THE MECHANICAL PROPERTIES OF HYBRID FIBRE REINFORCED COMPOSITE CONCRETE

F.A. Othman[1]*, M.I. Ghazali, A. Jameran and I.S. Ibrahim

Faculty of Civil Engineering, UniversitiTeknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

ABSTRACT

Fibres in concrete provide a means of arresting crack growth. Short discontinuous fibres have the advantage of being uniformly mixed and dispersed throughout the concrete. In this study, the mechanical properties of hybrid fibre reinforced composite concrete (HyFRCC) were investigated by combining polypropylene (PP) and steel fibres (ST). Polypropylene fibre is good in preventing micro cracks while steel fibre is reliabe in preventing macro cracks in the concrete. In this research, the specimens incorporated ST and PP fibres were in the mix proportion of 100-0%, 75-25%, 50-50%, 25-75%, and 0-100% by volume fraction of 0.5%. Compression, flexural tensile, cylinder splitting, and toughness tests were conducted to determine the mechanical properties of HFRCC. By combining these two fibres in concrete, it reduces the crack growth with PP was found to improve the tensile strain capacity whereas ST contributed on the improvement of the ultimate tensile strength. The results indicate that concrete containing fibre in combination of 75% ST + 25% PP fibres can be adjudged as the most appropriate combination to be employed in HyFRCC for all tests.

Keywords: Hybrid fibre, mechanical properties, steel, polypropylene.

1.INTRODUCTION

Fibres on concrete provide a means of arresting crack growth. Short discontiunous fibres have the advantage of being uniformly mixed and dispersed throughout the concrete.The increase in strength by the use of fibres, the degree of ductility, the extent of post-cracking behaviour, and simple or multiple cracking depend on the strength characteristics of the fibres themselves apart from the bond in the matrix-fibre interface, the ductility of the fibres, the volume of fibre reinforcement and its spacing. The dispersion and orientation of the fibres, their shape and aspect ratio, high strength, large volume, longer lengths, and smaller diameters have been found independently to improve the strength. Composites reinforced with steel, polypropylene and natural fibres have a wider social development to a country with low-cost and low-energy construction (Parameswaran, 1991).

(a) **(b)**

Figure 1: (a) Polypropylene fibre, and (b) steel fibre

[1]*Corresponding author and presenter:Email:faezahasmahani@yahoo.com

This research will explore the potentials for achieving balanced improvements in the performance characteristics of composite concrete materials through the combined use of different types of fibre. This combination is also known as hybrid fibres. Such efforts potentially can lead to the development of fibrous composite concrete that will provide superior performance under severe loading and environmental effects at reasonable costs. In this research, polypropylene (PP) was combined with steel (ST) fibres as shown in Fig. 1 and mix in concrete with various volume fractions to control the macro and micro crack growth development. Application to structural elements should able to reduce crack growth and resists tensile and flexural strength.

The use of PP fibres as a reinforcing medium can only be made in a cement matrices. Their natural abundance, wide range and type of fibres, immeasurable source and relative cheapness point to the direction of their development for housing and many related constructions. However, their inherent weaknesses such as low elastic modulus, high water absorption and low fire resistance contribute to their relatively poor performance and lack of stability and durability. It is, therefore, necessary that a great deal of developmental work should be carried out by mixing them with ST fibres with regard to the choice of fibres and fabrication process.

The objective of this study is to investigate the mechanical properties of hybrid fibre reinforced composite concrete at fresh and hardened state. Besides that, the toughness and ductility response of hybrid fibre reinforced composite concretewas also investigated.

2. RELATED WORKS

Based on (Faizal Fouad Wafa 1990), the mix of fibre reinforced concrete should have a uniform dispersion of the fibres in order to prevent segregation or balling of the fibres during mixing process. Most of the balling occurs during fibre addition process. Moreover, increase of aspect ratio, volume percentage of fibre, size, and quantity of coarse aggregate will intensify the balling tendencies and decrease workability.

The use of small size specimen for toughness test will enhance the influence of an increase in the fibre volume fraction. An increase in the fibre volume will lead to the increase in toughness parameters according to ASTM C1609/C1609M-07. Therefore, in this study, the specimen with size of 100 x 100 x 350 mm was chosen. Concrete due to its brittle behaviour has little ability to resist tensile stresses and strains. Therefore, discontinuous fibres were added to improve the energy absorption capacity and resistance to cracking (S.P. Singh et al. 2010).

Moreover, in 2004,N. Banthia and R. Gupta (N. Banthia and R. Gupta, 2004) carry out flexural toughness test for very high concrete strength by adding together a combination of different types of fibres. Control, single, two-fibre and three-fibre hybrid composites were cast using different fibre types such as macro and micro-fibres of steel, polypropylene, and carbon. The study shows that fibre combinations demonstrate maximum synergy in terms of flexural toughness.

There were some cited work from different researchers on the properties of FRC where the presence of fibresin concrete may alter the failure mode of cylinders. However, the fibre effect was minor to the improvement of concrete compressive concrete strength up toabout 15%. While for the Modulus of Elasticity, there was an increase to about 3%for volume fraction, V_f = 1%. It was reported that for every 4% of fibres added,it will increase by 2.5 times of the flexural strength. Meanwhile, for toughness, there was an increasebetween 10 and 40 times compared with plain concrete. As for the splitting tensile strength of mortar, there was an increase to about 2.5 times to that of the unreinforced one when V_f = 3% (Faizal Fouad Wafa 1990).

.

3. EXPERIMENTAL PROGRAMME

To achieve the objective of the study, laboratory work was carried out in two stages. In the first stage, the mechanical properties of each individual fibres of the industrialised steel (ST) and polypropylene (PP) fibres were investigated to determine its tensile strength and density. The type of PP fibre was of the Mega Mesh II and the concrete strength was design to achieve grade C30.In the second stage, the mechanical properties of hybrid fibre reinforced composite concrete (HyFRCC) was determined which includecompressive, flexural tensile, splitting tensile, and flexural toughness. Table 1 shows the fibre mix proportion between ST and PP fibres where the total volume fraction, $V_f$wasfixed at0.5%. The density and tensile strength for the ST fibre was 7850 kg/m^3 and 1100 MPa, whereas PP fibre was 869.14 kg/m^3 and 400 MPa respectively.For PP fibres, the aspect ratio (l/d) is in the range of 100 – 200, whereas the hooked-end type ST fibres have an aspect ratio, (l/d) of between 55 and 60.

Table 1: Fibrous concrete mixes

Type of fibres	Fibre mix proportion by volume (%)				
	Total volume fraction, V_f = 0.5%				
Steel fibres (ST)	100	75	50	25	0
Polypropylene fibre (PP)	0	25	50	75	100

The material proportion used for every concrete batch as shown in Table 2 were calculated based on the Department of Environment (DOE) method. This method uses the relationship between w/c ratio and compressive strength of concrete depending on the type of cement and the type of aggregate used. The proportion of water, cement, fine and coarse aggregates, and superplasticizer were same for every batch. An example calculation of weight for both fibres used as shown by the following expression:

Steel fibre : $\frac{75}{100} \times \frac{0.5}{100} \times 7850 \frac{\text{kg}}{\text{m3}} \times 0.122\, m3 = 3.591\, kg$ (1)

Polypropylene fibre : $\frac{25}{100} \times \frac{0.5}{100} \times 869.14 \frac{\text{kg}}{\text{m3}} \times 0.122\, m3 = 0.133\, kg$ (2)

Table 2: Material proportion in the concrete mixture

Batch		Water (L)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Superplasticizer (L)	ST Fibre (kg)	PP Fibre (kg)
Control		30.5	55.5	112.9	88.5	0.111	-	-
0.5% (ST-PP)	(100-0)	30.5	55.5	112.9	88.5	0.111	4.789	-
	(75-25)						3.591	0.133
	(50-50)						2.394	0.265
	(25-75)						1.197	0.398
	(0-100)						-	0.53

3.1 Compression Test

Compression test wascarried out in accordance to BS EN 12390-3:2009. The test setup is shown in Figure 2(a). The cube was of 150×150×150 mm and 9 samples were prepared for every concrete batch.The samples were water cured and tested at 3, 7, and 28 days. The compressive strengthandweight of each sample were recorded. The cracking patternwasalso compared with the control specimens.

3.2 Flexural Tensile Test

Flexural tensile test was carried out in accordance to BS 12390-5:2009. The test setup is shown in Figure 2(b). The data obtained from this test was the flexural strengthapart from the cracking patterns which was also compared for every fibre mix proportion. The size of sample is 100×100×500 mm and a total of 6 specimens were prepared for the test. An average of 3 samples was taken to determine the flexural strengthat 7 and 28 days. The samples were water cured until the test day.

3.3 Splitting Tensile Test

Splitting tensile test was carried out in accordance to BS EN 12390-6:2009. The test setup is shown in Figure 2(c). In order to obtain the tensile strength of HyFRCC, 3 cylindrical samples of 300 mm height ×150 mm diameter were prepared and tested at 28 days. All samples were water cured until the test day. The cracking pattern was also observed to make comparison for different concrete batch.

(a) (b) (c)

Figure 2: Test setup for the mechanical properties of HyFRCC: (a) Compressive, (b) flexural tensile and (c) splitting tensile

3.4 Toughness Test

Toughness test was carried out in accordance to ASTM C1609/C1609M-10. The test setup is shown in Figure 3. Since loading was applied manually, the mid-span deflection was recorded at every increment of 0.5 kN.This will ensure the consistency of the loading rate and continuously applied load as recommended in ASTM C1609/C1609M-10. 3 samples of 100×100×350 mm were prepared for the test and undergoes water curing process until the test day. The test was carried out at 28 days.

Figure 3: Toughness test setup

4. RESULTS AND DISCUSSION

4.1 Slump and Density of HyFRCC

The workability at fresh state of the control and HyFRCC specimens were determined by measuring the slump of the concrete. The design slump was in the range of 60 – 180 mm. The higher the slump values, the higher the concrete workability.In other words, workability is the ease and homogeneity inwhich the concrete can be mixed, transported, poured, consolidated and finished. Table 3 shows the slump result and density of the cube samples. As shown in Figure 4, the slump value decreases when the fibre volume increases. PP fibres were also found to absorb water during the mixing process. Therefore, the slump value decreases when the weight of PP fibre increases. The density relationship shown in Figure 5 shows either the concrete is dense or not.The finding shows thatHyFRCCis still dense eventhough fibres co-exist in the concrete with higher water-cement ratio of 0.55.

Table 3: Density of cube samples

Batch		Slump (mm)	Density (Kg/m3)											
			3 Days				7 Days				28 Days			
			C1	C2	C3	Average	C4	C5	C6	Average	C7	C8	C9	Average
Control		70	2326	2321	2320	2322	2330	2338	2361	2343	2360	2373	2388	2374
0.5% (ST-PP)	(100-0)	65	2347	2356	2373	2359	2379	2381	2381	2380	2379	2354	2376	2370
	(75-25)	50	2326	2342	2364	2344	2345	2373	2314	2344	2351	2381	2375	2369
	(50-50)	45	2344	2332	2314	2330	2310	2316	2307	2311	2304	2326	2363	2331
	(25-75)	40	2342	2326	2296	2321	2321	2296	2354	2324	2304	2304	2313	2307
	(0-100)	35	2296	2321	2321	2313	2324	2323	2308	2318	2319	2307	2338	2321

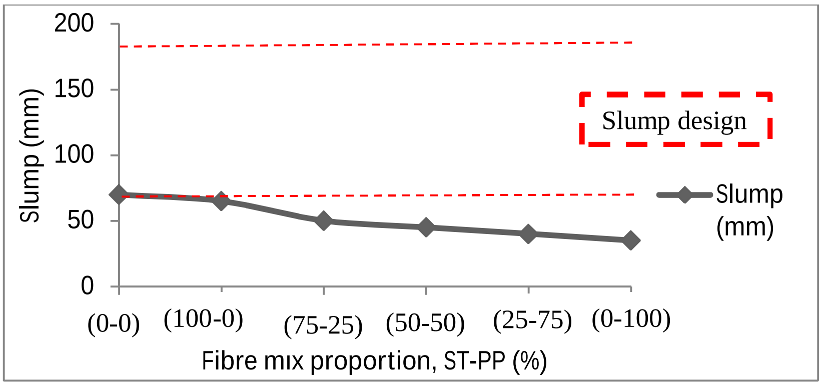


Figure 4: Slump result

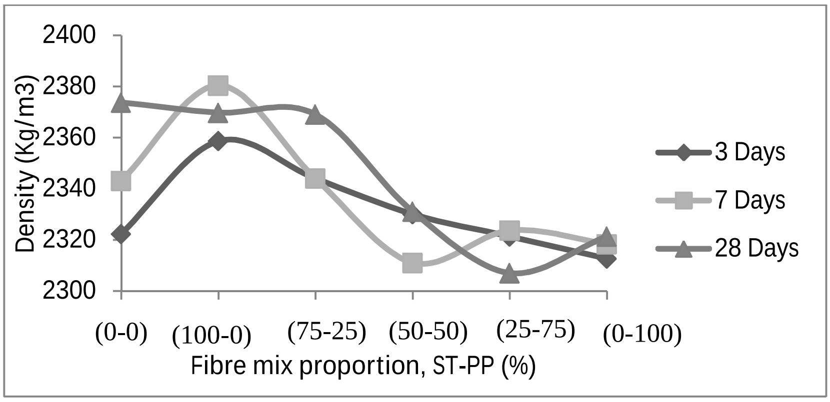


Figure 5: Density for every cube for each batch

4.2 Compression, Flexural, and Tensile Strength Test Results

The main reason by adding hybrid fibre in concrete is to increase the concrete strength comparedwiththe plain ones. As shown in Figure 6, the finding suggested that HyFRCC does not have much effect on its compressive strength. However, HyFRCCcritically affects its flexural and tensile strength, and also toughness.

Cracking pattern and propagation was much different for HyFRCCin comparison with plain concrete. Plain concrete is brittle and therefore, spallingwas observed under the applied load. This was not the case for HyFRCC. Table 4 shows the results of the compressive, flexural, and tensile strength of HyFRCC. From Figures7 and 8, the highest flexural and tensile strength was given by 0.5% (75%-25%) fibre mix proportion of ST-PP fibre. This was the highest added of ST fibre combined with the PP fibre. The PP fibre was found to delay the pre-cracking of micro crack while steel fibre will help in delaying post-cracking of macro cracks. These two fibres will grip the particle in the concrete when loading was applied.

Table 4: Results on compressive, flexural, and tensile strength

Batch		3 Days				7 Days				28 Days			
		Compressive strength, f_{cu} (MPa)											
		1	2	2	Average	4	5	6	Average	7	8	9	Average
Control		24.26	23.62	24.54	24.14	29.09	32.86	31.47	31.14	38.13	43.50	43.69	41.78
0.5%	(100-0)	22.22	23.23	22.33	22.59	30.97	31.68	32.49	31.71	41.74	41.23	41.19	41.38
	(75-25)	22.55	21.35	22.44	22.11	30.47	27.48	32.23	30.06	35.65	41.84	35.90	37.80
	(50-50)	20.15	20.36	20.15	20.22	25.35	26.69	25.35	25.79	34.10	35.97	33.00	34.36
	(25-75)	19.18	19.32	19.85	19.45	23.93	25.11	24.23	24.42	36.91	35.76	31.89	34.85
	(0-100)	19.18	19.32	19.85	19.45	25.96	23.21	23.93	24.37	33.53	34.13	36.07	34.58
Batch		Flexural strength, f_t (MPa)											
						1	2	3	Average	4	5	6	Average
Control						4.21	4.89	5.12	4.74	5.48	5.83	5.65	5.65
0.5%	(100-0)					5.12	5.37	4.93	5.14	5.99	6.09	5.92	6.00
	(75-25)					5.06	5.32	5.12	5.17	6.22	6.92	5.81	6.32
	(50-50)					4.89	5.06	4.55	4.83	5.51	5.41	5.79	5.57
	(25-75)					4.67	4.15	4.94	4.59	5.24	5.28	5.80	5.44
	(0-100)					4.65	4.76	4.36	4.59	5.05	5.65	5.06	5.25
Batch		Tensile strength (MPa)											
										1	2	3	Average
Control										4.46	4.64	4.39	4.50
0.5%	(100-0)									4.74	4.67	5.23	4.88
	(75-25)									4.79	4.91	4.46	4.72
	(50-50)									3.53	3.10	3.50	3.38
	(25-75)									3.92	2.97	3.28	3.39
	(0-100)									3.46	3.84	3.29	3.53

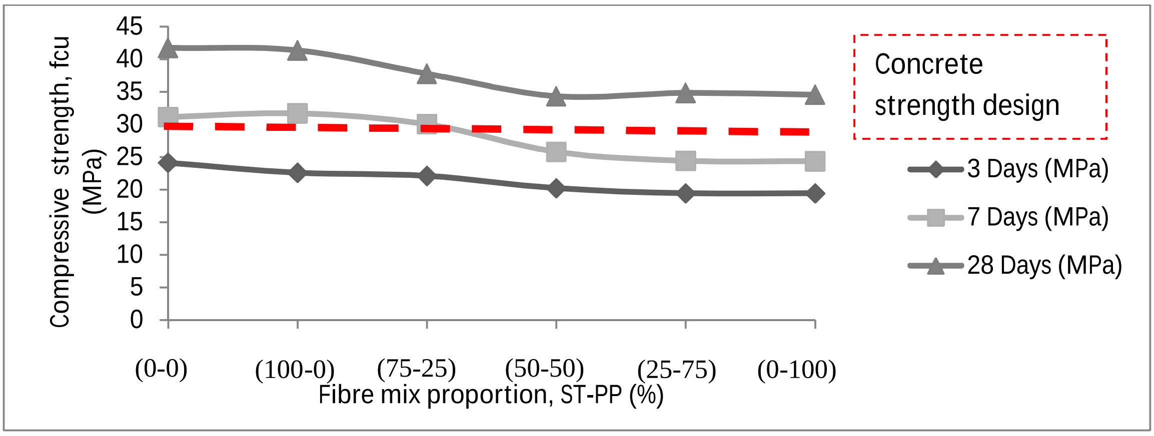


Figure 6: Compressive strength

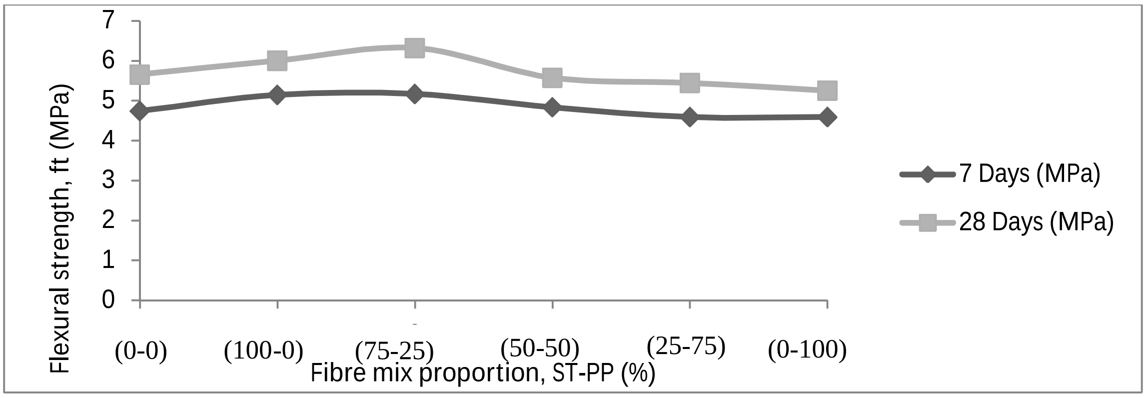


Figure 7: Flexural strength

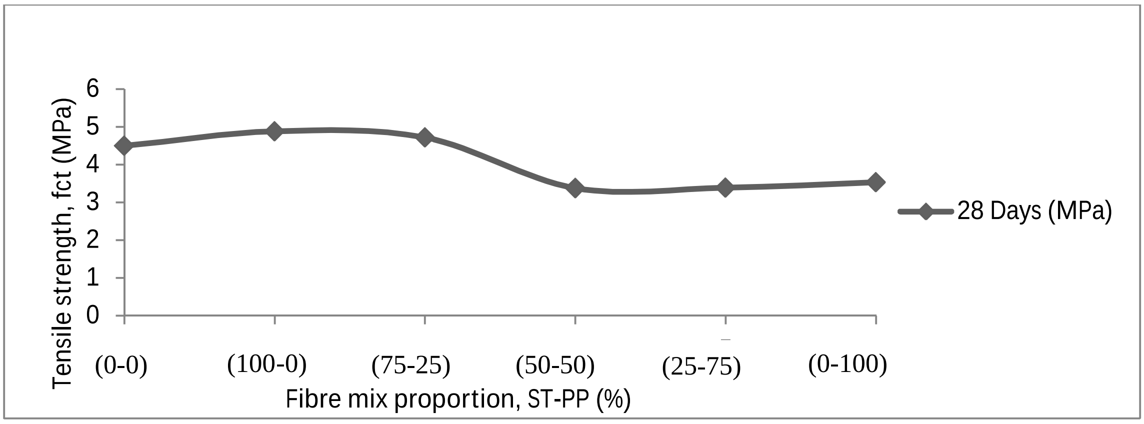


Figure 8: Tensile strength

4.3 Flexural Toughness Result

Table 5 shows the results of the flexural toughness indices. The highest toughness indices were given by the combined fibres of 75%-25% (ST-PP) for the total volume fraction of 0.5%. The finding shows that HyFRCCis more durable due to less cracks produce and can stand with high loading before it fails which are leads to less maintenance needed and more ductile compared with the plain concrete. High value of toughness, T at L/600 and L/150 will shows the HyFRCC is tougher than plain concrete.T_{600} and T_{150} is the parameter to measure the concrete toughness. PP fibre reduces the occurrence of plastic shrinkage cracking. Removal of the bleed water in concrete then takesplacewhen concrete start to set. Bleed water moves to the surface of concrete and will develop tiny capillary channels. Then, it will develop microscopic cracks in concrete. Additional microscopic cracks meet, join, and develop into large macro-cracks. Then PP fibre take place to intersected tiny macro-crack to prevent from further growth and remains in its initial small size. ST fibre will react when sample under loading. The concrete will absorb more energy before it fails.

Table 5: Flexural toughness indices

Fibre mix proportion by volume (%)		Fibre volume fraction (%)	Toughness indices					
ST	PP		P_{600} (kN)	P_{150} (kN)	f_{600} (MPa)	f_{150} (MPa)	T_{600} (Joules)	T_{150} (Joules)
0	0	0.5	15.0	14.0	4.5	4.2	7.625	29.5
100	0		15.0	12.5	4.5	3.75	7.750	27.7
75	25		16.5	15.0	4.95	4.5	8.625	31.2
50	50		9.5	7.8	2.85	2.34	4.875	17.6
25	75		12.5	10.5	3.75	3.15	6.375	23.5
0	100		9.0	7.5	2.7	2.25	4.750	17.5

Moreover, Figure 5 shows the pattern of graph for every batch. Load against deflection graph pattern can show the toughness and brittle behaviour of the HyFRCC. For plain concrete, after it reached its limits which are at first crack production, the specimen will break into two. Compared to HyFRCC after the first cracks produce, the samples are not break into two and still will give deflection readings.

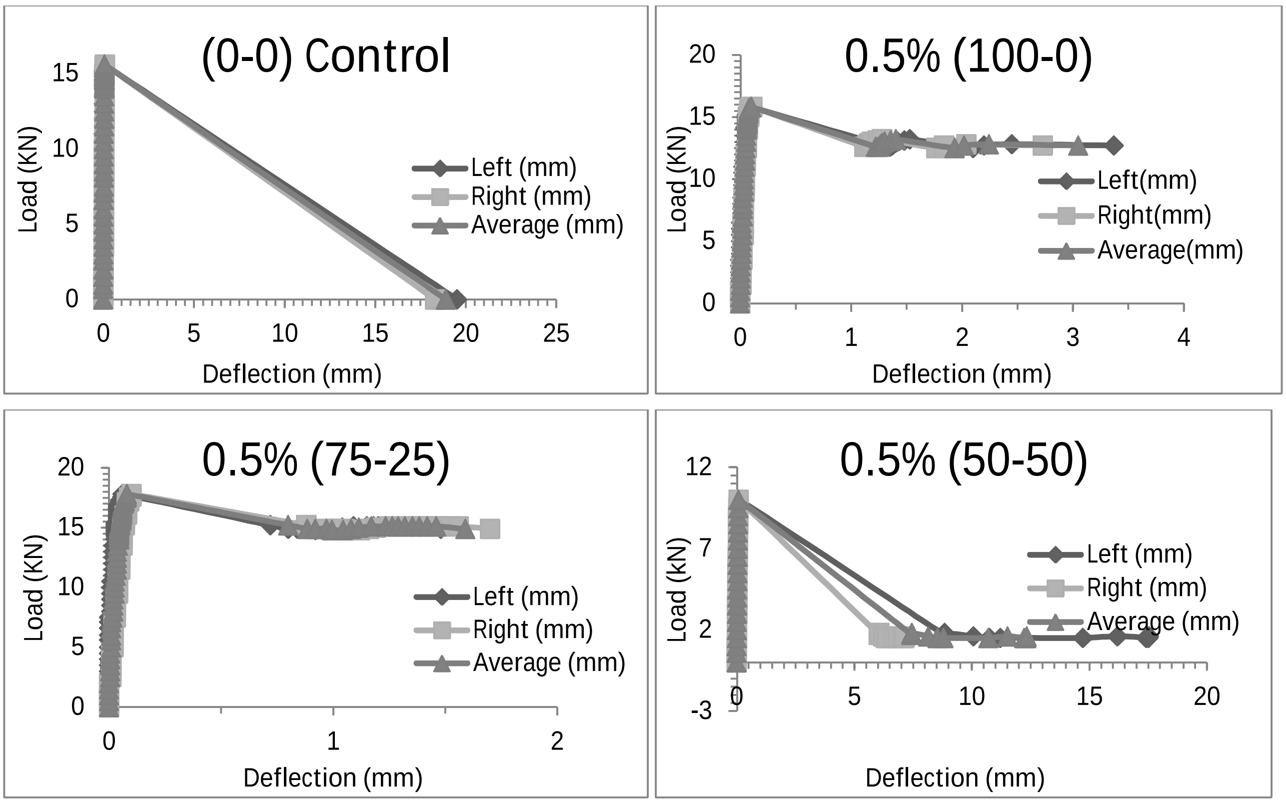
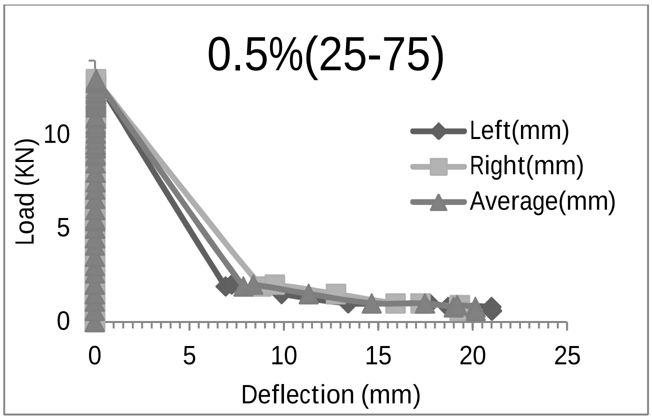


Figure 9: Load against deflection graph for every batch



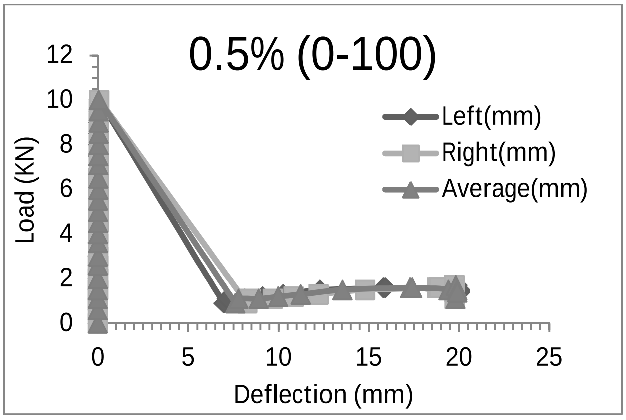


Figure 9: Load against deflection graph for every batch (Cont.)

5. CONCLUSION

As the conclusion, fibre in concrete helps in bridging the crack growth. For 0.5% of the total volume fraction, the best fibre mix proportion which gives highest value of flexural, tensile, and compressive strength is by adding 75% of ST fibre and 25% of PP fibre. This fibre mix proportion also gives high T_{600} and T_{150} value. It shows that HyFRCC is more durable compared to plain concrete. High value of steel fibre added need to grips the particle in the concrete when subjected to loading. It will absorb more energy before its fails. PP fibres in the concrete will helps in reducing plastic shrinkage crack. Too much PP fibres added in concrete, it will produce dry concrete and lead to low workability level. This is due to PP fibre is recognised absorb some water in concrete. All the hybrid fibre concrete will not break into two when under loading compared to plain concrete. Plain concrete will split into two when subjected under loading due to no bridging component exist.

Acknowledgement: This research is funded by the Ministry of Higher Education Malaysia under the Exploratory Research Grant Scheme (ERGS) No. 4L066. Special thanks go to all staffs in the Structure & Material Laboratory, UniversitiTeknologi Malaysia for their invaluable supports and advice throughout the research work.

REFERENCES

BanthiN, and Gupta R (2004). Hybrid Fiber Reinforced Concrete (HyFRC): Fiber Synergy in High Strength Matrices. Materials and structures.Vol. 37.Pp 707-716

BS EN 12390-3 (2009).Compressive Strength of Test Specimens.Testing Hardened Concrete.1-22.

BS EN 12390-6 (2009).Tensile Splitting Strength of Test Specimens.Testing Hardened Concrete.1-14.

BS EN 12390-5 (2009).Flexural Strength of Test Specimens.Testing Hardened Concrete.1-14.

C 1018 (1992). Standard Test Method for Flexural Toughness and First-Crack Strength of Fibre-Reinfoeced Concrete (Using Beam with Third-Point Loading). Annual Book of ASTM Standard, ASTM Committee. C-9: 514-20.

C 1609/C 1609M (2008). Standard Test Method for Flexural Performance of Fibre-Reinforced Concrete (Using Beam with Third-Point Loading). Annual Book of ASTM Standards, ASTM Committee. C09. 1-9.

Wafa FF (1990). Properties and Applications of Fibre Reinforced Concrete. Vol 2:49-63.

Parameswaran VS (1991). Fibre Reinforced Concrete: A Versatile Construction Material. Building and Environment. 26 (3): 301-305

Singh SP, Singh AP, and Bajaj V (2010). Strength and Flexural Toughness of Concrete Reinforced With Steel-Polypropylene Hybrid Fibres. Building and Housing. Vol 11: 495-507.