Experimental Study on Addition of Pine Fibers to High Strength Concrete

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Experimental Study on Addition of Pine Fibers to High Strength Concrete

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Abstract: *This study focuses on influence of pine fibres on unit weight, compressive strength and flexural strength of high strength concrete. Concrete mixes with 2%, 4% and 6% fibre content were produced while length of the fibres were varied from 10 mm to 40 mm. From the pine fibre reinforced mixes, 36 test cubes and 36 beam specimens were casted to identify the desired variations. Unit weight of the concrete showed significant variations in the test cubes. However, the variations of the unit weight observed in the beam specimens were low compared to the variations observed in test cubes. Compressive strength of the high strength concrete also reduced significantly with the addition of pine fibres. Also a reduction in flexural strength was observed. Variation of both compressive and flexural strength showed a relationship with the fibre content and fibre length as well.*

Keywords: *high strength concrete; compressive and flexural strength; pine fibres; unit weight*

1. INTRODUCTION

Concrete is being used as a major construction material in the 21st century for most of the construction works. Concrete is a composite material produced by blending cement with fine aggregates, coarse aggregates and water. Concrete as a construction material demonstrate both advantages and disadvantages. Prominent disadvantage of concrete is its weakness in tensile strength. Hence, steel reinforcement is used in construction work to provide adequate tensile strength, prevent cracks and other types of failures.

Steel is being used as the main reinforcement material in concrete due to its higher tensile strength, modulus of elasticity, expansion to heat and consistency in production. Major disadvantages of the steel reinforcement are higher initial cost, corrosion when exposed to corrosive conditions and associated repair costs. . In addition, steel has a big impact in dead load of a structure. . Corrosion of steel also limits the life span of the structure.

With the development in many fields, interest has been built over fibre reinforced concrete instead of steel reinforcing. In early stages glass and steel fibres were considered. These fibres are capable of improving aspects such as ductility, torsional capacity, flexural strength and resistance to cracking. Outcomes of these researches have shown that fibre reinforced concrete can reduce the requirement of steel.

In the recent past, there were interests to use natural fibres in concrete as fibre reinforced concrete. Fibre reinforced concrete is produced by adding different types of cellulose fibres to concrete mixes. Natural fibres enhance the aim of producing sustainable concrete as these fibres are abundantly available in most parts of the world.

Other importance factor of these fibres is that they are light in weight and have minimal impact on dead weight compared to steel fibres. Hence, structures could be optimized to reduce the construction cost where natural fibres can be used. The Research was carried out using pine fibres as reinforcing fibre, as pine trees are abundantly available in Sri Lanka and pine fibres are considered as a waste material that prevents undergrowth. Therefore, use of pine needles will create many positive environmental impacts as well.

2. BACKGROUND

Numerous studies carried out on fibre reinforced concrete have shown that there are two main material characteristics, which affects the properties of concrete when fibre reinforcements were added. Those are proportion of the added fibres (by volume or by weight) and aspect ratio of added fibres, Chanh (2003).

From the studies, performed using basalt fibres it has been identified that failure found to be less catastrophic with the increase of fibre content in a concrete mixture, Sandeepani (2013). An increase in concrete compressive strength was observed at 0.5% fibre – cement weight ratio and the strength observed decrease as the fibre - cement weight ratio increased to 1% and 1.5%. It was suspected that the reduction in strength was due to the increase of void content in concrete. The study has also showed that the workability of concrete also reduced with the increase of fibre- cement weight ratio, Sandeepani (2013).

A study by Dong et al (2014) investigated the feasibility of using pine needles from Maritime Pine (Pinus pinaster) as a reinforcing material for the composites. This study showed that the tensile strength of Maritime pine fibres varying between 31.4 MPa and 33.4 MPa with the change of fibre length. Maximum tensile strength observed in this study was 65 MPa. Due to the low tensile, the study suggested using use pine needles from Maritime Pine mainly in low stress or non-load bearing concrete elements.

Singha (2010) used pine needles as a reinforcing material for urea formaldehyde based polymer composites. In this case, results, which were obtained by the testing done on universal testing machine, showed an increase in both compressive strength and flexural strength of the composite. Results also showed that the increase in both compressive and flexural strength are much higher in short fibre reinforced composite compared to long fibre reinforced composite. This study showed that pine needles has the potential to be a good natural fibre material when mixed with composites.

Nemati (2015) and Chanh (2003) suggested using a mix design with certain properties to study the effect of fibre reinforced concrete. Those studies have stated that mix designs should contain higher cement content and higher ratio of fine to coarse aggregate than do ordinary concretes. Use of super plasticizer based admixtures are also advised in these studies.

Mohr (2005) has observed an increase in flexural first crack and peak strength with the increase of the fibre content. However, there are many dissimilarities between the findings of the various studies on optimum fibre content for the peak strength. However, as the optimum fibre content most studies found values varying between 6% and 20%, Mohr (2005).

3. MATERIALS AND TEST METHODS

All the fibre reinforced concrete mixes used in this study were based on single mix proportion of concrete. Fibre reinforced concrete mixes with three different fibre contents and three different fibre lengths were prepared for the study.

3.1. Materials

Ordinary Portland Cement conforming to BS EN 199 – 1:2000 was used. Natural sand and 10mm, 20mm crushed aggregates were used as fine and coarse aggregates respectively. Polycarboxylate based admixture was used as superplasticizer in conformity to ASTM C494 type A, F, G and EN 934-2.

Pine fibres of size 10 mm, 25 mm and 40 mm were used according to the ASTM C1609 standards. Fibres were manually chopped in to the selected sizes. These fibres were placed in sodium hydroxide (NaOH) concentration of 7% for 48 hours. This provides solvent properties for lignin and hemicellulose in the natural fibres. It is expected to avoid the reduction of compressive strength of fibre reinforced concrete (FRC). Diameter of the pine fibers were measured by using the micrometer screw gauge. These measured data were used to calculate the average diameter of the pine fibers. In this study average diameter of the pine needles were found to be 0.62 mm.

Water replacement technique was used to identify the density of the pine fibers. In this method weight of the sample of fibers were recorded first. Then this fiber sample was put into a beaker and water was filled until 800 mm level of the beaker. As the next step fibers in the beaker was removed slowly and then by using electronic pipette water level was restored back to 800 mm level. From this method, average value of volume of water replaced was recorded. Then with the collected data density of the pine, fibers were determined as in Table 1.

Table 1 Density of pine fibers

Weight of pine fiber sample	5.6 g
Average volume of water replaced	17 ml
Calculated density of pine fibers	0.32 g/cm^3

3.2. Concrete mix design details

Suitable mix design was found by performing four trial mixes on four different mix designs and reviewing their test results. Grade 60 (C50/60) mix design was selected for this study. Material proportions used in this mix design are listed in Table 2. Aggregates were assumed to be in oven-dry condition for the calculations of water quantity in the mixture. Moisture correction was performed accordingly to minimize the variation of water content. Cube compressive strength was determined for the pine fibre reinforced concrete by performing the compressive strength test according to BS EN 12390-3:2009.

28-day compressive strength of each pine fibre reinforced concrete mix was determined by testing 3 samples from each of the mixes and then by taking the average value. All of these samples were cured for 28 days before testing. Compressive strength test was performed for total of 36 test cubes including 9 test cubes, which were made with plain concrete. All the pine fibre reinforced concrete mixes were based on Grade 60 (C50/60) concrete mix design.

Table 2 Mix proportions for 1m^3 of concrete

Cement	400 kg	Total Water	175 kg
Total Aggregates	1825 kg	Free Water	170.12 kg
Fine Aggregates	639 kg	Admixture (Super plasticizer)	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

36 test cubes and prisms were casted including nine using plain concrete. Tensile strength was estimated using prisms while compressive strength was observed using test cubes. Test matrix used for preparing test samples is shown in Table 3. Dimension of test cubes were 150 mm x 150 mm x 150 mm while prisms were of size 100 mm x 100 mm x 350 mm. These prisms were subjected to flexural strength test to test the flexural strength of each mix. To achieve the main aim of enhancing tensile capacity, higher fibre contents were proposed.

Drum mixer was used instead of hand mixing to achieve the consistency throughout all the 11 mixes. During mixing water was added in full quantity after mixing of cement and sand for about 1 minute in the drum mixer. Then 0.5% of admixture was added an in 30 seconds after this coarse aggregate were added to the slurry and mixing was continued for 1 minute. Finally, fibres were added in small quantities into the rotating drum. For each mix 3 test cubes and prisms in each were casted.

According to the BS EN 14845 compaction of test cubes was done using tamping rod with 35 blows per each layer. However, and external vibration techniques was used was used for the consolidation of prism specimens based on ASTM C1609. Cause for this is to avoid any damage to fibres when they are compacted. For the external vibration, 1" poker vibrator was used as the shutter vibrator.

Table 3 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

4. MATERIALS AND TEST SETUP

4.1. Mechanical Properties of Pine Fibres

Using the universal testing machine, direct tensile strength of pine fibres were determined. The test results showed an average tensile strength of 82.78 MPa for pine fibres. A comparison with data obtained from literature showed that tests by Dong et al (2014) showed that tensile strength of pinus pinaster fibres were varying between 15 to 65 MPa. The study reported in this paper used pinus caibaea and no literature found to compare the test results. However, the results by Dong et al (2014) show that the test results of the pine fibre is within acceptable limits.

4.2. Strength of Concrete

4.2.1. Compressive strength test

Figure 1 shows the variation of 28-day compressive strength with the change of added pine fibre percentage. Comparison of compressive strength shows that compressive strength of all the 9 fibre reinforced concrete cubes tested were less than that of plain concrete. Furthermore, excessive reduction in compressive strength was observed with the increase of added fibre percentage. Reduction in compressive strength varied between 38% and 57% as the fibre percentage increased from 2% to 6%. Comparison of variation of compressive strength with the size of fibres indicate a slight reduction in strength with the increment of fibre sizes. Concrete mix added with 10 mm fibre showed higher compressive strength than other sizes.

Severe reductions in the compressive strength is significant because concrete is generally used as a design material considering its ultimate compressive strength. The reduction in concrete strength can be suspected to balling effect that happens when fibres added to concrete. Due to balling effect, unit weight of the concrete reduces and the bond between particles can also reduce.

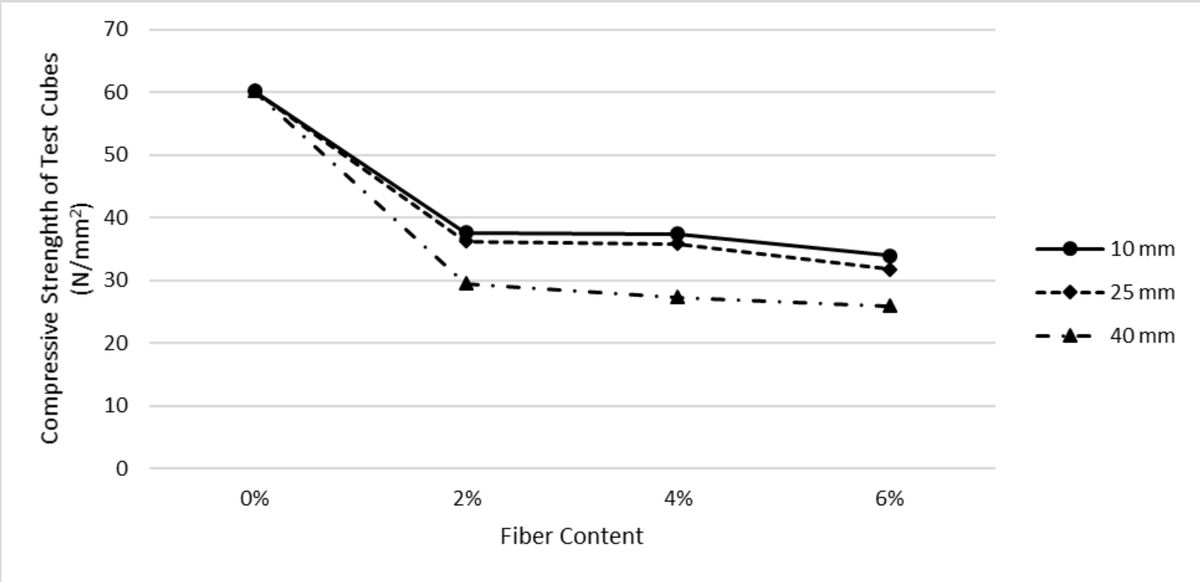

Figure 1 Compressive strength of concrete vs Fibre content

4.1.2 Flexural Strength Test

Three point bending test was performed on the beams produced using pine fibre reinforced concrete to estimate the flexural strength of the fibre reinforced concrete. The values obtained from the test are used as a measure of indirect tensile strength of pine fibre reinforced concrete mixes. As shown in Figure 2, universal testing machine was used to test the flexural strength of the test specimens.

Figure 2 Flexural strength test on beam specimens

Flexural strength obtained from the tests are compared with the fibre content in Figure 3. In most cases, a lower flexural strength was obtained for pine fibre reinforced concrete than plain concrete. A 17.5% reduction in flexural strength was noticed for 2 percentage of 40mm fibre reinforced concrete. However, this strength increased with the increase of fibre content and reached the flexural strength of plain concrete. A comparison of flexural strength of mixes with different sizes of fibres show that comparatively a higher flexural strength were obtained for mixes added with 25 mm fibres.

From the trend observed in the Figure 3 it can be said without any generality that the flexural strength could increase with the increase of fibre content. However, this requires further investigation as to study the influence of higher fibre content on compressive strength, workability and flexural strength.

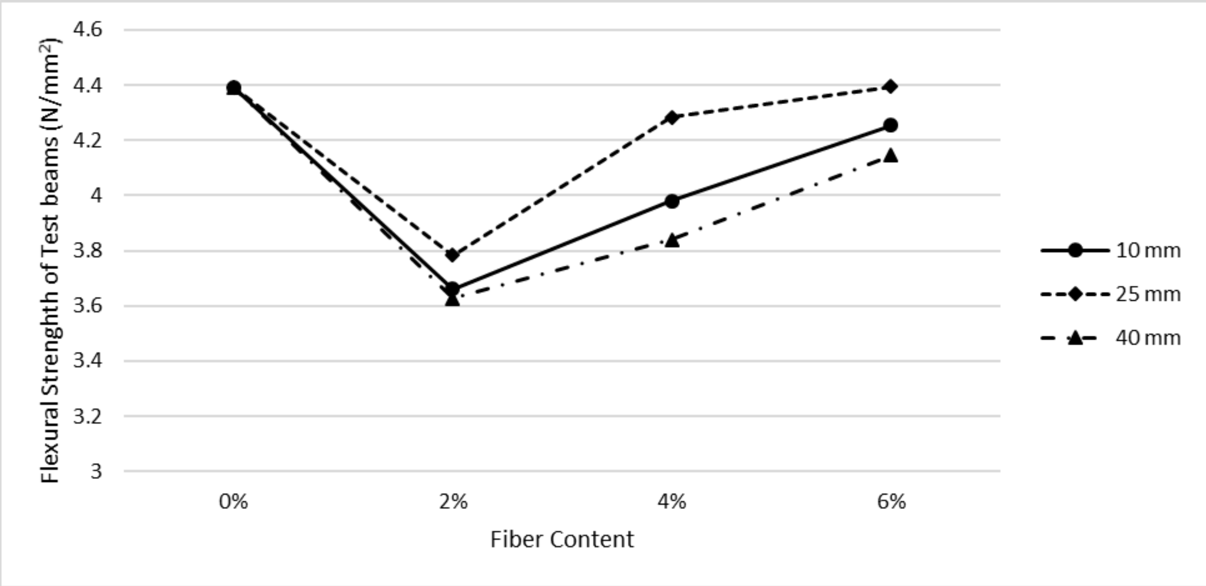

Figure 3 Flexural tensile strength of concrete vs. Fibre content

4.1.3 Unit Weight of Concrete

Figure 4 shows the variation of unit weight of concrete in test cubes with the addition of pine fibres. It can be noticed from the figure 4 that the fibre reinforced samples recorded lower weight than plain concrete. The reduction of the unit weight varied from 9.6% to 2% compared to the plain concrete cubes as the fibre content increased. However, the change did not follow any trend and can be suspected to the balling effect. This reduction of unit weight could be due to the increase of void content in the concrete and addition of lower dense materials (pine fibres).

Figure 5 shows the variation of the unit weight in beam specimens with the change of fibre content. It can be noticed that the unit weight of the concrete did reduce in comparison to the plain concrete. From the results of unit weight determination, no trend was identified with the increase of fibre content or with the increase of fibre length. The reduction of unit weight varied between 0.2% and 4%. Therefore, the reduction of unit weight occurred in pine fibre reinforced specimens is minimal. The reduction of unit weight in beam samples was much less than the unit weight reduction in concrete samples. This change could be due to the difference of compaction procedures. Compaction of the cube specimens was performed using tamping rod whereas the compaction of beam specimens was carried out using the poker vibrator. To comply with the ASTM C1609 standard, poker vibrator was used to provide the shutter vibration. However, it was difficult to provide shutter vibration to the cube moulds.

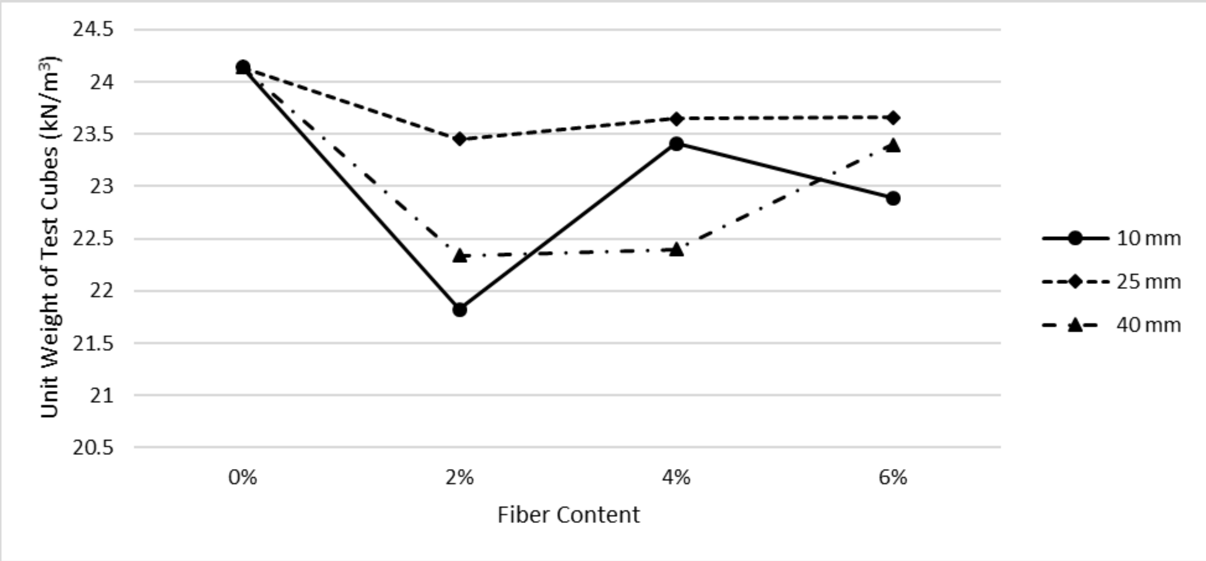

Figure 4 Unit weight of concrete in cubes vs. Fibre content

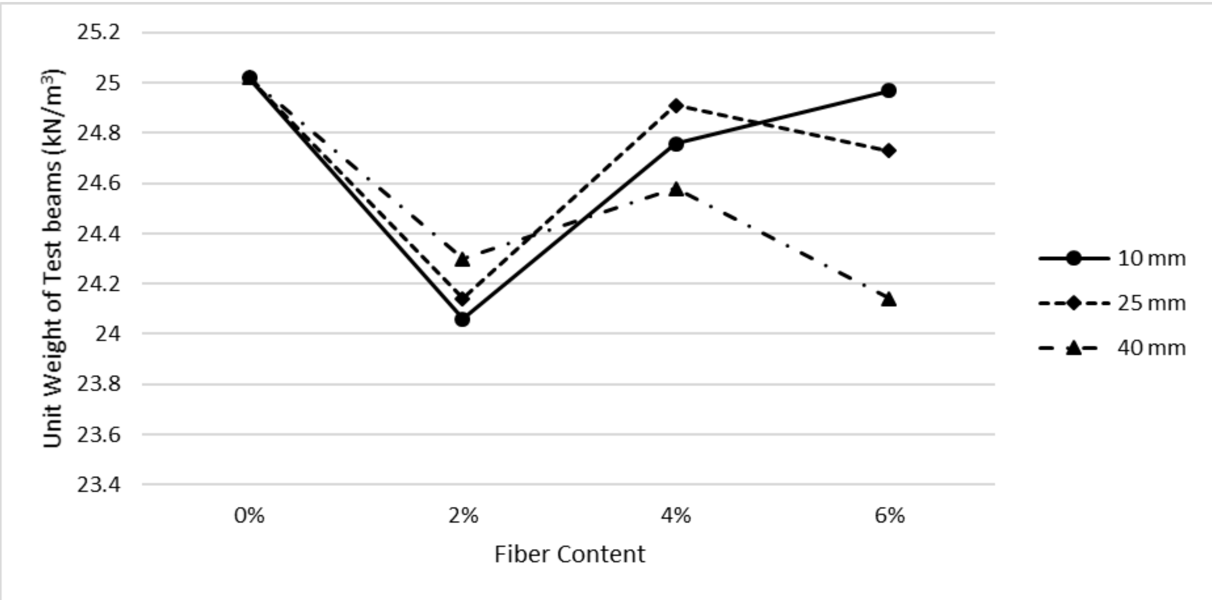

Figure 5 Unit weight of concrete beams vs. Fibre content

5. CONCLUSIONS

- Reduction in compressive strength was observed when pine fibres added to the concrete. A sharp reduction (38%) in compressive strength was observed between 0% fibre added concrete and 2% fibre added concrete. However, the reduction in compressive strength was relatively lower between 2% fibre added concrete and 6% fibre added concrete.
- Reduction in flexural tensile strength was obtained when fibres were added to concrete. An 18% reduction in tensile strength can be noticed from Figure 3. As the fibre content was increased, an increase of flexural tensile strength was obtained.
- Comparison of Figure 4 and Figure 5 can indicate fluctuation in unit weight of cubes and beam samples. However the fluctuation was less than 10% among various percentage contents.

- Overall, the study shows reduction in compressive strength when fibres added to concrete. However, the flexural tensile strength showed a reduction initially and then an increase in tensile strength with the increase of fibre content.

6. ACKNOWLEDGEMENT

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