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Procedia Engineering 14 (2011) 2616–2626

Procedia Engineering

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The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction

Effects on Mechanical Properties of Industrialised Steel Fibres Addition to Normal Weight Concrete

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Abstract

Five groups of concrete grade C25 were produced with the addition of steel fibres (SFs) at different volumetric percentages: 0% (as control specimen), 0.50%, 0.75%, 1.00% and 1.25% by absolute concrete weight. SFs with aspect ratio, l/d = 80 with 0.75 mm diameter and hooked at both ends were used in this study. The effects of adding SFs in concrete on its mechanical properties were measured for the cube compressive strength (f_{cu}), splitting tensile strength (f_{ct}), flexural tensile strength (f_t) and also the Modulus of Elasticity in compression. For each group, nine cubes of 100 × 100 × 100 mm, four cylinders of 150 mm diameter × 300 mm long and four prisms of 100 × 100 × 500 mm were prepared and tested at 7, 14 and 28 days. The mechanical properties of grade C25 concrete with and without SFs were determined in a comparative way by developing relationships between f_{cu}, f_t, f_{ct} and percentage of steel fibres. These relationships were experimentally determined to reveal the quantitative effects of additional SFs to concrete for these measured properties.

Keywords: Steel fibres, mechanical properties, concrete strength, normal weight concrete.

1. Introduction

Concrete is one of the most important materials in the constructions nowadays that promises a lot of advantages. The ability of concrete itself can be cast in any shape, excellent resistant to water and high temperature, required less maintenance are among the obvious advantages. Concrete is also known as an economical material as compared to all other available materials. Yet, concrete is a brittle material and associated with creep and drying shrinkage which induce to cracking problems and concrete

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doi:10.1016/j.proeng.2011.07.329

deteriorations. Adding steel fibres (SFs) in the concrete mix produces new kind of concrete known as steel fibre reinforced concrete (SFRC). The endeavour looked as a better idea to prevent shrinkage cracking and control of early thermal contraction right after placing the fresh concrete in the formwork. Among other advantages, SFRC increases in concrete toughness, energy absorption capacity, tensile strength and improves concrete durability.

SFRC had been applied with an increasing rates in the constructions nowadays i.e. ground bearing floor slabs (by enhancing load bearing capacity especially for those large slabs of factories and warehouse), heavy duty pavements for airports, docks and harbours, tunnel linings and prestressed fiber reinforced concrete (e.g. hollow core slabs). The main point concerned in SFRC mixes is the mechanical properties which consist of compressive, tensile, flexural and shear strength. Also, creep and shrinkage together with Modulus of Elasticity might also be included. Theoretically, there are three (3) parameters which influence the mechanical properties of SFRC (Xu and Shi 2009); (i) SFs itself by considering type, geometry, aspect ratio, volume fraction, orientation and distribution of SFs in concrete, (ii) matrix by considering strength and maximum aggregate size used, water/cement ratio, type of cement and supplementary cementitious material, and (iii) specimen by considering the size, geometry and method of preparation of the specimen.

Therefore, this study is conducted to achieve several objectives:

(a) To study the mechanical properties of SFRC i.e. compressive strength, splitting tensile strength, and flexural strength and Modulus of Elasticity of grade C25 concrete with five (5) different SFs volumetric percentages of 0%, 0.5%, 0.75%, 1.0% and 1.25% by absolute concrete weight.

(b) To determine the mechanical properties of SFRC and the relationship between them.

2. Related works

In 2004, Roesler et al. studied the fracture behaviour of plain and fibre reinforced concrete slab under monotonic loading. The primary objective of the study was to compare the various cracking strengths i.e. tensile, flexure and ultimate strength of concrete slab and small scale test beam. A total of five (5) slabs were cast where (a) two slabs contained discrete steel fibre (crimped and hooked end) with two different fibre content, (b) two slabs contained synthetic macrofibre also at two different fibre content, and (c) control specimen of plain concrete slab with 0% fibres. They found that the discrete fibres improved the load-deformation characteristics compared with plain concrete slab. The monotonic fracture test demonstrates that the type of fibres and content did not affect the tensile cracking load of the concrete slab. Discrete fibres contribute to the increase of between 1.8 and 2.2 times in flexural strength compared with either the synthetic macrofibre or the plain ones. Other than that, discrete fibres contribute 1.4 times greater flexural strength compared with plain concrete, and therefore increase the flexural cracking load between 25 to 55%. The study also found that the type of fibre (material, aspect ratio and geometry) and content were the main factors which increase the ultimate load-carrying capacity of the concrete slabs. Further comparison with synthetic macrofibres found that steel fibres has better bridging effect, thus, increased the ultimate load-carrying capacity of the concrete slab.

A year later in 2005, Khaloo and Afshari carry out experimental works on small SFRC slabs to study the flexural behaviour with varied fibre length (25 mm and 35 mm length), volumetric percentages of fibres (ratio of the volume of fibres to the volume of matrix between 0% and 1.5%) and concrete strength (cylindrical concrete strength of 30 MPa and 45 MPa at 28 days). They found that the rate of improvement in energy absorption reduced with the increased in fibre content ranging from 1.0% to 1.5%. Also, longer steel fibre with higher aspect ratio provides higher energy absorption of SFRC. They recommended that the addition of steel fibres in concrete must be within the volumetric percentages of between 0.75% and 1.75%. Later in 2007, Altun et al. studied the effects of adding SF on the mechanical properties of reinforced concrete (RC) beams. RC beams of grade C20 and C30 concretes were prepared with three (3) different SF dosages of 0, 30 and 60 kg/m^3. They came out with some concluding remarks where SFs dosages of 30 kg/m^3 is better than 60 kg/m^3 in terms of concrete toughness, flexural strength, crack formation, crack size and crack propagation for both concrete strengths.

The correlation among mechanical properties of SFRC was investigated by Xu and Shi in 2009. They concluded that strong correlations were found between compressive strength and splitting tensile strength and also between splitting tensile strength and flexural strength for SFRC with water-cement ratio, SFs aspect ratio and volume fraction in the range of 0.25 – 0.5, 55 – 80 and 0.5% – 2.0%, respectively. It was also recommended that investigations on potential correlations among mechanical properties of SFRC is necessary due to inapplicability of previous published empirical relations proposed to normal concrete, polypropylene fibre reinforced concrete (PFRC) and glass fibre reinforced concrete (GFRC).

It was also observed that the optimum volumetric percentages of SFs dosages must be in the range of between 0.75% and 2.0%. Obviously, SFs dosage higher than 2.0% become ineffectively because of the physical difficulties in providing a homogenous distribution of SFs throughout the structural members as well as decrease in the compressive strength as compared with the plain concrete (Altun et al. 2007). As for SFs dosage less than 1.0%, it also becomes ineffective due to the decrease in tensile and flexural strength. Yet, there are no particular studies that concentrate into the effects on mechanical properties of concrete with less than 1.25% dosage of SFs.

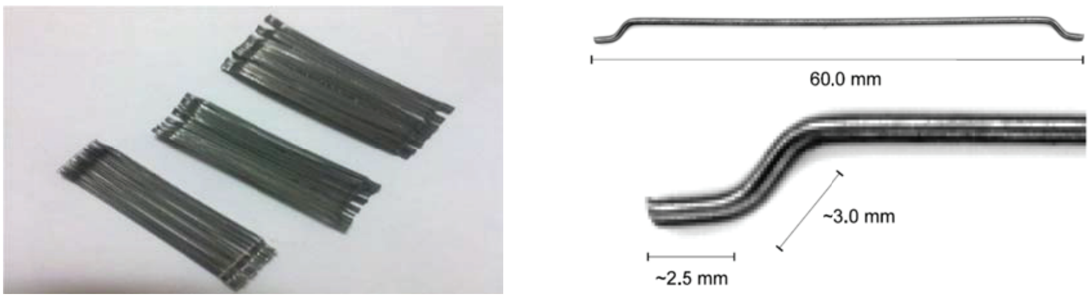
3. Research methodology

Normal weight concrete with grade C25 was prepared in this study in order to determine the static mechanical properties of SFRC. The tests conducted includes (see Fig. 1); (1) tests on cube concrete samples of 100 × 100 × 100 mm for compressive strength, (2) tests on cylindrical concrete samples of 150 mm diameter × 300 mm long for splitting tensile strength and static Modulus of Elasticity in compression, and (3) tests on 100 × 100 × 500 mm prisms for flexural strength. Altogether five concrete batches were prepared with five different volumetric percentages of SFs i.e. 0% (plain concrete as control specimens), 0.50%, 0.75%, 1.00% and 1.25% by absolute concrete weight. The type of SFs used in this study is shown in Fig. 2 with diameter of 0.75 mm and 60 mm long hooked ends, giving an aspect ratio (*l/d*) of 80.

(a) **(b)**

(c) **(d)**

Figure 1: Type of tests conducted; (a) cube compressive strength test, (b) splitting tensile strength test, (c) Modulus of Elasticity in compression, and (d) flexural strength test



(a) **(b)**

Figure 2: Type of steel fibres used: (a) steel fibres glued together in packing, and (b) detail dimension of the steel fibre

The method of concrete mix design for plain concrete with no SFs dosage was according to the method in designing normal concrete mixes (Teychenné et al. 1988). The controlled slump of fresh concrete was in the range of 30 – 60 mm and super-plasticizer admixture was added during the mixing process in order to increase the workability of the fresh concrete. All proportions of concrete mixes were remained exactly the same for all five concrete batches including the one with the added 0.50%, 0.75%, 1.00% and 1.25% of SFs dosages. Table 1 gives the mix proportions for the concrete mixes. During the mixing process, SFs were added last to the fresh concrete in the drum mixer at a rate of 20 kg/min, rotating at high speed for 5 minutes as recommended by RILEM (RILEM TC162-TDF 2000). Fig. 3 shows the SFRC at the end of the mixing process.

Nine cubes, four cylinders and three beams were cast from each batch and compacted using poker vibrator. All samples were cured in water at control temperature of between 19^{o}C and 21^{o}C until the test day i.e. 7, 14 and 28 days. The method of testing in compressive strength, splitting tensile strength and flexural strength were in accordance with BS EN 12390-3 2009, BS EN 12390-6 2009 and BS EN 12390-5 2009.

For the Modulus of Elasticity, a pair of strain gauges was installed on the opposite sides of the cylindrical specimens. The specimens were placed in a compression machine under stress of 0.5 N/mm^2 (as basic stress). The stress was then increased at a constant rate of 1.0 N/(mm^{2}s) until the stress is equal to one-third of the compressive strength of the concrete. The stress was maintained for 60 seconds before decreasing it back to the basic stress. Two additional preloading cycles were repeated at the same constant rate before the specimens were compressed until failure. The test procedures were in accordance with BS 1881-121 1983.

Figure 3: Physical appearance of fresh SFRC in the drum mixer

Table 1: Mix proportions for concrete mixes

Concrete Batch	Design Concrete Compressive Cube Strength at 28-days (N/mm^2)	Total Volume (m^3)	Ordinary Portland Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (max. size 10 mm) (kg)	Water (kg)	Steel fibres (kg)	Water-cement Ratio	Super-plasticizer (ml)
Batch 1 (Plain concrete)	25	0.065	22.0	68.2	49.4	15.0	0.00	0.68	45.0
Batch 2 (0.50%)							0.78		
Batch 3 (0.75%)							1.17		
Batch 4 (1.00%)							1.56		
Batch 5 (1.25%)							1.95		

4. Result and discussion

The micromechanical advantages for adding SFs in plain concrete obviously can be seen by its post-cracking effects, ductility and energy absorption. The SFs when uniformly dispersed throughout the specimens, acting as a reinforcement and help for better distribution of stresses. Therefore, the cracks occurred in SFRC specimens are smaller in size compared with plain concrete (and even more will break up at ultimate load). For example, the type of failure in compression for SFRC cube specimens was completely different with the plain concrete. Plain concrete cube samples fails (see Fig. 4a) as satisfied in

BS EN 12390-3 2009 where all four exposed faces breaks approximately equal with little damage to the top and bottom faces which was in contact with the loading plates. Meanwhile, SFRC cube samples failed (see Fig. 4b) with all four exposed faces bulges and still in contact. The experimental investigation also observed two types of failure for the cylindrical specimens (see Fig. 5) during the splitting tensile strength test. For plain concrete, the cylindrical specimens were completely split into two parts, but for SFRC there was only a single crack line occurred on the cross-section starting from the top to the bottom loading plate. The crack line also continued along the length of the cylindrical specimen. Flexural strength test also resulted in two types of failure as shown in Fig. 6. There was no sudden failure in bending at ultimate load for SFRC beam specimens i.e. only a crack line developed at the moment when SFRC beams failed, approximately at beam mid-span. This was opposite to plain concrete beams where the failure was sudden and breaks into two parts near to mid-span at ultimate load. Hence, this shows that the addition of SFs to concrete will distribute stresses better than plain concrete with good bonding and interfacial shear strength. Apart from that, SFs reduce the risks of catastrophic failure of concrete as brittle material which commonly break or explode under ultimate load.

The results for compressive strength, splitting tensile strength, flexural strength and Modulus of Elasticity are summarised in Table 2. The cube compressive strengths at 28-days for all specimens with varied SFs dosages were lower than plain concrete. The lowest compressive strength was observed for specimens with 0.50% SFs dosages as compared with plain concrete. As SFs dosage increases (between 0.75% and 1.25%) it shows constant increased in the cube compressive strength. However, the cube compressive strength with various SFs dosages is still acceptable since they are higher than the designed strength of 25 N/mm^2 at 28-days. Besides that, it proof that the higher aspect ratio (i.e. l/d = 80) may induce lower compressive strength but increase in toughness and peak strain of SFRC which lead to better crack control and energy absorption (Wang et al. 2010). Different results were obtained from the cylinder splitting tensile and beam flexural strength, where both tests resulted in an increase in strength. The splitting tensile strength increased by 1.52%, 1.14%, 4.18% and 6.08% and, the flexural strength increased by 10.94% 14.06%, 21.88% and 23.44% at 28-days for specimens with SFs volumetric percentages of 0.5%, 0.75%, 1.00% and 1.25%, respectively. The experimental investigation shows that SFRC is better than plain concrete especially under tensile and flexural load where SFs take part in absorbing the applied load. Fig. 7 and 8 onwards were then developed to determine the relationships between concrete cube compressive strength, cylinder splitting tensile strength, flexural strength and SFs volumetric percentages.

(a) **(b)**

Figure 4: Failure of cubes in compression: (a) Plain concrete, and (b) SFRC with 0.75% volumetric percentage

(a) **(b)**

Figure 5: Cylindrical splitting tensile failure: (a) Plain concrete, and (b) SFRC with 1.0% volumetric percentage

(a) **(b)**

Figure 6: Flexural failure of beams: (a) Plain concrete, and (b) SFRC with 0.75% volumetric percentage

Table 2: Average mechanical properties for concrete with different SF volumetric percentages

	Concrete Cube Compressive Strength Test (N/mm^2)			**Cylinder Splitting Tensile Strength (N/mm^2)**	**Flexural Tensile Strength (N/mm^2)**			**Modulus of Elasticity (kN/mm^2)**
Concrete Batch	**7-days**	**14-days**	**28-days**	**28-days**	**7-days**	**14-days**	**28-days**	**28-days**
Batch 1 (Plain concrete)	19.7	25.9	35.1	2.63	5.3	5.5	6.4	16.20*
Batch 2 (0.50%)	18.6	23.0	31.9	2.67	5.3	6.3	7.1	28.90
Batch 3 (0.75%)	21.3	25.0	32.8	2.66	4.4	6.6	7.3	28.75
Batch 4 (1.00%)	24.7	28.3	34.2	2.74	4.9	6.5	7.8	32.30
Batch 5 (1.25%)	25.5	30.3	34.6	2.79	5.4	6.9	7.9	33.65

** Strains gauges were not in good working condition resulted in lower Modulus of Elasticity*

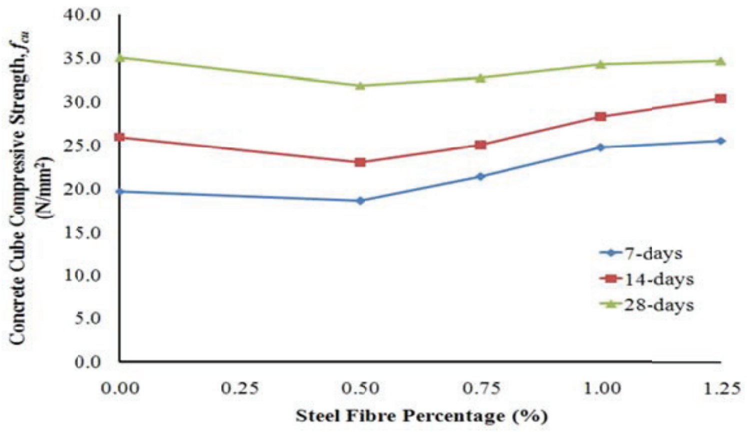


Figure 7: Relationship between concrete cube compressive strength (f_{cu}) and steel fibre percentage (%)

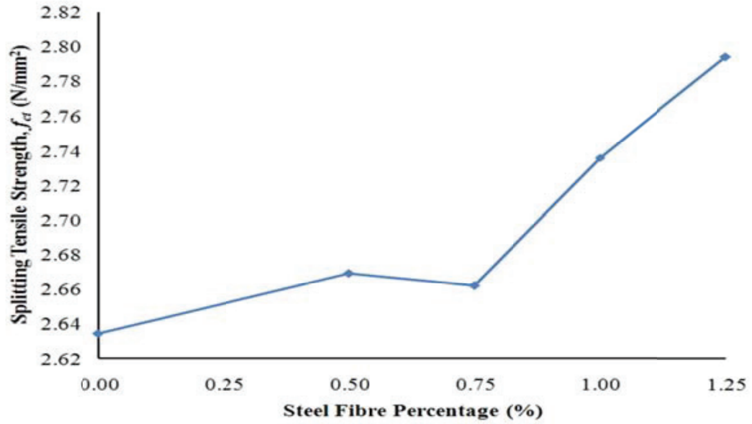


Figure 8: Relationship between concrete splitting tensile strength (f_{ct}) and steel fibre percentage (%) at 28-days

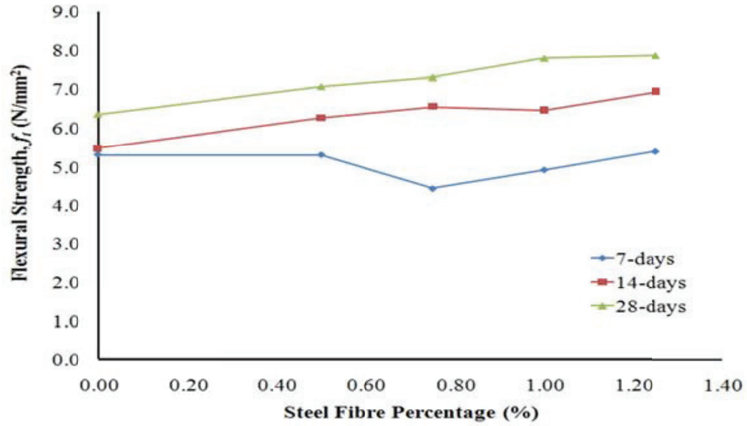


Figure 9: Relationship between concrete flexural strength (f_t) and steel fibre percentage (%)

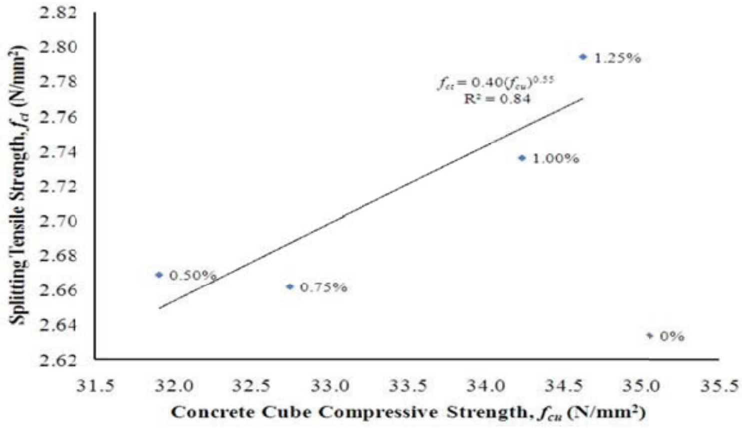


Figure 10: Relationship between concrete splitting tensile strength (f_{ct}) and cube compressive strength (f_{cu})

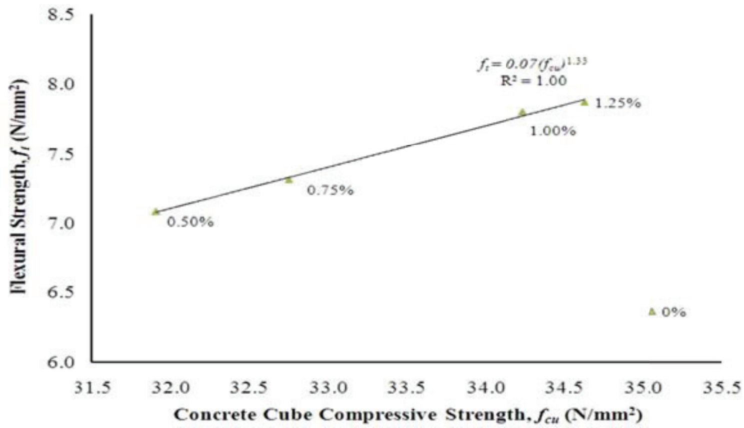


Figure 11: Relationship between concrete flexural strength (f_t) and cube compressive strength (f_{cu})

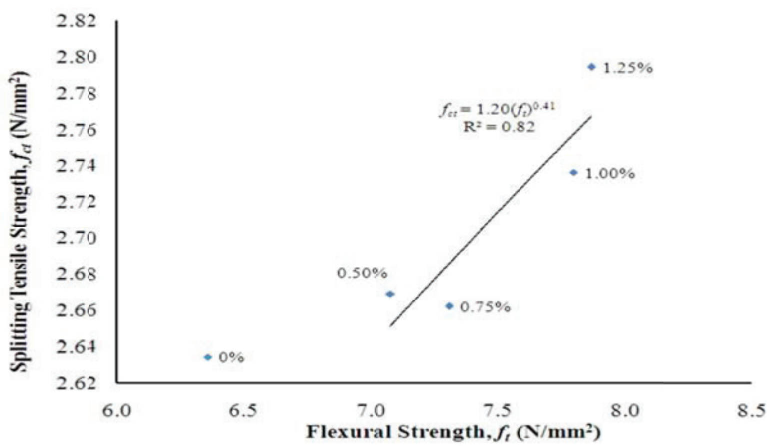


Figure 12: Relationship between concrete splitting tensile strength (f_{ct}) and flexural strength (f_t)

The Modulus of Elasticity for SFRC in compression as given in the Table 2 shows an increase in strength as SFs dosages increases. The increasing Modulus of Elasticity in SFRC shows that SFs dosages can absorb higher stress, thus, support the finding by the previous researchers (Khaloo and Afshari 2005) in improving the energy absorptions.

From Fig. 7, it can be observed that all SFRC (except for 0.50% SFs) gained early cube compressive strength at 7-days and even higher than plain concrete. However, the growth rates decreases at 14 and 28 days. For flexural strength (see Fig. 9), plain concrete gained higher early strength but the growth rates decreases at later age. Meanwhile, SFRC specimens show an increase in strength at 28-days and much better than plain concrete. The study also found that both the cube compressive and splitting tensile strengths indicated that there is not much effect for SFRC volumetric percentage less than 1% due to the slow growth strength rates at 28-days. Comparing the results of the cube compressive strength, splitting tensile strength and flexural strength for SFRC with 1.00% and 1.25% of SFs volumetric percentages, the strengths at 28-days are not much differ from each other. Therefore, it can be concluded that SFRC with 1.00% volumetric percentage should be a better choice along with the economical considerations.

As shown in Fig. 10, relationship between concrete splitting tensile strength (f_{ct}) and compressive cube strength (f_{cu}) was found. The empirical relation obtained can be expressed as:

$$f_{ct} = 0.40(f_{cu})^{0.55} \quad (1)$$

The coefficient of determination (R^2) for this proposed relation is 0.84 which indicates a strong correlation for both parameters involved. Meanwhile in Fig. 11 shows the relationship between concrete flexural strength (f_t) and compressive cube strength (f_{cu}). The empirical relationship obtained can be expressed as:

$$f_t = 0.07(f_{cu})^{1.33} \quad (2)$$

The coefficient of determination (R^2) for this proposed relation is 1.00 indicating very strong correlation for flexural strength and concrete cube compressive strength. Also, in Fig. 12 shows the relationship between concrete splitting tensile strength (f_{ct}) and flexural strength (f_t) which can be expressed as:

$$f_{ct} = 1.20(f_t)^{0.41} \quad (3)$$

The corresponding coefficient of determination (R^2) for this proposed relation is 0.82 also suggesting a strong correlation between the splitting tensile strength and flexural strength.

5. Conclusion

The results from the experimental works on the properties of compression, splitting tensile and flexural strengths show SFRC with SFs dosages of 0.50% and 0.75% are merely ineffective because there is not much improvement on the mechanical properties and even for the Modulus of Elasticity as compared with plain concrete. Meanwhile, SFRC with 1.00% and 1.25% SFs resulted in the increase of the splitting tensile strength and flexural strength. However, there is not much improvement in strength for SFs dosage between 1.00% and 1.25%. Clearly, the study shows that SFs dosages with 1.00% are better than 1.25% for SFRC considering the economical factor and ease of work. At 1.25% dosage and for this particular type of SFs used in the study, there was difficulty in casting which can lead to segregation between the concrete matrix and SFs.

This study also found strong correlations between concrete splitting tensile strength (f_{ct}), compressive cube strength (f_{cu}) and flexural strength (f_t) where R^2 were between 0.82 and 1.00 for steel fibres with an aspect ratio of l/d = 80 and volumetric percentage ranging from 0.5% to 1.25%. The quantitative values for this study can be improved by conducting a study with various types of SFs available in the market i.e. aspect ratios, SFs shapes and different concrete classes i.e. normal concrete or even high strength concrete.

Acknowledgments

The writers wish to acknowledge all technicians at the Department of Structures & Materials, Faculty of Civil Engineering, Universiti Teknologi Malaysia for their invaluable help and support while conducting this study and also to Timuran Engineering Sdn. Bhd. for supplying the steel fibres.

References

[1] Altun F, Haktanir T, and Ari K. *Effects of Steel Fiber Addition on Mechanical Properties of Concrete and RC Beams. Construction and Building Materials.* 21 (3); 2007, pp. 654-661.

[2] British Standard Institution. *Testing Hardened Concrete, Part 3: Compressive Strength of Test Specimens*. London, BS EN 12390; 2009.

[3] British Standard Institution. *Testing Hardened Concrete, Part 5: Flexural Strength of Test Specimens*. London, BS EN 12390; 2009.

[4] British Standard Institution. *Testing Hardened Concrete, Part 6: Tensile Splitting Strength of Test Specimens*. London, BS EN 12390; 2009.

[5] British Standard Institution. Testing Concrete, Part 121: *Method for Determination of Static Modulus of Elasticity in Compression*. London, BS 1881; 1983.

[6] Khaloo AR and Afshari M. *Flexural Behaviour of Small Steel Fibre Reinforced Concrete Slabs. Cement and Concrete Composites*. 27 (1); 2005, pp. 141-149.

[7] RILEM TC162-TDF. *Test and Design Methods for Steel Fibre Reinforced Conrete: Bending Test. Mater Struct*: 33 (January-February); 2000, pp. 3-5.

[8] RILEM TC162-TDF. Test and Design Methods for Steel Fibre Reinforced Conrete: σ-ε Design Method. Mater Struct: 33 (March); 2000, pp. 75-81.

[9] Roesler JR, Lange DA, Altoubat SA, Rieder KA, and Ulreich GR. *Fracture of Plain and Fibre-Reinforced Concrete Slabs Under Monotonic Loading*. Journal of Materials in Civil Engineering. 16 (5);2004, pp. 452-460.

[10] Teychenné DC, Franklin RE, and Erntroy HC. *Design of Normal Concrete Mixes. Department of the Environment*. HMSO, 1988

[11] Wang ZL, Wu J, and Wang JG. *Experimental and Numerical Analysis on Effect of Fibre Aspect Ratio on Mechanical Properties of SFRC. Construction and Building Materials*. 24 (4); 2010, pp. 559-565

[12] Xu BW and Shi HS. *Correlations among Mechanical Properties of Steel Fiber Reinforced Concrete. Construction and Building Materials*. 23 (12); 2009, pp. 3468-3474.