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Hybrid Steel-Polypropylene Fibres Concrete

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ABSTRACT

This paper presents the properties of hybrid steel-polypropylene fibres concrete at different dosage levels. The properties of the hybrid steel-polypropylene fibres concrete were determined based on the compressive, flexural, splitting tensile and interfacial bond strength tests. The testing was carried out on hardened concrete at the specimens' ages of 7 and 28 days. Five dosage levels of different steel fibre and polypropylene fibre were used with total percentage of 4 %. It deduces that the use of higher dosage level of 4 % steel fibre with 0 % polypropylene fibre increases the mechanical strength of the specimen than the use of 0 % steel fibre with 4 % polypropylene fibre. Hence, as the steel fibre dosage level increases, the mechanical properties of the specimens increase.

KEYWORDS: Steel-Polypropylene Fibre, Concrete, Mechanical Properties.

INTRODUCTION

Concrete is the popular material used in civil engineering construction all over the world. Concrete is also often requiring repairing or strengthening due to damaging or deterioration of concrete constitutes. The reduction of the concrete strength may lead to the tendency of reducing service life of concrete structures. Hence, it would increase the cost of maintenance of the concrete structures. The maintenance is vital to maintain the integrity of the structure and can reduce the shortcoming of the concrete performance. The shortcoming of the concrete structure can be reduced by improving the quality of the concrete composite. One can be used is with the inclusion of fibres in the concrete mix.

The concrete mix with the inclusion of fibres such as steel fibre and polypropylene fibre can be used to improve the performance of the concrete. The use of fibres in the retrofitting concrete helps to control the shrinkage cracking. It is also lead to improve the concrete strength. However, the concrete strength is close related to the geometry of the fibres, orientation of the fibre in the concrete mix and types of the fibre used. The most geometric fibres characteristic is the aspect ratio such as length per diameter. The aspect ratio is defined the slenderness and the shape of the fibre. The combination of two types of fibres are also can be used to improve the performance of the concrete structure. For instance, the use of steel fibre can be used to increase the concrete strength. Meanwhile, the use of polypropylene fibre can be used to improve the crack resistance of the concrete. Hence, the combination of both fibres (steel fibre and polypropylene fibre) may help to increase the strength and reduce the crack of the concrete structure.

To identify the performance in term of characteristics of the concrete structure, several testing can be adopted. The compressive strength test can be utilised to identify the compressive strength of the specimen. The flexural strength test can be used to identify the bending strength of the beam when subjected to point load. Splitting strength test can be carried out to identify the splitting strength of the cylindrical specimen. The interfacial bond strength test can be applied to obtain the bond strength between the composite of the concrete and fibres with steel bar that submerged at the centre of the specimen. Those tests can be used to determine the mechanical properties of the concrete when added with the hybrid steel-polypropylene fibres. In the present study, the main objective is to investigate the properties of the hybrid steel-polypropylene fibres concrete. The strength effectiveness of this combination is also presented. Four types of experiments would be conducted namely compressive strength, flexural strength, splitting tensile strength and interfacial bond strength tests.

LITERATURE REVIEW

The use of synthetic fibres and fibre composites within the construction industry certainly has advantages in terms of their superior strength characteristics, relatively light weight and good chemical resistance making their inclusion into concrete and attractive proposition. Researches have shown the physical nature of the fibres and quantity of fibres incorporated, which have an effect on the final physical performance of the reinforced concrete (RC)[1-8]. The effects are seen in terms of compressive, flexural and tensile properties.

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Furthermore, according to [9], addition of two fibres with different aspect ratios of 65 and 80 improved high strength concrete (HSC) toughness. As the volume fraction of steel fibre increases, the HSC toughness increases and high value of aspect ratios give higher toughness. In [10] stated that corrugated steel fibre with combination of two percentages and sizes of 65% (50 mm long) + 35% (25 mm long) can be pronounced as the most applicable combination to be utilised in steel fibre RC for improving the compressive strength, splitting tensile strength and flexural strength of concrete. Meanwhile, the workability can be improved by using the shorter fibres in the concrete mix.

In [11] found that steel fibre added RC beam with dosage level of 30kg/m^3 give higher toughness compared to RC beam having the same conventional reinforcement without steel fibre. Increment of dosage level to 60kg/m^3 gives small improvement in term of ultimate load and toughness compare to dosage level of 30kg/m^3. In spite of that the optimum dosage level should be within the range of 1.0 % to 2.5 % of absolute concrete volume. It is because the dosage level below and beyond the range would effect to the distribution of the fibre in the concrete mix. At the same time, it causes a significant drop in the strength compared to the plain concrete.

Cement and Concrete Institute enhanced that the steel fibre is generally used in the range of 0.25 % to 2 % of concrete volume. The steel fibre contents in the concrete mix above 2 % of concrete volume may pronounce to the lower workability. The range was also affected to the steel fibre distribution in the concrete mix. In order to have a good concrete mix paste, coarse aggregate size below 10 mm is recommended.

The effect of steel fibre on the performance of concrete pipes has been investigated by [12]. The steel fibre is found enhanced the performance of concrete pipe. Then, the comparison has been made on standard RC pipes and concrete pipes containing steel fibre (known as steel fibre concrete pipes-SFCP). Three-edge-bearing and crack size measurement tests were carried out. The tests were performed on plain concrete, RC and SFCP. Diameter of the steel fibre RC80/60-BN type was 500 mm with dosage level of 25 kg/m^3. From the tests found that the steel fibre concrete pipes contain steel fibre dosage level of 25 kg/m^3 seems close to optimum strength. It is because the increase of the amount of steel fibres up to 60 % results to the minor improvements. From these findings, it can be deduced that the addition of steel fibre in the concrete mix would increase the strength of concrete at certain dosage level. However, the addition of polypropylene into the mixing concrete with steel fibre would provide different performance.

Polypropylene fibre is a chemical in polyolefin family, where typically to hydrophobic, which does not absorb the water and not corrosive. It has excellent resistance against alkalis, chloride and chemicals and has low heat conductivity. Typically, polypropylene fibres are benefited to improve mix cohesion, pumpability over long distance, resistance to explosive spalling in case of severe fire, impact resistance and increase resistance to plastic shrinkage. In [13] stated that polypropylene fibres will increase the ductility behaviour and improving the fire resistance of high strength concrete. At the same time, it can be used to improve the toughness of the specimen where the toughness is the amount of absorbed energy before and after fracture. In [13] added that the polypropylene fibre may improve the post-cracking behaviour of concrete as well as ductility when subjected to dynamic loading. It is potentially to alter the concrete tensile strength. The strength is dependent upon to the type of fibre used and volume of the fibre added in the concrete mix. According to [14], the addition of polypropylene fibre in high strength lightweight aggregate concrete up to 0.56 % by volume concrete caused the increase of indirect tensile strength up to 90 % and increases the modulus of rupture up to 20 % compared to the plain concrete.

Instead of standalone either concrete mix with steel fibre or polypropylene fibre, the concrete strength can be increased by combination of both fibres, which so called as hybrid steel-polypropylene fibres concrete. The proportion and length of fibres are influenced the physical performance of the concrete. The mechanical properties of HSC containing combination of hybrid fibres (non-metallic fibre and hooked steel fibre up to 0.5% of volume fraction) have been investigated by [15]. It was found that compression and flexural strength for combination steel and polypropylene and steel and polyester is increased. The pre-peak and post-peak region of the load –deflection curve of HSC can be enhanced by addition of fibre, induced the increase of toughness index and flexural strength. It is also contributed to the energy absorption as bridging action, whereas the non-metallic fibres resulted in delaying of the formation of micro cracks.

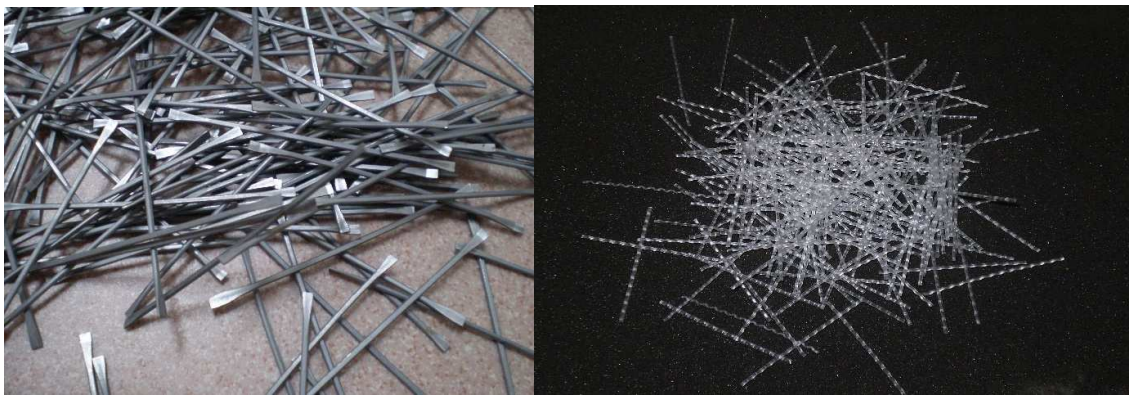
From the review, it is found that the study on the properties of the hybrid steel-polypropylene fibres in the concrete mix is still limited. Hence, the main objective of the present study is to investigate the properties of the hybrid steel-polypropylene fibres concrete. Four types of experiments would be conducted namely compressive strength test, flexural strength test, splitting tensile strength test and interfacial bond strength test.

METHODOLOGY

Preparation of the Materials

The concrete used to prepare the beams and cylinders was made of Ordinary Portland Cement (OPC), coarse aggregate, fine aggregate, water and different dosage levels of combination of steel fibres and polypropylene fibres. The maximum size of coarse aggregate of 20 mm was used. The steel fibre used was NOVOCON 1050 as shown in Figure 1(a) and the chemical and the physical properties are depicted in Table 1. Meanwhile, the propylene fibre was ENDURO HPP45 as shown in Figure 1(b). The chemical and physical properties of the

polypropylene fibre are shown in Table 2. According to standard technical specification recommended from Propex Concrete Systems, typically ENDURO HPP45 macro-synthetic dosage used in the range of 4.5 kg to 9 kg per cubic meter of concrete. In the present study, the inclusion of combination of steel fibres and polypropylene (PP) fibres in the concrete mix is depicted in Table 3. This combination called as hybrid steel-polypropylene fibre reinforced concrete (HSPFRC).



(a) **(b)**

Figure 1: The fibres used in the concrete mix (a) the steel fibres (b) polypropylene fibres

Table 1: Chemical and Physical Properties of NOVOCON 1050 [16]

NOVOCON 1050 Properties	Description
Fibre length	50 mm
Equivalent diameter	1.0 mm
Aspect ratio	50
Tensile strength	1050 MPa
Deformation	Flat end (FE)
Appearance	Bright and clean wire

Table 2: Chemical and physical properties of ENDURO HPP45 fibres [17]

ENDURO HPP45 properties	Description
Fibre length	45 mm
Type/Shape	Macro/Monofilament
Specific gravity	0.91
Electrical and thermal conductivity	Low
Acid and salt resistance	High
Melt point / Ignition point	164^0C (328^0F) / >550^0C (1022^0F)
Alkali resistance	Alkali proof

In the preparation of HSPFRC, the ingredients without fibres were initially mixed with the proportion of 1: 0.57: 2.42: 2.63 of cement: water: fine aggregate: coarse aggregate. The fibres were then added in small amount in the concrete mix. The combination of steel fibres and polypropylene fibres was based on the percentage of cement weight as depicted in Table 3. The control (C) specimen is a beam that has no inclusion of fibres. The fibre concrete was then placed into the relevant moulds and compacted using vibrator. After + 24 hours, the specimens were de-moulded and cured in water until they are required for testing at the ages of 7 and 28 days.

Table 3: Dosage levels of the hybrid steel-polypropylene fibre reinforced concrete

Designation	Dosage Levels		
	Steel Fibres (%)	PP Fibres (%)	Total (%)
Control (C)	0	0	0
PS1	4	0	4
PS2	3	1	4
PS3	2	2	4
PS4	1	3	4
PS5	0	4	4

Testing of the Concrete Specimens

A total of 154 specimens with different sizes were prepared for the experimental study. Four main types of concrete testing were carried out, which are compressive strength, flexural strength, splitting tensile strength and

interfacial bond strength tests. The tests were performed after 7 and 28 days of moist curing. The testing, the specimen type, size of the specimen and number of specimens prepared are depicted in Table 4.

Table 4: The testing, the specimen type and size and number of specimens prepared for the experimental study

Testing	Specimen Type	Size (mm)	Number of Specimens
Compressive strength	Cylinder	150 Ø x 300	42
Flexural strength	Beam	100 x 100 x 500	42
Splitting tensile strength	Cylinder	150 Ø x 300	28
Interfacial bond strength	Cylinder	100 Ø x 200	42

The compression test was used to identify the compressive strength of hardened cylindrical concrete specimens, to evaluate the performance of the materials and to establish mixture proportions in order to get the required strength [18]. The test was conducted to the specimens taken from the same age and the same concrete batch. The compressive strength can be expressed as in the Equation (1).

$$\sigma = P/A \ (N/mm^2) \quad (1)$$

The flexural strength is the ability of a beam or prism to resist failure in bending [19]. The flexural strength is defined as rupture modulus and measured in N/mm^2. In this study, the load is applied perpendicular to the longitudinal axis of specimen sized 100 mm width, 100 mm depth and 500 mm long. The Equation (2) is used to define the flexural strength of the beam.

$$R = PL/bd^2 \quad (2)$$

where R is the modulus of rupture (N/mm^2), P is the maximum applied load (measured in N), L is the span length (mm), d is the average depth of specimen (mm) and b is the average width of specimen (mm).

The splitting tensile strength tests were carried out on cylindrical concrete 150 mm diameter x 300 mm height. This load was compressively applied along the length of the cylindrical concrete until failure. The cylinder was tested within the range from 50 to100 kN/min until the specimen failed. The maximum applied load was then recorded and the failure modes of the concrete were noted. The splitting tensile strength was identified using the Equation (3).

$$T = 2P/\pi ld \quad (3)$$

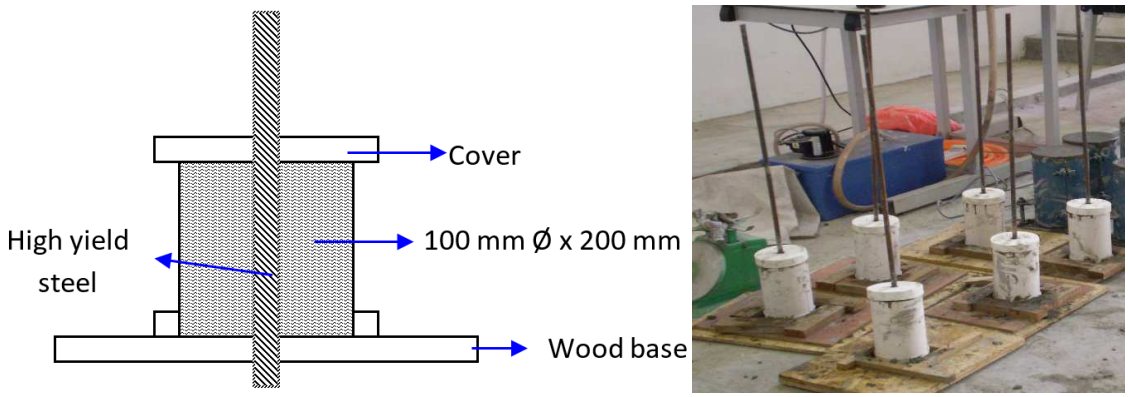
where T is the splitting tensile strength (MPa), P is the maximum applied load (N), l is the length (mm) and d is the diameter (mm) of the cylinder.

The interfacial bond strength tests were carried out to identify the bond strength between the steel bar and the combination of steel fibres and polypropylene fibres concrete cylinders. Prior to the test was carried out, specimen mould shall be prepared using UPVC pipe with diameter of 100 mm. UPVC pipe were cut into several pieces with 200 mm specified length. The center of the end cap pipe was then drilled 14 mm diameter hole and fixed them by 200 mm length UPVC pipe with special pipe glue. The mould was then clamped onto the wood base plate. The fresh concrete was then put into the mould and a 14 mm diameter by 700 mm length high yield steel then submerged vertically into the concrete at midpoint (axis) as illustrated in Figure 2(a).

Then, the specimen was stored at + 24 hours in the storage room as depicted in Figure 2(b) and remoulded prior to submerging into curing tank in the specified time. After 7 and 28 days of moist curing, specimens were taken out from the curing tank. Their surfaces were wiped with dry cloth prior to conducting the test. The specimens were tested for interfacial bond strength using Universal Testing Machine (UTM) with 0.07 kN/s pace rate was applied and maintained until the specimen completely fail. The maximum load applied and crack pattern at the end of test were recorded. The interfacial bond strength was calculated using Equation (4).

$$U = P/\pi DL \quad (4)$$

where, U is the bond strength, P is the maximum applied load, D is the diameter of reinforcement in concrete and L is the length of reinforcement in concrete.



(a) (b)

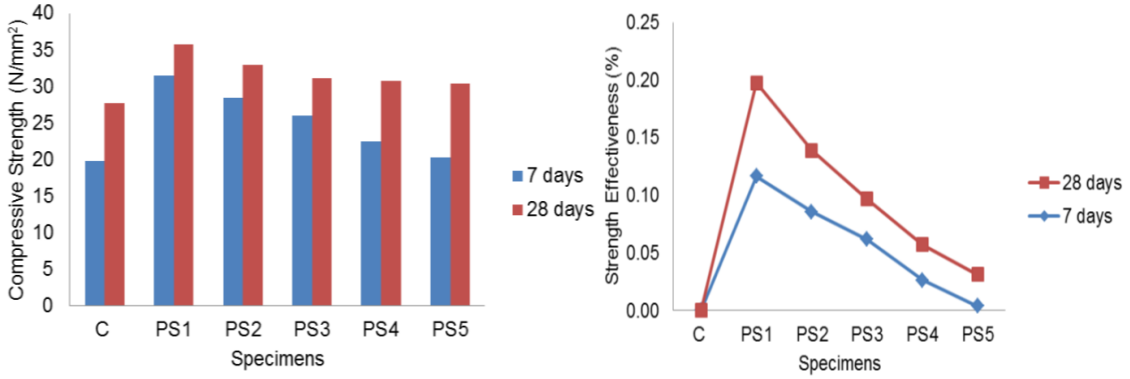
Figure 2: (a) Cross section of the specimen (b) the specimens stored in the storage room prior to demoulded for interfacial bond strength test

RESULTS AND DISCUSSION

Compressive Strength

Figure 3 shows the results of the compressive strength of the cylindrical specimens size 150 mm diameter by 300 mm height. The compressive strength of control specimen (C) is lower than that of the concrete mix with different inclusion of fibres. From the results in Figure 3(a) shows that adding the higher dosage level of steel fibres increase the compressive strength of the beam than that of adding the higher dosage level of polypropylene fibres. It can be depicted by compressive strength in specimens PS1 to PS5, where specimen PS1 is a combination of steel fibre of 4 % of the cement weight and 0% of polypropylene fibres. The compressive strength for PS1 is 31.50 N/mm^2 at 7 days and 35.79 N/mm^2 at 28 days. Meanwhile, PS5 indicates the combination of 0 % steel and 4 % polypropylene hybrid fibre by cement weight which is the compressive strength reduces to 20.26 N/mm^2 at 7 days and 30.40 N/mm^2 at 28 days. It was affirmed by [2] that the increase of steel fibres percentages increase the compressive strength of concrete containing oil palm shell and oil palm shell fibre RC at the age of 28 days. The increase of the dosage levels reduced the compressive strength of the specimens.

The results also indicate that the inclusion of steel fibre with high dosage level in the concrete mix increases the strength effectiveness of the concrete specimen as presented in Figure 3(b) by the result of PS1.



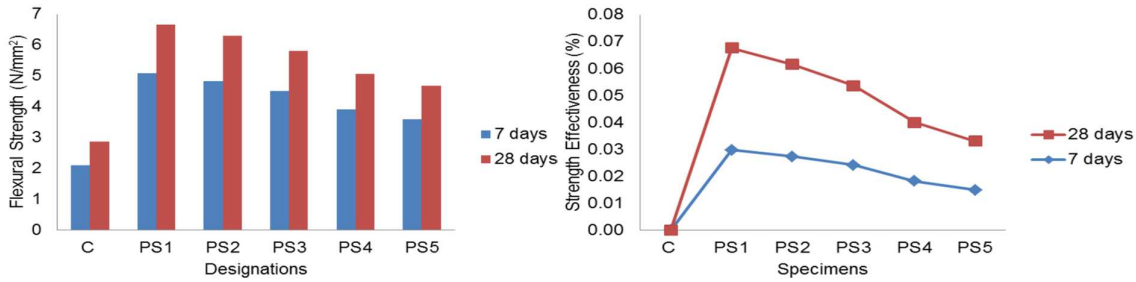
(a) (b)

Figure 3: (a) The compressive strength of HSPFRC cylinders (b) the strength effectiveness of the HSPFRC cylinders with different inclusion of fibres dosage levels

Flexural Strength

Figure 4 shows the results of flexural strength of HSPFRC beams. Figure 4(a) represents the trend of the flexural strength at 7 and 28 days at different beam specimens with different inclusion of dosage levels. It is found that the flexural strength at 7 days is lower than the flexural strength of HSPFRC beams at 28 days. It was due to the optimum strength of the HSPFRC beams can be achieved when reached age of 28 days. It is also found that the flexural strength of HSPFRC beams is influenced by the inclusion of fibre dosage levels. The flexural strength of control specimen is lower than the specimens added with the fibres. However, the type of fibre is also influenced the strength of the concrete beam. From the result, it is found that the inclusion of steel fibre increased the strength of the concrete beam than the polypropylene fibre. The flexural strength of the HSPFRC increased as

the dosage levels of steel fibre increased. However, the increase of polypropylene fibre with decrease of the steel fibre dosage level reduced the strength of the HSPFRC beams. It was affirmed by [4] that high dosage level of steel fibre leads higher splitting tensile strength than specimen that has silica fume specimen only. Indeed, the strength effectiveness of the HSPFRC beams is also reduced when the inclusion of steel fibre reduces as depicted in the Figure 4(b).

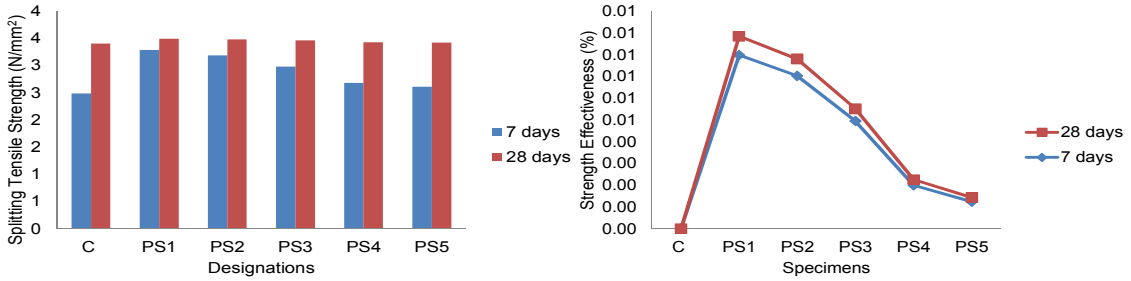


(a) (b)

Figure 4: (a) The flexural strength of HSPFRC beams (b) the strength effectiveness of the HSPFRC beams with different inclusion of fibres dosage levels

Splitting Tensile Strength

The splitting tensile strength of the HSPFRC cylinders is presented in Figure 5(a) and Figure 5(b). The splitting tensile strength of the control sample is lower than the strength of cylinders added with fibres as depicted in Figure 5(a) at 7 and 28 days. Splitting tensile strength was more greatly affected by steel fibre than polypropylene. Splitting tensile strength of the specimens with 4 % steel fibre and 0 % polypropylene fibre (PS1) was increased by 0.008 % and 0.0009 % for 7 and 28 days respectively. However, the splitting tensile strength of the specimen with 4 % polypropylene fibre and 0 % steel fibre (PS5) increased by 0.0012 % and 0.0002 % at 7 and 28 days respectively. It is found that the strength effectiveness of HCPFRC added with high dosage level of steel fibre increase the strength of the specimens. The higher dosage levels of polypropylene fibre reduced the splitting tensile strength of the specimens.

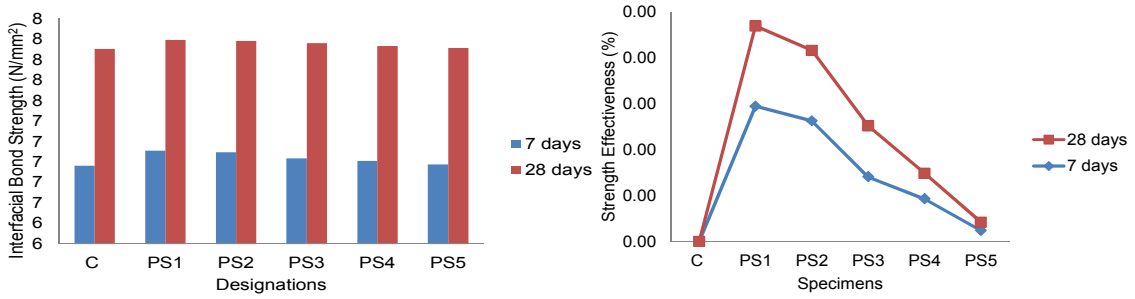


(a) **(b)**

Figure 5: (a) The splitting tensile strength of HSPFRC cylinders (b) the splitting tensile strength effectiveness of the HSPFRC cylinders with different inclusion of fibres dosage levels

Interfacial Bond Strength

The interfacial bond strength tests were carried out to determine the bond strength between the steel bar and the combination of steel fibres and polypropylene fibres concrete cylinders. Figure 6 represents the interfacial bond strength of the HSPFRC at 7 and 28 days with different inclusion of steel-polypropylene fibres. From Figure 6(a), the interfacial bond strength of HSPFRC is increased compared to control specimen. The interfacial bond strength effectiveness of the concrete with inclusion of 4 % steel fibre and 0 % polypropylene fibre is 0.009 % as depicted in Figure 6(b).



(a) **(b)**

Figure 6: (a) The interfacial bond strength of HSPFRC (b) the interfacial bond strength effectiveness of the HSPFRC with different inclusion of fibres dosage levels

The inclusion of 4 % polypropylene fibre and 0 % steel fibre increases the strength effectiveness in only 0.001 % compared to the inclusion of high dosage level of steel fibre. This might be the bond strength between the steel bar and hybrid steel-polypropylene fibres are low. Hence, it would reduce the bond between steel bar and hybrid steel-polypropylene fibre.

CONCLUSION

Based on the 154 samples of HSPFRC prepared to investigate on the compressive strength, flexural strength, splitting tensile strength and interfacial bond strength, the following conclusions are derived from this study:

1. It can be concluded that the addition of 4 % steel fibre and 0 % polypropylene hybrid fibre enhanced the strengths of the HSPFRC significantly such as compressive strength, flexural strength, splitting tensile strength and interfacial bond strength.
2. The inclusion of 4 % polypropylene fibre and 0 % steel fibre in the concrete mix increase the strength of the composite compare to control specimen. However, the strength is lower than the concrete mix with composite of 4 % steel fibre and 0 % of polypropylene fibre.
3. It can be deduced that the inclusion of steel fibre increase the strength of the concrete mix and the inclusion of polypropylene fibre increase the post-cracking of the specimen.

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