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Full Length Research Paper

Strength properties of hybrid nylon-steel and polypropylene-steel fibre-reinforced high strength concrete at low volume fraction

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The strength properties of hybrid nylon-steel fibre-reinforced concrete were investigated in comparison to that of polypropylene-steel fibre-reinforced concrete, at the same volume fraction (0.5%). The content of the high performance macro structure steel fibres is at 0.4% volume fraction, and the content of micro nylon and polypropylene-fibres is at 0.1% volume fraction. The experimental results show that the compressive strength and splitting tensile strengths and modulus of rupture (MOR) properties of the nylon-steel fibre concrete improved by 3.2, 8.3 and 10.2%, respectively, over those of the polypropylene-steel fibre concrete. On the impact resistance, the first-crack and failure strengths, and the percentage increase in the post first-crack blows improved more for the nylon-steel-fibre concrete than for its polypropylene-steel fibre concrete counterpart. These two forms of fibres work complimentarily and there is a synergy effect in the hybrid fibres system. The aforementioned listed improvements of the hybrid nylon-steel fibers register a higher tensile strength, possibly due to its better dispersion of concrete, and they are bond with mixture as well.

Key words: Mechanical properties, fibre reinforcement, hybrid composite, concrete.

INTRODUCTION

Concrete is characterized by quasi-brittle failure, the nearly complete loss of loading capacity, once failure is initiated. This characteristic, which limits the application of the material, can be overcome by the inclusion of a small amount of short randomly distributed fibres (steel, glass, synthetic and natural) and can be practiced among others that remedy weaknesses of concrete, such as low growth resistance, high shrinkage cracking, low durability, etc.

Concrete failure initiates with the formation of microcracks which eventually grow and coalesce together to form macrocracks. The macrocracks propagate till they reach an unstable condition and finally result in fracture. Thus, it is clear that cracks initiate at a micro level and lead to fracture through macrocracking. Fibres, used as reinforcement, can be effective in arresting cracks at both microcracks and macrocracks from forming and propagating (Bentur and Mindess, 1990).

It has been shown recently (Jiang et al., 2011; Ding and You, 2010; Hsie and Tu, 2008; Li and John, 2007; Deng and Li, 2006; Yao et al., 2003), that many researchers have an orientation to discuss the mechanical properties of the concept of hybridization with two different fibres incorporated in a common cement matrix, and the hybrid composite can offer more attractive engineering properties, because the presence of one fibre enables the more efficient utilization of the potential properties of the other fibre. However, majority of the previous researchers focused on the steel-polypropylene-fibre-reinforced concrete (Banthia and Nandakumar, 2003; Chen and Liu, 2000; Qian and Stroeven, 2001; Song et al., 2005; Sun et al., 2001; Sukontasukkul, 2004). The strength properties of hybrid nylon-steel-fibre reinforced very high strength concrete at 0.5% volume fraction fibre which has not been studied previously. However, the establishment was waiting as to how the nylon-steel fibres compete with the polypropylene-steel fibres rivals in advancing the performance of concrete

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Table 1. Properties of steel, nylon and polypropylene fibres.

Parameter	Steel	Nylon	Polypropylene
Length (mm)	35	19	19
Density (g/cm³)	7.84	1.14	0.91
Modulus (GPa)	210	5.2	4.1
Tensile strength (MPa)	1200	1000	413
Melting point (˚C)	1200	225	160

Table 2. Concrete mix proportions.

Material	Quantity
Type I cement (kg/m³)	406
Silica fume (kg/m³)	45
Sand (kg/m³)	904
Crushed granite (kg/m³)	935
Water (kg/m³)	140
Superplasticizer (kg/m³)	4.5 - 9.0
Slump (mm)	30 - 210

under compression, tension, flexural and impact resistance. Therefore, the strength properties of the hybrid nylon-steel fibre-reinforced concrete were under investigation, in comparison with those of the hybrid polypropylene-steel fibre-reinforced concrete counterpart.

EXPERIMENTAL PROCEDURE

Materials

The cement used in all concrete mixes was ordinary Portland cement which corresponds to American Society for Testing and Materials (ASTM) Type I. The sand used was local mining sand with specific gravity of 2.62. The coarse aggregate was crushed granite with a maximum size of 20 mm and specific gravity of 2.65. A polycarboxylate ethyl (PCE) superplasticizer was used to aid in workability.

Properties of the nylon, polypropylene and steel fibres are shown in Table 1. The nylon and polypropylene fibres were smooth and straight, while the steel fibres were hooked end.

Table 2 presents the control concrete mix proportions used in the testing program. For the concretes containing fibres, the dosage of superplasticizer was increased accordingly.

Mixing and curing

The procedures for mixing the fibre reinforced concrete involved the following. Firstly, the crushed granite and sand were placed in a concrete mixer and dry mixed for 1 min. Secondly, the cement and silica fume were spread and dry mixed for 1 min. After which, the specified amount of fibres were distributed and mixed for 3 min in the mix. This was followed by the addition of water and the superplasticizer with a mixing time of 5 min. After pouring the mix into oiled molds, a poker vibrator was used to decrease the amount of air bubbles in the mix. The specimens were demolded after 1 day and then placed in a curing room with 90% relative humidity and 23°C for 28 days until age of testing.

Testing procedures

For each mixture, forty-two specimens (twelve 100 × 100 mm cubes, twelve 150 × 300 mm cylinders, twelve 100 × 100 × 500 mm prisms and six 50 × 600 × 600 mm slabs) were prepared. The compressive and splitting tensile tests were carried out on the 100 × 100 mm cube and 150 × 300 mm cylinder specimens, respectively. The two-point loading flexural tests were carried out at a loading rate of 0.05 mm/min on the 100 × 100 × 500 mm beams according to the requirements of BS1881: Part118:1983. During the flexural tests, the load and the midspan deflection were recorded on a computerized data recording system, and the flexural load was obtained.

Concrete panel drop weight test

The impact strength assessment is based on the modification of Allied Construction Industries (ACI) committee 544 recommendations (ACI Committee 544, 1988), which subjects an impact specimen to repeated blows on the same spot as shown in Figure 1. The number of blows to the first visible crack that occurs on the specimen top served as the first-crack strength, and the failure strength was recorded. The stage of the failure is clearly recognized by the energy that the specimens absorbed until it fractured.

RESULTS AND DISCUSSION

All test results are summarized in Table 3. Each strength value presented in Table 3 is the average of six specimens.

Slump

Slump tests were carried out to determine the consistency of fresh concrete. Table 3 shows the slump of the hybrid fibre-reinforced concrete. The slump changed due to the different type of fibre content and form. For plain concrete, the slump is 220 mm. When adding hybrid fibres at 0.5% volume fraction, the slump values of fresh concretes fell down to 30 mm, respectively. The reason of lower slump is that adding hybrid fibres can form a network structure in concrete, which restrain mixture from segregation and flow. Due to the high content and large surface area of fibres, fibres are sure to absorb more cement paste to wrap around, and the increase of the viscosity of mixture makes the slump loss (Chen and Liu, 2000).

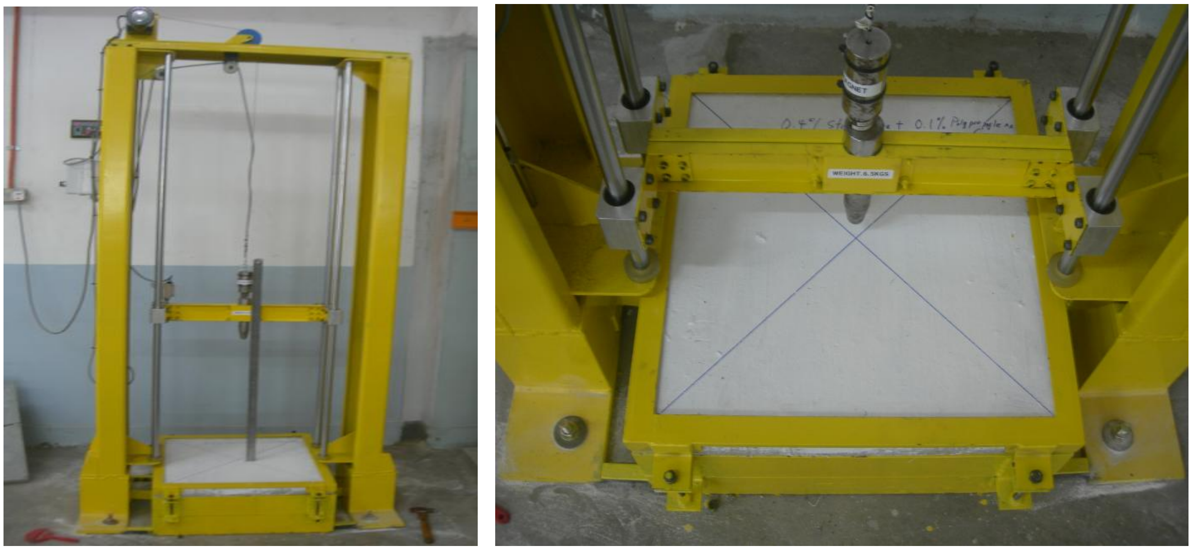

Figure 1. Concrete panel drop weight test.

Table 3. Mechanical properties of hybrid nylon-steel, polypropylene-steel fibres and plain control concrete.

Concrete type	Descriptive statistics	Compressive strength (MPa)	Splitting tensile strength (MPa)	Modulus of rupture (MPa)	Slump (mm)
Hybrid nylon-steel-fibre-reinforced concrete	Mean	100.6	6.5	10.29	30
	Standard deviation	1.54	0.22	0.12	
	Coefficient of variation (V)	2.37	0.05	0.01	
Hybrid polypropylene- steel-fibre-reinforced concrete	Mean	97.5	6.0	9.34	30
	Standard deviation	2.76	0.22	0.28	
	Coefficient of variation (V)	7.60	0.05	0.08	
Plain control concrete	Mean	96.6	4.9	8.63	220
	Standard deviation	1.05	0.13	0.20	
	Coefficient of variation (V)	1.10	0.02	0.04	

Each strength value is the average of 12 samples.

Compressive strength

Table 1 presents the experimental results of the compressive strength, splitting tensile strength and modulus of rupture (MOR) of the two hybrid fibre-reinforced concretes and the non-fibrous control concrete. From the table, the compressive strength of the hybrid nylon-steel fibre-reinforced concrete improved by 4.1% over the non-fibrous control counterpart, followed by the hybrid polypropylene-steel fibre-reinforced concrete at 0.9%. It can be observed that, under axial loads, cracks that occur in microstructure of concrete and fibres limit the formation and growth of cracks by providing pinching forces at crack tips. They bear some stress that occurs in the cement matrix and transfer the other portion of stress at stable cement matrix portions. It reduced the crack-tip stress concentration, thus blocking the forward propagation of the crack and even diverting the path of the crack. The blunting blocking, and even diverting of the crack allowed the fibrous concrete cubes to withstand additional compressive load, thus upgrading its compressive strength over the non-fibrous control concrete.

The compressive strength of the hybrid nylon-steel fibre concrete topped that of the hybrid polypropylene-steel fibre concrete by 3.2% increase. The increase stemmed from the hybrid nylon-steel fibres recording the higher tensile strength, which resulted in greater tensile stresses being transferred from a cracked matrix to the hybrid nylon-steel fibres than to the hybrid polypropylene-steel

Table 4. Statistical evaluation of impact test results for nylon-steel- and polypropylene-steel fibre-reinforced concretes and plain control concrete.

Concrete type	Descriptive statistics	First-crack strength (blows)	Failure strength (blows)
Plain control concrete	Mean	3	4
	Standard deviation	1	1
	Coefficient of variation (*V*)	0	0
Hybrid polypropylene- steel-fibre-reinforced concrete	Mean	14	32
	Standard deviation	2	2
	Coefficient of variation (*V*)	3	5
Hybrid nylon-steel-fibre-reinforced concrete	Mean	32	40
	Standard deviation	1	2
	Coefficient of variation (*V*)	2	4

fibres, thus leading to the increase in the compressive strength of the hybrid nylon-steel fibre concrete.

Splitting tensile strength

Following Table 3, it was found that the splitting tensile strengths of the hybrid nylon-steel- and hybrid polypropylene-steel-fibre-reinforced concretes were 32.7 and 22.4% higher, respectively, than that of the unreinforced control concrete. The substantial increase in splitting-tensile strength can contribute to the bridging action of the fibres. Once the splitting occurred and continues, the fibres bridging across the split portions of the matrix acted through the stress transfer from the matrix to the fibres and, thus, gradually supported the entire load. The stress transfer improved the tensile strain capacity of the two fibre-reinforced concretes and, therefore, increased the splitting tensile strength of the reinforced concretes over the unreinforced control counterpart.

As just stated, the greater number of hybrid nylon-steel fibres is intersecting the split sections, the concrete can be effective in arresting cracks at both micro and macro-levels, accordingly, declaring the splitting tensile strength to be 8.3% higher for the hybrid nylon-steel fibre concrete than for the hybrid polypropylene-steel fibre concrete. This declaration was consistent with the statement that the splitting tensile strength of fibre-reinforced concrete behaved in proportion to the number of fibres intersecting the fracture surfaces (Potrebowski, 1983).

Modulus of rupture (MOR)

The MOR of the hybrid nylon-steel fibre concrete posted a 19.2% increase over the non-fibrous control concrete, with the hybrid polypropylene-steel fibre concrete registering 10.2%. The increase resulted primarily from the fibres intersecting the cracks in the tension half of the reinforced prism. These fibres accommodated the crack face separation by stretching themselves, thus providing an additional energy-absorbing mechanism and also stress relaxing the microcracked region neighboring the crack-tip. Apart from the fibre-crack intersection, the hybrid nylon-steel fibres topped the hybrid polypropylene-steel fibres in the in-concrete fibre dispersion and the tensile strength.

As stated for compressive and splitting tensile strengths, the hybrid nylon-steel and hybrid-polypropylene-steel fibres additions made bearable differences in the variability carried by the MOR for the two fibrous concretes as compared to the plain concrete counterpart.

Impact resistance

The concrete panel drop weight impact test results, reportedly exhibit dispersion (Nataraja and Dhang, 1999; Song et al., 2005), which was determined in the current work. In view of the dispersion, the current drop weight test results were evaluated statistically. The statistical evaluation of the 18 discs in this work appears in Table 4. The drop weight impact tests method have been carried out to evaluate the impact resistance of nylon-steel-fibre-reinforced slabs and found that, the mean number of blows required to produce the first crack and failure strengths increased by 967 and 900%, respectively, over the plain concrete slabs, whereas the figures for the polypropylene-steel-fibre-reinforced slabs were 367 and 700%, respectively. All these figures emulated the benefit of hybrid nylon-steel and polypropylene-steel fibres additions, and displayed the hybrid nylon-steel fibres addition outperforming the polypropylene-steel fibres counterpart in benefiting the two strengths. The minimum

V value for the hybrid nylon-steel fibres concrete arose, because the hybrid nylon-steel fibres addition worked better in unbearing the local weakness of the slabs and, thus prompted the redistribution of stresses through the slabs during the period of each impact event.

Conclusion

The inclusion of hybrid nylon-steel fibre-reinforced concrete outperformed its hybrid polypropylene-steel fibre companion in the upgrading of compressive strength, splitting tensile strength, MOR and impact resistance. This may contribute to the higher tensile strength of the hybrid nylon-steel fibres and possibly, the better distribution of the hybrid fibres through the concrete mass can be effective in arresting cracks at both micro and macro-levels.

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REFERENCES

ACI Committee 544 (1988). Measurement of properties of fibre-reinforced concrete. ACI Mater. J., 85(6): 583-593.

Banthia N, Nandakumar N (2003). Crack Growth Resistance of Hybrid Fiber Composites, Cem. Con. Comp., 25(1): 3-9.

Bentur A, Mindess S (1990). Fibre Reinforced Cementitious Composites, Elsevier Applied Science, London, UK. http://enpub.fulton.asu.edu/cement/cbm_CI/CBMI_Separate_Articles/Article-40.pdf.

Chen B, Liu J (2000). Contribution of hybrid fibers on the properties of the **....**polypropylene hybrid fibers. Cem. Con. Comp.. 22(4): 343-351.

Deng ZC, Li JH (2006). Mechanical behaviors of concrete combined with steel and synthetic macro-fibers. Int. J. Phys. Sci. 1(2): 57-66.

Ding Y, You Z (2010). Hybrid fibre influence on strength and toughness of RC beams. Comp. Struct., 92(9): 2083-2089.

Hsie M, Tu C (2008). Mechanical properties of polypropylene hybrid fibre-reinforced concrete. Mater. Sci. Eng. A, 494(1-2): 153-157.

Jiang GP, Huan S, Jiao CJ, Tao WJ (2011). Study on the mechanical behavior of steel reinforced high strength concrete subjected to impact loading. Int. J. Phys. Sci., 6(13): 3099-3104.

Li G, John M (2007). Experimental study of hybrid composite beams. Constr. Buid. Mater. 21(3): 601-608.

Nataraja MC, Dhang N, Gupta AP (1999). Statistical variations in impact resistance of steel fibre-reinforced concrete subjected to drop weight test. Cem. Con. Res., 29(8): 989-995.

Potrebowski J (1983). The splitting test applied to steel fibre reinforced concrete. Int. J. Cem. Compos. Lightweight Concrete, 5(1): 49-53.

Qian CX, Stroeven P (2001). Fracture properties of concrete reinforced with steel- polypropylene hybrid fibers, Cem. Con. Comp. 22(4): 595-601.

Song PS, Hwang S, Sheu BC (2005). Strength properties of nylon- and polypropylene-fibre-reinforced concretes. Cem. Con. Res., 35(8): 1546-1550.

Song PS, Wu JC, Hwang S, Sheu BC (2005). Statistical analysis of impact and**...** hybrid fiber-reinforced concrete. Constr. Buid. Mater. 19(1): 1-9.

Sukontasukkul P (2004). Tensile Behaviour of Hybrid Fibre Reinforced Concrete. Adv. Cem. Res. 16(3): 115-122.

Sun W, Chen H, Luo X, Qian H (2001). The effect of hybrid fibres and expansive agent on the shrinkage and permeability of high performance concrete. Cem. Con. Res., 31(4): 595-601.

Yao W, Li J, Wu K (2003). Mechanical properties of hybrid fiber-reinforced concrete at low fiber volume fraction. Cem. Con. Res., 33(1): 27-30.