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FLEXURAL PERFORMANCE OF STEEL-POLYPROPYLENE HYBRID FIBER REINFORCED CONCRETE BEAM: EXPERIMENTAL INVESTIGATIONS

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ABSTRACT

This study mainly investigates the flexural performance of reinforced concrete beam (RCC) using polypropylene and steel fibers separately as well as combination of both fibers. Prior to specimen preparation, the physical and mechanical properties of polypropylene and steel fibers were determined. Moreover, the physical properties of binding material, coarse aggregates and fine aggregates were determined. In this research, four categories of beam specimens (4´ x 6´´ x 6´´size and selected suitable mixing ratio of 1:2:4) were constructed encompassing normal RCC beam (control); addition of 1.5% steel fiber; 2% polypropylene fiber; and combination of 0.5% steel fiber and 1.5% polypropylene fiber in volume of concrete. Experimental results showed that there is considerable increase of flexural strength due to addition of 1.5% steel fiber and 2% polypropylene fiber in concrete. However, the addition of both fibers (hybrid fiber) in combined not only increase the flexural performance but also the ductility of reinforced concrete beam members resulting to the cost effective. Hybrid fiber shows synergic effect on flexural behavior of concrete.

Keywords: *Polypropylene fiber, Steel fiber, Hybrid fiber, RCC beam, Flexural strength.*

1 INTRODUCTION

As concrete offers numerous well-known benefits such as low cost, wide obtainability and applicability, it is the most widely used construction material. Since concrete is brittle in nature, therefore, numerous materials have been utilized now-a-days to enhance this essential characteristics of concrete. Fibers are being used extensively in construction arenas because fiber reinforcement in concrete can decrease brittleness of concrete and make improvement of the properties of concrete especially in tensile strength and toughness (Wang, Huang, Jiang & Wu, 2012). Wang et al. (2012) also reported that different types of fibers are used to get different desired properties such as wire steel fiber are used to enhance the toughness properties of concrete once cracking, the use of mill cut steel fibers can increase initial cracking strength of concrete with its superior bond on concrete and polypropylene fibers can make improvement of impact strength of concrete. Therefore, the interest in the utilization of hybrid fiber in concrete has persistently growing now-a-days in prospect of obtaining concrete with enhanced properties.

Concrete with the inclusion of polypropylene fibers have appreciated an extensive rise in its application, comprising ground slab, concrete pipe, bridge deck, tunnel, pavement construction, canal, and repair and rehabilitation works (Al-Hadidy & Yi-Qiu, 2009; Behfarnia & Behravan, 2014; Kassimi, El-Sayed & Khayat, 2014; Khan & Ali, 2016). The surface roughness of the concrete matrix increases due to the integration of steel fibers (Armandei & de Souza Sanchez Filho, 2017). Based on the experimental study, Usman, Farooq, Umair & Hanif (2020) established that the utilization of steel fibers in high strength concrete has small effect on the compressive strength, although it expressively enhanced the ductility and post peak performance of concrete. Rapoport, Aldea, Shah, Ankenman & Karr (2002) conducted experimental study to examine the permeability of concrete containing steel fibers, and specified that the permeability of concrete decreases with the increase of steel fibers substance. However, macro polypropylene fibers demonstrate the benefits of light weight in addition to no corrosion (Ding, Li, Zhang & Azevedo, 2017).

Mohseni et al. (2017) made an effort to use steel or polypropylene fibers in concrete and investigated that there is considerable enhancement of splitting tensile strength as well as permeability attributable to increase of fiber contents. The tensile strength and toughness of concrete increases with the addition of steel fibers (Ahmadi, Farzin, Hassani & Motamedi, 2017; Gao, Zhang & Nokken, 2017; Gao & Zhang, 2018). The fracture energy as well as toughness of concrete after exposure to elevated temperatures can be significantly enhanced due to inclusion of steel fibers (Chen, Yang, Lin, Chen, He & Zhang, 2016). Zollo (1984) revealed that concrete incorporating polypropylene fibres (19mm long) and acrylic material (10mm long) exhibit lower shrinkage and crack width. The splitting tensile and flexural strengths of concrete increases with the incorporation of 0.5 % polypropylene fibers (Fathima & Varghese, 2014). Hanumesh et al. (2018) performed experimental study to observe the performance of recycle aggregate concrete containing polypropylene fibers and found that the compressive, split and shear strengths of concrete increases because of integration of polypropylene fibers. Zhao (1999) investigated that the incorporation of steel fibers with volume fraction larger than 2% may consequence in intense reduction of concrete flowability. Conversely, the effect of steel fibers with volume fraction lesser than 0.5% in concrete is unremarkable. Several researches disclosed that the integration of steel fibers with other kinds of fibers (for instance, polypropylene fibers, carbon fibers, glass fibers) into the plain concrete can evidently enhance the bond strength (Aslani & Nejadi, 2012; Hameed, Turatsinze, Duprat & Sellier, 2013; Ganesan, Indira & Sabeena, 2014). Amalgamation of fiber of different length enhances not only the toughness but also the impermeability of concrete (Lawler et al. 2002). Huang, Xu, Chi, Deng & Zhang (2019) investigated the performance of bond strength of embedded deformed bar in steel-polypropylene hybrid fiber reinforced concrete matrix, and revealed that the execution of steel-polypropylene hybrid fiber have noticeable optimistic effects on the bond strength, because of the substantial influences in preventing the spread of cracks at multi-scale as well as multi-phases.This study mainly investigates the flexural performance of reinforced concrete beam (RCC) using polypropylene and steel fibers separately as well as combination of both fibers. Prior to specimen preparation, the physical and mechanical properties of polypropylene and steel fibers were determined.

2 EXPERIMENTAL WORKS

2.1 Materials

In this study, Ordinary Portland cement (OPC), fine aggregate, coarse aggregate, polypropylene fibers, steel fibers and deformed bars were utilized to make concrete. The laboratory testing program for these materials comprised of the sieve analysis of both fine and coarse aggregates, unit weight of fine aggregate, coarse aggregates, steel fiber and polypropylene fiber, tensile strength test of steel fiber, polypropylene fiber and deformed bars.

2.1.1 Cement

Portland cement is commonly used around the world as a fundamental constituent of concrete. Ordinary Portland Cement (OPC) of type CEM I encompassing a strength of 52.5 MPa was used in this study. The specific gravity, initial setting time and final setting time of this type of cement were determined and obtained 3.15, 155 minutes and 270 minutes correspondingly, following standard specification (ASTM C150) for Portland cement.

2.1.2 Aggregates

Coarse (Sylhet) sand were used as fine aggregate to produce concrete. Sieve analysis for both fine aggregates and coarse aggregates was carried out in accordance with ASTM C136 to obtain fineness modulus and gradation curves as exhibited in Table 1 and Figure 1 respectively. The specific gravity, fineness modulus, bulk density, moisture content and water absorption of sand were determined and found 2.60, 2.56, 1560 kg/m^3, 1.7% and 2.3% respectively. Stone chips were used in concrete as coarse aggregate. The utilized nominal size of stone chips was 19 mm. The specific gravity, fineness modulus, bulk density, moisture content and water absorption of used stone chips were found 2.69, 7.74, 1490 kg/m^3, 1.1% and 0.3% respectively.

Table 1: Determination of fineness modulus of fine aggregates through sieve analysis

Sieve#	Wt Retained (gm)	Cum wt. retained (gm)	Cum wt. retained (%)	% Finer	FM
#4	5.6	5.6	1.1	98.9	2.56
#8	13.0	18.6	3.7	96.3	
#16	51.9	70.5	14.1	85.9	
#30	177.7	248.2	49.6	50.4	
#50	192.4	440.6	88.1	11.9	
#100	56.2	496.8	99.4	0.6	
Sum of Cumulative Weight Retained (%) =			256.0		

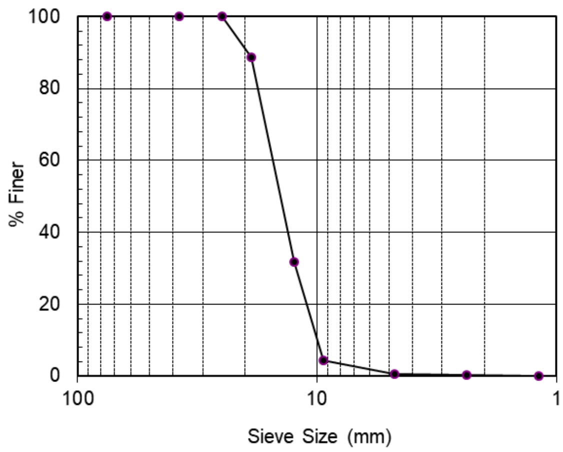

Figure 2: Gradation curve for stone chips

2.1.3 Fibers

Two types of fibers such as polypropylene fibers and steel fibers were utilized in this study to fabricate hybrid fibers. Appearances of polypropylene fibers and steel fibers are displayed in Figure 2. Polypropylene is partially crystalline and non-polar and possesses good abrasion and fatigue resistance, chemical resistance and electrical insulation (Alwesabi, Bakar, Alshaikh & Akil, 2020). However, existence of steel fibers in concrete is a cause of change in physical properties, resistance against cracking, fatigue, durability, impact, and bending. The polypropylene used in this study is the commodity plastic with the lowest density of 853 kg/m^3. Polypropylene fibers (length = 25 mm, width = 10 mm and thickness = 1.3 mm) possesses a tensile strength of 38 MPa, whereas, mill cut steel fibres (25.4 mm in length and 1.15 mm in diameter with an aspect ratio of 22) contains the tensile strength of 358 MPa. Table 2 depicts the physical and engineering properties of polypropylene and steel fiber.

(a) Steel fibers

(b) Polypropylene fibers

Figure 2: Appearances of polypropylene fibers and steel fibers

Table 2: Physical and engineering properties of polypropylene and steel fiber

Parameter	Polypropylene fiber	Steel fiber
Length (mm)	25	25.4
Thickness/diameter (mm)	1.3	1.15
width (mm)	10	--
Density (Kg/m^3)	853	7346
Tensile strength (MPa)	38	358

2.2 Mix Proportioning

The strength of concrete prominently depend on mix ratio of concrete. It is the ratio of binding material: fine aggregate: coarse aggregate. Three (03) controlled reinforced concrete beams and nine (09) reinforced concrete beams were constructed with a number of fibre combinations as provided in Table 3. It should be mentioned that three samples were prepared for each batch of concrete mixing. Each batch of concrete mixing used the identical water-cement ratio of 0.45 with the ratio of cement: sylhet sand: black stone chips of 1:2:4. In this study, the utilized volume fraction of three fibre combinations were 1.5% steel fiber alone, 2% polypropylene fiber alone and 0.5% steel fiber-1.5% polypropylene fiber. The workability for each batch of concrete mixing was determined compliant with ASTM C143 and obtained the slump value in the range of 75 to 100 mm.

Table 3: Details of fiber content in different reinforced concrete beams.

Sl. No.	Specimen designation	% of fiber (by volume)		Total fibre volume (%)
		Steel fiber	Polypropylene fiber	
1.	NRB	0	0	0
2.	SFRB	1.5	0	1.5
3.	PFRB	0	2	2.0
4.	SPRB	0.5	1.5	2.0

2.3 Preparation of specimen

In this study a total of 12 reinforced concrete beam specimens were prepared. Each mix had three beam specimens. The dimensions of each beam specimen was 1200 x 150 x 150 mm (length x width x depth). For simplicity, 10 mm deformed bars were used as main bar, whereas, 8 mm deformed bars were used as shear reinforcement to prepare beam specimen. In order to prepare concrete mix at first fine and coarse aggregates were put to the rotating mixer and mixed for 2 minutes. After that, cement was inserted to the mixer using the dry mixing and maintained for another 1.5 minutes. Then, 70% of required water was provided into the rotating mixer and sustained mixing for further 2 minutes. Afterward, the rest of the water was poured into the mixture and mixed for 1.5 minutes up to obtaining homogeneity. Thereafter, the fibers were disperse into the rotating mixer and continued mixing for 3 to 4 minutes until homogeneity of concrete. The beam specimens were cast into steel moulds. Once casting accomplished, each beam specimens were enclosed by polythene sheet at ambient temperature for 24 hours. Finally, each reinforced concrete beams were detached from the steel moulds and provided in a water chamber for curing up to 28 days.

2.4 Test Method

Slump test was performed according to provisions specified by ASTM C143. The slump value for each batch of concrete mixing was obtained by determining the difference of vertical distance between the uppermost of the overturned mould and the center of the upper surface of the concrete mix. Flexural strength test was carried out according to ASTM C78 on each reinforced concrete beams using a calibrated hydraulic jack with the capacity of 500 kN. An axial displacement was implemented at the mid-point of beams at a constant rate of 0.1 mm/min according to the requirements recommended by ASTM C78. The typical test setup for the flexural strength of reinforced concrete beams is presented in Figure 4. The axial displacement was applied until the failure of samples.

Figure 4: Typical test setup for flexural strength of reinforced concrete beam

3 RESULTS AND DISCUSSIONS

3.1 Flexural Strength

The ultimate Load, deflection, failure patterns are analyzed and discussed in this section. This study discusses the comparative effect of using additional fiber materials on flexural behavior of concrete. To analyze the load and deflection relationship, deflection of beams under corresponding loading were recorded. The failure load for each beam was noted for finding flexural strength. The load-deflection behavior for each mixes of reinforced concrete beams at 28 days is demonstrated in Figure 5. Table 4 and Figure 6 demonstrates the results of flexural strength tests for such reinforced concrete beams. It should be noted that the obtained results are the average of the results of three samples. From Figure 5 it has been found that the maximum load carrying capacity of RCC beam without containing any fiber is 70 kN whereas, beams containing 1.5% steel fibers, 2% polypropylene fibers and combination of 0.5% steel fibers and 1.5 % polypropylene fibers carrying maximum load of 81 kN, 85 kN, and 90 kN respectively. While the polypropylene fibers enhance the strain capacity as well as toughness of the post-crack region, the robust and harder steel fibers increase the ultimate strength of concrete (Komloš, Babal, & Nürnbergerova, 1995).

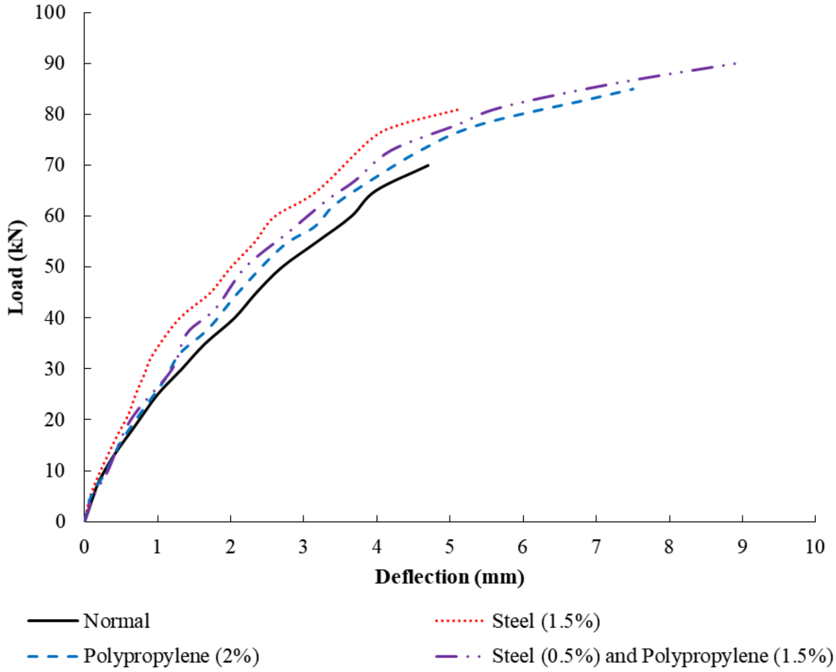

Figure 5: Comparison of load-deflection behavior of different reinforced concrete beams

The integration of fibers in concrete also enlarges the ductility in addition to toughness of the RCC beam as presented in Figure 5. The flexural strength for each beam was calculated according to specified formula. The flexural strength of RCC beam without containing any fiber was 36.2 MPa. Meanwhile, SFRB, PFRB and SPRB produced flexural strengths of 41.9 MPa, 43.9 MPa and 46.5 MPa correspondingly. The flexural strength of RCC beam increases with the increase of fiber content. The percentage increase of flexural strength were found 15.7%, 21.4% and 28.5% with the incorporation of 1.5% steel fibers, 2% polypropylene fiber and combination of 0.5% steel fiber and 1.5 % polypropylene fiber, respectively. The uppermost flexural strength of RCC beam was observed in SPRB mix reinforced with hybrid fiber (combination of 0.5% steel fiber and 1.5 % polypropylene fiber). Therefore, the combination of steel fibers and polypropylene fibers have positive effect on the flexural strength of reinforced concrete.

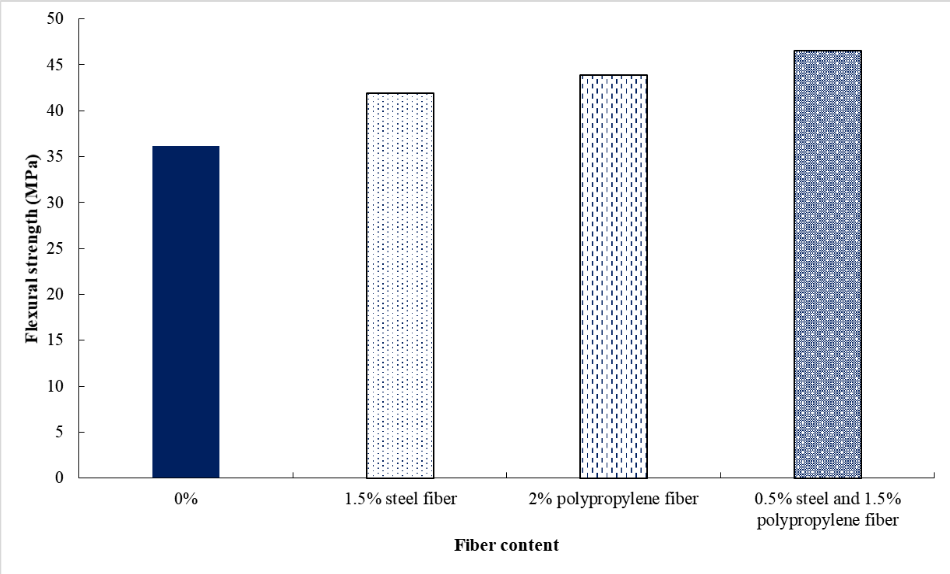

Figure 6: Effect of fiber content on the flexural behavior of reinforced concrete beams

Table 4: Load carrying capacity and flexural strength of different reinforced concrete beams

Specimen designation	Combination	Ultimate load (kN)	Maximum deflection (mm)	Flexural strength (MPa)	Increased flexural strength (%)
NRB	Normal RCC beam	70	4.7	36.2	-
SFRB	1.5% steel fiber	81	5.1	41.9	15.7
PFRB	2% polypropylene fiber	85	7.5	43.9	21.4
SPRB	0.5% steel fiber and 1.5% polypropylene fiber	90	8.9	46.5	28.5

3.2 Failure Patterns

Fiber reinforcement has extensive been understood to enhance the mechanical properties of concrete through restraining the development of cracks (Chi, Xu & Zhang, 2014).The failure modes for each mixes of reinforced concrete beams under mid-point loading conditions at 28 days is presented in Figure 7. For RCC beam without containing any fiber, the propagation of cracks occurrence is presented in Figure 7(a). There were some vertical and diagonal cracks observed in the beam. Crack Propagation can’t be controlled under flexure. As there is no fiber, so the rigidity and load carrying capacity of the beam is less and there is a number of crack. In this case, crack pattern is brittle in manner. The cracking behavior of beam is changed from brittle manner when there was inclusion of 1.5% steel fiber in concrete (shown in Figure 7b). Flexural strength is moderately higher than normal RCC beam, but slightly lower than polypropylene fiber containing beam. Steel fiber imparts ductility. The commencement and propagation of cracks in concrete can be postponed due to incorporation of steel fibers (Chen et al. 2016).

(a) Cracks in normal RCC beam

(b) Cracks in 1.5% steel fiber beam

(c) Cracks in 2% polypropylene fiber beam

(d) Cracks in hybrid fiber beam

Figure 7: Failure patterns for each mixes of reinforced concrete beams

Cracks are brittle in manner which were observed in the beam containing 2% polypropylene fiber. There is shear crack under the ultimate load for which crack occurs (shown in Figure 7c). Although incorporation of 2% polypropylene fiber increased the flexural strength compared to normal RCC beam, but this fiber has insignificant effect on cracking. Macro polypropylene fibers can modify the characteristics of concrete as soon as the matrix has fractured and the fibers enhance the ductility as well as energy absorption capability of concrete (Koniki & Prasad, 2019). The inclusion of steel fibres in concrete is not only an extremely cost-effective but also time-effective approach as it permits prohibiting of reinforcement bars throughout the manufacture and design processes. Polypropylene fiber-reinforced concrete has been focus on now-a-days research due to their remarkable toughness, low cost as well as good shrinkage cracking resistance (Afroughsabet & Ozbakkaloglu, 2015). Reinforcement with one category of fiber in concrete improves the mechanical properties within a rationed assortment. On the other hand, hybrid concrete with the incorporation of different types of fibers exhibit the combined interfaces of all fiber and therefore, possess outstanding properties. In this study, the cracks produced in the surface of beam is more ductile in manner due to addition of 0.5% steel fiber and 1.5% polypropylene fiber (shown in Figure 7d). The integrated utilization of steel fibers and polypropylene fibers in reinforced concrete beams can be observed as enormously advantageous as it not only enhances the flexural strength of concrete but also resolves the concern of brittle failure to a considerable amount. Polypropylene fiber resist the cracking in earlier stage and steel fiber resist the crack propagation in later stage (Yap, Bu, Alengaram, Mo & Jumaat, 2014). Therefore, the incorporation of various fibers with different lengths and sizes is a possible strategy to inhibit the cracks problem taking place at different phases in concrete.

4. SUMMARY AND CONCLUSIONS

This study predominatly investigates the flexural performance of reinforced concrete beam (RCC) using polypropylene and steel fibers separately as well as combination of both fibers. In this research, four categories of RCC beam specimens were constructed encompassing normal RCC beam (control); addition of 1.5% steel fiber; 2% polypropylene fiber; and combination of 0.5% steel fiber and 1.5% polypropylene fiber in volume of concrete. Based on the experimental study, the following conclusions have been sorted out:

- The flexural strength of RCC beam increases due to addition fiber content. Compared to RCC beam without containing any fiber, flexural strength increases by 15.7%, 21.4% and 28.5% due to the incorporation of 1.5% steel fibers, 2% polypropylene fiber and combination of 0.5% steel fiber and 1.5 % polypropylene fiber, respectively.
- The initiation and propagation of cracks in RCC beam can be controlled due to incorporation of steel fibers by 1.5% in volume of concrete.
- The incorporation of polypropylene fiber by 2% in volume of concrete in RCC beam not only increases the flexural strength compared to normal RCC beam, but also enhance the ductility in considerable extent.
- The combined use of 0.5% steel fiber and 1.5% polypropylene fiber have positive effect on the flexural strength of reinforced concrete. The hybrid fiber in reinforced concrete beams can be observed as enormously advantageous as it not only enhances the flexural strength of concrete but also resolves the concern of brittle failure to a considerable amount. Therefore, the incorporation of a number of fibers with different lengths and sizes is a possible strategy to inhibit the cracks problem taking place at different phases in concrete.

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