres were added into lower grade concrete. Since this study was performed on high strength concrete of Grade 60, lower enhancement could be due the limitation of tensile strength of coir fibres.

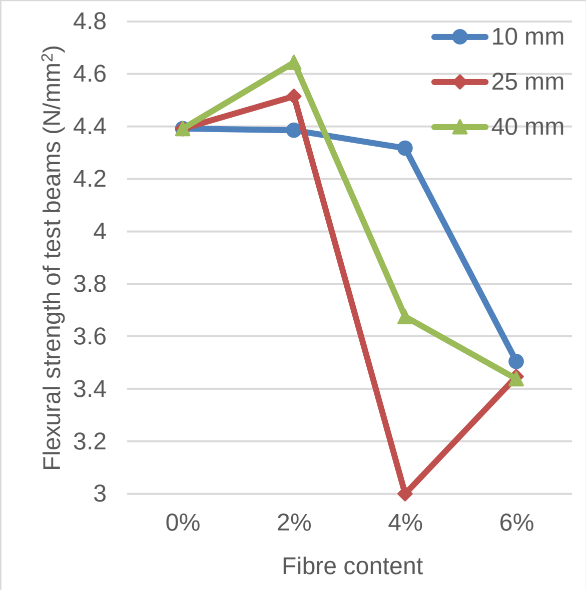


*Fig. 3 : Flexural Strength of Concrete vs Fibre content.*

***Unit weight of concrete***

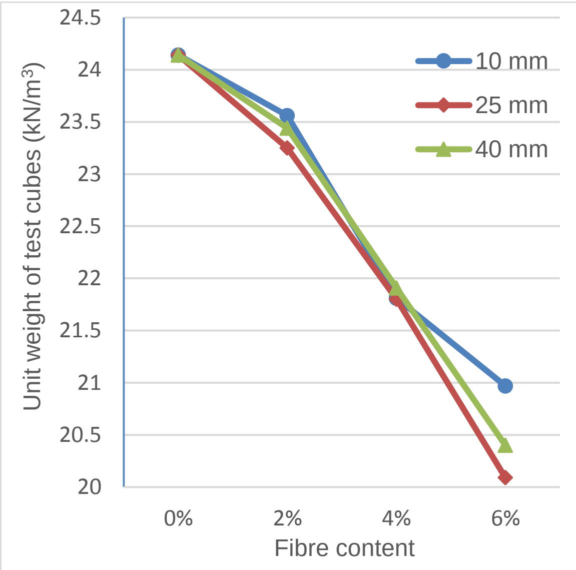


*Fig. 4 : Unit weight of concrete in cubes vs Fibre content.*

Average unit weight values shown in the Fig. 4 were calculated by using the measured weight from casted test cubes. A unit weight of 24.14 kN/m$^3$ was obtained for Grade 60 plain concrete test cubes. Therefore, plain concrete specimens show unit weight which lies in the acceptable limit for grade 60 concrete [Trevor 2009]. From Fig. 4, it can be noticed that a reduction in unit weight with addition of coir fibres. With the addition of 2%, 4%, 6% fibre content, a unit weight reduction of 2.9%, 9.5%, 15% compared to plain concrete was observed. Therefore, reduction is more severe when the fibre content is high. However, the variation of the unit weight between different fibre length is minimal for a particular fibre content. Therefore, the effect of fibre length to the variation of unit weight can be considered negligible. \

Test specimens which were casted for testing flexural strength of concrete were consolidated by providing shutter vibration to the mould. After 28-days, mass of each these specimens were measured to calculate unit weight of the beam specimens. Grade 60 plain concrete beam specimens did obtain unit weight of 25.02 kN/m$^3$. Therefore, plain concrete specimens show unit weight which lies in the acceptable limit for grade 60 concrete [Trevor 2009].

But as with cubical specimens even in beam specimens, unit weight of the coir fibre reinforced concrete did reduce with the addition of coir fibres. From the data shown in Fig. 5 it can be noticed that the reduction was less than 8% in all the specimens. Even in these beam specimens there was no significant impact from the change of fibre length to the unit weight of the concrete.

But in comparison to cube specimens the reduction of unit weight in beams with the addition of coir fibres is significantly lower. Therefore, in comparison to the use of tamping rod for compaction, the use of external shutter vibration can be considered as a more suitable method for compaction of coir fibre reinforced concrete.

As discussed in the section 3.1, obtained specific density of the coir fibres used in this study was 0.68 g/cm$^3$. From the results stated in the Fig. 4 and Fig. 5 it can be observed that the specific density of plain concrete varied between 2.46 g/cm$^3$ to 2.55 g/cm$^3$. Therefore, in comparison to density of concrete; density of coir fibres is relatively small. Thus, the reduction of unit weight with the increment of added fibre percentage observed in the Fig. 4 and Fig. 5 could be explained by the addition of lower dense material to plain concrete. Also, increment of fibre content could have increased the entrapped air percentage and void content in the test specimens. This can also influence on the decrement of the unit weight of test specimens.

Investigation of the compression and flexural properties of coir fibre reinforced concrete showed reduced performance in most of the fibre contents as in Fig. 1 and Fig. 3. Reduction in the unit weight of the samples could be a reason behind the observed compression and flexural strength decrements with the addition of coir fibres. And with the increment of fibre content and fibre length balling effect of the fibres were noticeably increased. Poor fibre dispersion could also be a reason behind reduced overall reinforcement efficiency [Heidi P 2011, Nando GB 1996, Sreekumar 2007, Devi LU 1997].

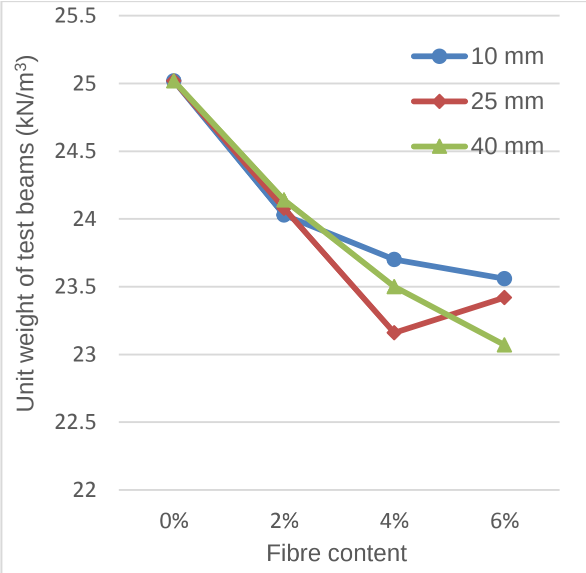


*Fig. 5 : Unit Weight of Concrete beams vs Fibre content.*

## 5 CONCLUSIONS

- Unit weight of the coir fibre reinforced concrete was reduced by 3% to 5%. As the fibre content increases the reduction of the unit weight in test cubes is more severe.
- With the addition of coir fibres compressive strength of high strength concrete did reduce severely by 20% to 75%. Compressive strength was also noted to be decrease with the increase of fibre length.
- With the addition of coir fibres unit weight of the shutter vibrated beam specimens was reduced by 3.5% to 8% in comparison to plain high strength concrete. But in comparison to unit weight of test cubes from same fibre mix proportion; unit weight of beams was higher.
- In comparison to flexural strength of high strength plain concrete, only 3% to 6% enhancement of flexural strength was observed in 2% (25 mm, 40 mm) fibre added mixes. In rest of the fibre mix proportions flexural strength was reduced by 2% to 32%.

## 6 ACKNOWLEDGEMENT

Authors acknowledge all the people who provided guidance, support and encouragement for the progress of this research work. Authors also like to acknowledge the financial support provided by the Sri Lanka Institute of Information Technology.

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