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THE INFLUENCE OF STEEL FIBER WASTE TYRE ON HIGH STRENGTH CONCRETE CONTAINING PALM OIL FUEL ASH AND RICE HUSK ASH

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ABSTRACT: High strength concrete (HSC) has high compressive strength, but low tensile and flexural strength, toughness, low resistance to cracking, and brittle fracture characteristics. To enhance these engineering properties, steel fiber can be used in the HSC. Steel fiber from waste tyres (SFWT) can be used as an alternative steel fiber for HSC due to low cost of the material. It needs more study to explore deeply the effect of SFWT on HSC containing Cement Replacement Materials (CRM). This paper presents an experimental investigation on the effect of SFWT on high strength concrete containing palm oil fuel ash (POFA) and rice husk ash (RHA). The contents of each CRM (POFA and RHA) on the HSC are 5% and 10% by weight of cement. The addition of SFWT in HSC containing POFA and RHA are 0%, 0.5%, 1.0%, 1.5%, and 2% by concrete volume. The 28-days compressive and tensile strengths are tested for all HSC mixtures. The results show that the addition of SFWT on HSC containing POFA (HSCP) and RHA (HSCR) reduce concrete workability but increase the mechanical properties of the concrete. More SFWT are added, the higher compressive and tensile strength is obtained. The higher compressive and tensile strengths on each HSCP and HSCR mixtures are observed at the addition of 2% SFWT with 5% content of POFA (HSCP 5%) and RHA (HSCR 5%). For HSCP 5%, the addition of 2% SFWT improves the compressive and tensile strengths up to 26.62% and 37.59%, respectively, while for HSCR 5%, it improves up to 21.60% and 23.34%, respectively.

Keywords: HSC, Steel fiber waste tyre, Palm oil fuel ash, Rice husk ash, Concrete properties

1. INTRODUCTION

Concrete as a construction material has been used extremely widely in high rise buildings, bridges, and other structures, due to its low cost, flexibility, durability, high strength, and resistance to fire [1]. In the last few decades, high strength concrete (HSC) has been developed for construction, especially for modern construction buildings that have a large load. High strength concrete (HSC) is typically recognized as concrete with a 28-days cylinder compressive strength greater than 40 MPa. The main objective of using high strength concrete is to reduce the weight, creep, or permeability issues and to improve the durability of the structure [2].

HSC is a non-linear, non-elastic, and brittle material, which is strong in compression and very weak in tension. It also has low ductility, low energy absorption, and weak crack resistance. The use of steel fiber in HSC is a solution to resolving these problems [3]. The steel fiber has the ability to transfer stresses across a cracked section, which increases concrete strength and resistance to cracking and crack propagation of concrete [4-5]. Steel fiber extracted from waste tyre (SFWT) can be used as an alternative steel fiber material in concrete [6]. In Indonesia, the waste tyre is one of the disposal materials with a very large amount of production, more than 50 million per year [7]. The utilization of SFWT on concrete not only reduces environmental but also reduces the cost of concrete production, in which the cost of SFWT is was approximately ten times less than manufactured steel fiber [8].

Some previous studies have been carried out on the effect of SFWT on the normal concrete, including concrete containing Cement Replacement Materials (CRM) such as fly ash (FA) and palm oil fuel ash (POFA), with the results showed that the use of SFWT improves the engineering properties of concrete, such as tensile strength, flexural strength, and prevent the concrete crack propagation [7, 9]. The influence of SFWT on High Strength Concrete (HSC) and HSC containing FA and silica fume also has been investigated in previous studies; with the result shows the addition of 2% SFWT improves the tensile strength of HSC containing fly ash and silica fume by 62.99% and 63.73%, respectively [10 -11].

Furthermore, more research is needed to explore deeply the effect of SFWT on HSC, especially on HSC containing other CRM from waste materials. As it is known that the use of CRM to replace cement in some proportion will reduce the pollution as well as the concrete cost. Therefore, this study will investigate the influence of SFWT on high strength concrete containing POFA and RHA.

2. MATERIAL

2.1 Cement

Ordinary Portland Cement (OPC) produced by the cement factory in Padang, Indonesia, is used in this study.

2.2 Coarse Aggregate

The coarse aggregate used is locally available aggregate with a maximum size of 10 mm as per ASTM C 128 – 07a. The properties of coarse aggregate are given in Table 1.

Table 1 Properties of coarse aggregate

Property	Value
Specific Gravity	2.41
Absorption	5.93 %
Fine Modulus (FM)	3.40
Water Content	1.99 %

2.3 Fine Aggregate

Fine aggregate (sand) used is good quality river sand with a maximum size of 4.75 mm. The properties of fine aggregate are given in Table 2.

Table 2 Properties of fine aggregate

Property	Value
Specific Gravity	2.54
Absorption	3.0 %
Fine Modulus (FM)	2.85
Water Content	1.83 %

2.4 Water

Potable tap water is used for mixing and curing the high strength concrete.

2.5 Steel Fiber Waste Tyre

The steel fiber was obtained by extracting steel wires from used car tyres (Fig. 1) by manual cutting process with a special tool. Fig. 2 shows the steel wires after removing them from the tyre. Furthermore, the steel wires were cut into small fibers (± 4 cm length), as shown in Fig. 3. In this study, four different fiber volumes were added to the high strength concrete mixes at 0.5%, 1.0%, 1.5%, and 2% by concrete volume. The amount of SFWT in the concrete is commonly limited to about 2% by concrete volume due to a reduction in workability, and difficulty to ensure uniform dispersion [12]. The properties of SFWT are shown in Table 3.

Fig. 1 Used car tyres

Fig. 2 Steel wires from waste tyre

Fig. 3 Steel fiber waste tyre (± 4 cm length)

Table 3 Properties of steel fiber waste tyre

Characteristic	Description
Form	Irregular, Sharp
Size	Diameter 0.5 mm and Length 40 mm
Aspect ratio	80
Density	7850 kg/m^3
Tensile Strength	500-2000 N/mm^2

2.6 Palm Oil Fuel Ash (POFA)

Palm oil fuel ash (POFA) is a waste by-product that is produced by burning palm oil shell and husk as fuel in a palm oil mill boiler. It can be utilized as cement replacement materials (CRM) in the concrete [13]. In this study, POFA was collected from palm oil factory in Sangir, Dharmasraya, West Sumatera, Indonesia, with the chemical composition as shown in Table 4.

Table 4 Chemical composition of POFA

Composition	%
Silicon dioxide (SiO_2)	62.84
Aluminium oxide (Al_2O_3)	2.19
Iron oxide (Fe_2O_3)	2.6
Lime (CaO)	9.57
Magnesium oxide (MgO)	3.48

2.7 Rice Husk Ash (RHA)

Rice husk ash (RHA) is an agricultural waste material obtained from the rice processing mill. It can be a highly reactive pozzolanic material produced by the controlled burning of rice husk [14]. This material was collected from the rice husk burning, which was used as cement replacement material on concrete. The chemical composition of RHA is given in Table 5.

Table 5 Chemical composition of rice husk ash

Composition	(%)
Silicon dioxide (SiO_2)	90.13
Aluminium oxide (Al_2O_3)	1.88
Iron oxide (Fe_2O_3)	0.89
Lime (CaO)	0.23
Magnesium oxide (MgO)	0.87

2.8 Superplasticizer

Viscocrete 8670 produced by Sika Factory was used as a superplasticizer or high range water reducer (HRWR) based on ASTM C 494-92. This superplasticizer was used to achieve the desired level of workability in all HSC mixtures.

3. EXPERIMENTAL WORK

3.1 Mix Design

Mix design of HSC with targeted compressive strength of 50 MPa and w/c = 0.39 is calculated based on ACI 211.4R-93. There are four variations of high strength concrete namely, HSC containing 5% and 10% POFA (HSCP 5% and HSCP 10%) and HSC containing 5% and 10% RHA (HSCR 5% and HSCR 10%).

Table 6 Mix proportions of HSCP 5%

Material	SF 0	SF 0.5	SF 1.0	SF 1.5	SF 2.0
Cement (kg/m^3)	527.6	527.6	527.6	527.6	527.6
Sand (kg/m^3)	645.6	645.6	645.6	645.6	645.6
Split 5/10 (kg/m^3)	929.4	929.4	929.4	929.4	929.4
Water (kg/m^3)	218.6	218.6	218.6	218.6	218.6
SFWT (%)	0.00	0.50	1.00	1.50	2.00
POFA (kg/m^3)	27.8	27.8	27.8	27.8	27.8
Visco-crete (%)	2	2	2	2	2

Note: SF = Steel Fiber

Table 7 Mix proportions of HSCP 10%

Material	SF 0	SF 0.5	SF 1.0	SF 1.5	SF 2.0
Cement (kg/m^3)	499.8	499.8	499.8	499.8	499.8
Sand (kg/m^3)	645.6	645.6	645.6	645.6	645.6
Split 5/10 (kg/m^3)	929.4	929.4	929.4	929.4	929.4
Water (kg/m^3)	218.6	218.6	218.6	218.6	218.6
SFWT (%)	0.00	0.50	1.00	1.50	2.00
POFA (kg/m^3)	55.5	55.5	55.5	55.5	55.5
Visco-crete (%)	2	2	2	2	2

Table 8 Mix proportions of HSCR 5%

Material	SF 0	SF 0.5	SF 1.0	SF 1.5	SF 2.0
Cement (kg/m^3)	527.6	527.6	527.6	527.6	527.6
Sand (kg/m^3)	645.6	645.6	645.6	645.6	645.6
Split 5/10 (kg/m^3)	929.4	929.4	929.4	929.4	929.4
Water (kg/m^3)	218.6	218.6	218.6	218.6	218.6
SFWT (%)	0.00	0.50	1.00	1.50	2.00
POFA (kg/m^3)	27.8	27.8	27.8	27.8	27.8
Visco-crete (%)	2	2	2	2	2

Table 9 Mix proportions of HSCR 10%

Material	SF 0	SF 0.5	SF 1.0	SF 1.5	SF 2.0
Cement (kg/m^3)	499.8	499.8	499.8	499.8	499.8
Sand (kg/m^3)	645.6	645.6	645.6	645.6	645.6
Split 5/10 (kg/m^3)	929.4	929.4	929.4	929.4	929.4
Water (kg/m^3)	218.6	218.6	218.6	218.6	218.6
SFWT (%)	0.00	0.50	1.00	1.50	2.00
POFA (kg/m^3)	55.5	55.5	55.5	55.5	55.5
Visco-crete (%)	2	2	2	2	2

POFA and RHA content in the HSC mix was conducted by being partially replaced the cement weight. The additional steel fiber on HSCP and HSCR varied from 0.5% to 2% with the incremental 0.5% based on concrete volume. The proportion of HSCP and HSCR mixtures with different variations of steel fiber waste tyre is given in Tables 6, 7, 8, and 9, respectively.

3.2 Specimen Preparation

A total of 120 cylinders specimens were prepared, consisting of 60 cylinders for compressive strength testing and 60 cylinders for tensile strength testing. Table 10 shows the number of tested specimens.

Table 10 Number of test specimens

Type of Concrete	Number of specimens	
	Compressive	Tensile
HSCP 5%	15	15
HSCP 10%	15	15
HSCR 5%	15	15
HSCR 10%	15	15

Cylindrical molds with diameter 150 mm and 300 mm height are used in the manufacture of test specimens for the compressive and tensile strength tests. The specimens are cast with 0%, 0.5%, 1%, 1.5%, 2% content of SFWT on HSCP 5%, HSCP 10%, HSCR 5% and HSCR 10% mixtures. All specimens were kept in the curing cabinet until the testing periods.

3.3 Testing of Specimens

The compressive strength test on cylindrical specimens was tested based on ASTM C 39-99, and the tensile strength testing based on ASTM C 496-86. Both tests were conducted using Universal Testing Machine (Figs. 4 and 5) in the concrete laboratory. In this study, both tests were conducted on specimens at the age of 28 days.

Fig. 4 Compressive test on cylindrical specimen

Fig. 5 Splitting tensile test on cylindrical specimen

4. RESULTS AND DISCUSSION

4.1 Workability

In this study, the workability of the concrete mixtures was measured by using the slump flow test. The slump flow results of HSCP and HSCR mixtures with a variation of SFWT content are shown in Figs. 6 and 7, respectively. As seen in these figures, the workability of HSC containing POFA and RHA decrease as the percentage of SFWT increase. The lowest slump of all mixtures was observed at 2% SFWT content. For HSCP mixtures, the trend of slump flow decrease between HSCP 5% and HSCP 10% was almost similar; with a different value around 4 cm at each SFWT content (Fig. 6). In HSCP 5%, the addition of SFWT 2% led to reducing slump flow diameter from 64 cm to 60 cm, while for HSCP 10%, it reduces from 62 cm to 57 cm. A similar trend was also observed on the workability of HSCR mixtures, but the different slump values between HSCR 5% and 10% varied from 1.5 cm (0% SFWT) to 3 cm (2% SFWT), as shown in Fig. 7.

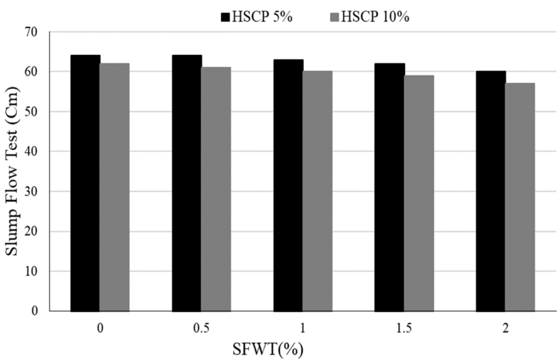

Fig. 6 Comparison of slump flow between HSCP 5% and HCSP 10% with different SFWT content

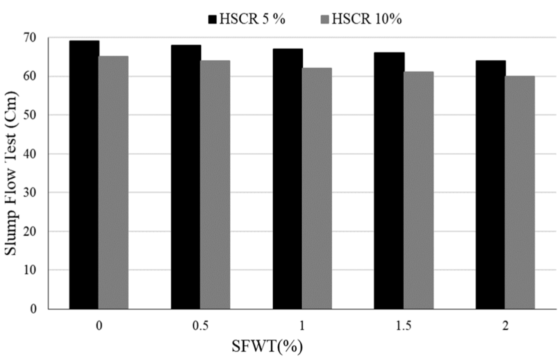

Fig. 7 Comparison of slump flow between HSCR 5% and 10% with different SFWT content

In HSCR 5%, by adding 2% SFWT to the mixture led to reducing slump flow diameter from 69 cm to 64 cm, while for HSCR 10%, the slump value reduces from 65 cm to 60 cm. The addition of high rates of SFWT affected the fluidity of HSCP and HSCR mixtures because the SFWT prevents the flow of the cement paste. Fig. 8 shows the comparison of slump flow between HSCP and HSCR mixtures. From the figure, it is revealed that HSC containing RHA has a higher slump flow than that of HSC containing POFA. This might be due to the different surface area and water absorption capacity between RHA and POFA materials.

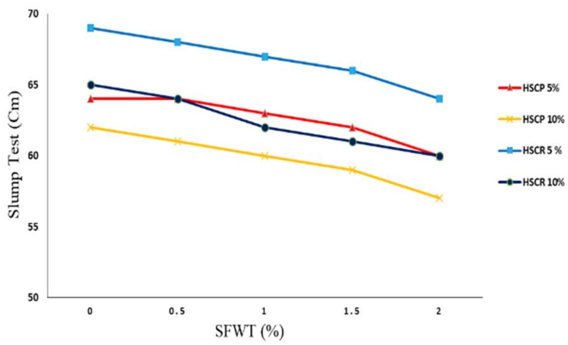

Fig. 8 Slump flow of HSCP and HSCR mixtures with different SFWT content

4.2 Compressive Strength

The compressive strength of all mixtures was tested after 28 days of casting. The results of the compressive tests performed on HSCP with different percentages of SFWT are shown in Table 11 and Fig. 9. As seen in Table 11, the compressive strength increases with the increase of fiber content. In HSCP 5%, the increase of compressive strength is more significant when SFWT was added at a rate of 1.5%, which is 26.16% compared to HSCP 5% without SFWT. After that, the compressive strength remains constant that reached 64.82 MPa at 2% SFWT content, which increases by 26.62%. For HSCP 10%, a slight increase of compressive strength was observed at 0.5% SFWT content, which is around 1.53% compared to HSCP 10% without SFWT. A continuous increase in the strength was recorded at the addition of SFWT at the rate of 1% and 1.5%. The highest strength of 47.3 MPa was obtained when added 2% SFWT, which is 21.72% higher than the HSCP 10% without SFWT. As seen in Fig. 9, the compressive strength of HSCP 5% was higher than HSCP 10% in each SFWT content. This indicates that the use of POFA with a high percentage decreases the compressive strength of the HSC concrete.

Table 12 and Fig. 10 show the test results of the compressive strength of HSCR mixtures at different SFWT content. For HSCR 5%, the compressive strength slightly increases at 0.5%

SFWT content and continues to increase until it reached the maximum strength of 52.52 MPa at 2% SFWT, which increases 21.6% compared to HSCR 5% without SFWT. In HSCR 10%, the increase of strength at 0.5% SFWT content is slightly higher than that of HSCR 5%, which increases 5.33% in comparison to the mixture without SFWT. The maximum strength of 48.23% was observed at a rate of 2% SFWT, which increases 20.81% compared to the specimen without fiber. The trend of compressive strength results of HSCR was found to be almost similar to the HSCP mixtures, in which the strength of HSCP 5% was higher than HSCP 10% in each rate of SFWT. As shown in Fig. 10, the higher RHA content, the lower compressive strength of the HSCR.

Table 11 Compressive strength result of HSCP

No	SFWT (%)	Compressive Strength (MPa)		Percentage of Increase (%)	
		POFA 5%	POFA 10%	POFA 5%	POFA 10%
1	0	51.19	38.86	-	-
2	0.50	57.06	39.45	11.47	1.53
3	1.00	59.86	42.51	16.94	9.41
4	1.50	64.58	45.84	26.16	17.97
5	2.00	64.82	47.30	26.62	21.72

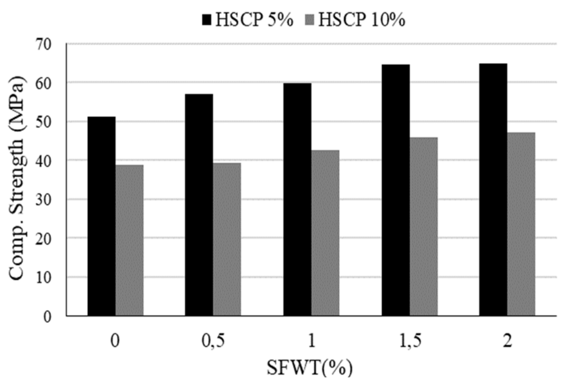

Fig. 9 Comparison of compressive strength between HSCP 5% and HSCP 10% with different SFWT content

Comparing the strength results between HSCP and HSCR, it was found that HSC containing 5% POFA has a higher compressive strength than HSC containing 5% RHA, while for 10% replacement, the compressive strength of HSCR is slightly higher than that of HSCP. This indicates that replacement of OPC by 5% POFA with 2% SFWT is the best in compressive strength of the HSC mixtures, as shown in Fig. 11.

Table 12 Compressive strength result of HSCR

No	SFWT (%)	Compressive Strength (MPa)		Percentage of Increase (%)	
		RHA 5%	RHA 10%	RHA 5%	RHA 10%
1	0	43.19	39.92	-	-
2	0.50	44.40	42.05	2.79	5.33
3	1.00	48.62	44.62	12.57	11.75
4	1.50	50.00	47.76	15.75	19.62
5	2.00	52.52	48.23	21.60	20.81

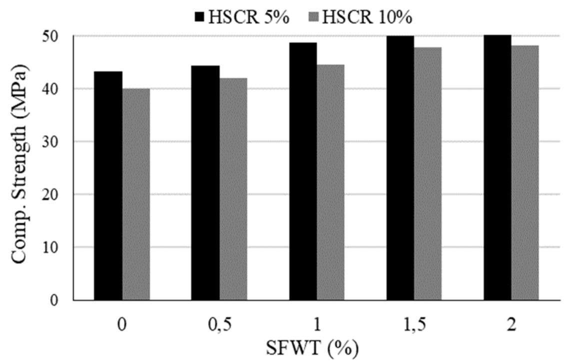

Fig. 10 Comparison of compressive strength between HSCR 5% and HSCR 10% with different SFWT content

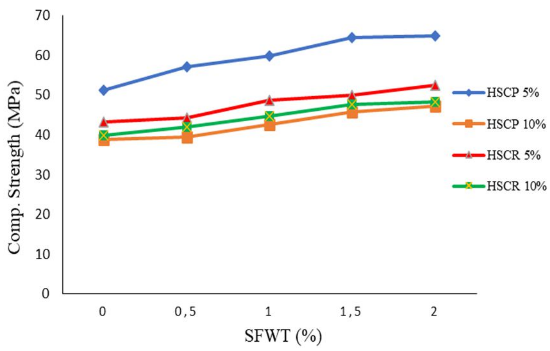

Fig. 11 Compressive strength of HSCP and HSCR mixtures with different SFWT content

4.3 Tensile Strength

The results of the splitting tensile tests performed on HSCP mixtures with different percentages of SFWT are shown in Table 13 and Fig. 12. As seen in Table 13, the tensile strength of HSCR mixtures increases with an increase in the percentage of SWFT. For HSCP 5%, the highest tensile strength of 6.07 MPa was found at 2% SFWT content, which increases 37.59% compared with the HSCP 5% without fiber content. Meanwhile, in HSCP 10%, the percentage increase of tensile strength was 30.81%, in which the maximum strength of 4.59 MPa was reached at 2% SFWT content. Fig. 12 shows that the tensile strength of HSCP 5% was higher than HSCP 10% in each SFWT content. This indicates that the higher replacement OPC by POFA results in a decrease in the tensile strength of the HSC.

Table 13 Splitting tensile strength of HSCP

No	SFWT (%)	Tensile Strength (MPa)		Percentage of Increase (%)	
		POFA 5%	POFA 10%	POFA 5%	POFA 10%
1	0	4.41	3.51	-	-
2	0.50	5.23	3.86	18.66	9.95
3	1.00	5.46	4.25	23.72	21.13
4	1.50	5.66	4.44	28.28	26.58
5	2.00	6.07	4.59	37.59	30.81

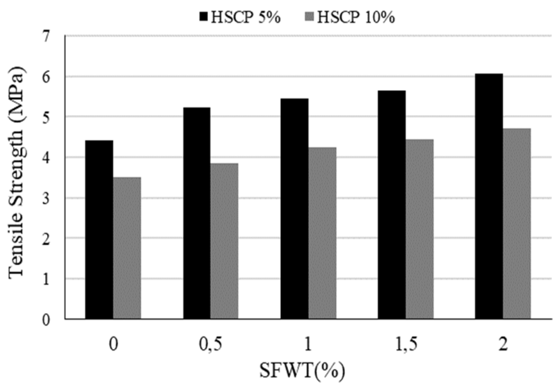

Fig. 12 Comparison of splitting tensile strength between HSCP 5% and HSCP 10% with variation SFWT content

The tensile test results of HSCR with different SFWT content are shown in Table 14. As seen in the table, the maximum splitting tensile strength on HSCR 5% was obtained with the addition of 2% SFWT, which is 5.23 MPa. This strength value increases by 23.34% as compared to HSCR without fiber. In HSCR 10%, the maximum percentage increase of the tensile strength at 2% SFWT content is less than those in HSCR 5%, that is 21.20% (Tensile strength = 4.72 MPa). Fig. 13 shows the comparison of splitting tensile strength between HSCR 5% and HSCR 10% with variation fiber content. From the figure, it can be seen that the tensile strength of HSCR 5% is higher than that of HSCR 10% at each SFWT content. This indicates that the lower replacement of OPC by RHA results in higher tensile strength.

In general, HSCP 5% has the highest tensile strength compared with other mixtures at each steel fiber content, as shown in Fig. 14. The pattern of tensile strength increase varied among the mixtures, while the different strength between HSCP 5% and HSCP 10% is higher than that of between HSCR 5% and HSCR 10%. Also, it is observed that the HSCP 5% is higher than HSCR 5%, while it is reverse when comparing the HSCP 10% and HSCR 10%. The tensile splitting strength increases as the increase of the fiber content from 0% to 2% on both HSCP and HSCR mixtures. The increase of the tensile strength might be due to the bridging action of the SFWT, which results in a more strong mechanical interlocking force in the concrete.

Table 14 Splitting tensile strength of HSCR

No	SFWT (%)	Tensile Strength (MPa)		Percentage of Increase (%)	
		RHA 5%	RHA 10%	RHA 5%	RHA 10%
1	0	4.24	3.90	-	-
2	0.50	4.44	3.99	4.74	2,35
3	1.00	5.12	4.46	20.73	14.44
4	1.50	5.15	4.63	21.35	18.94
5	2.00	5.23	4.72	23.34	21.20

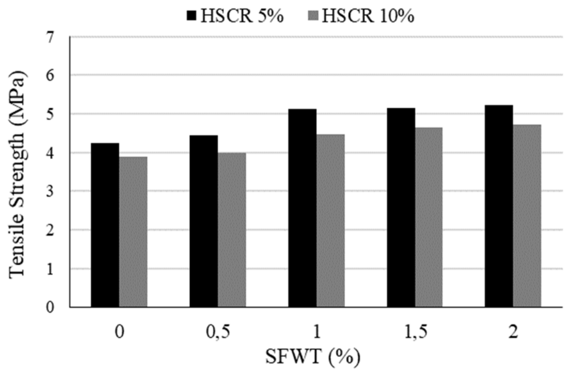

Fig. 13 Comparison of splitting tensile strength between HSCR 5% and HSCR 10% with variation SFWT content

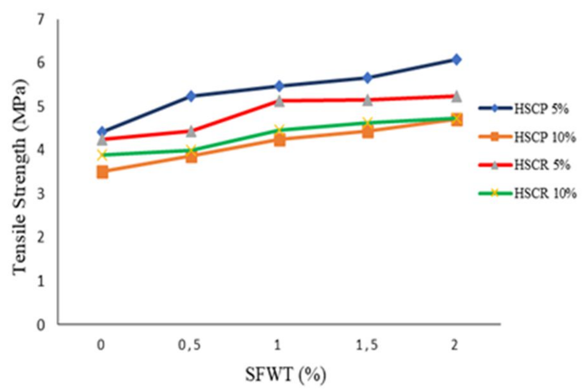

Fig. 14 Splitting tensile strength of HSCP and HSCR mixtures with different SFWT content

5. CONCLUSION

1. The addition of SFWT from 0.5% to 2% in HSC containing POFA and RHA decreases the workability, but it increases the compressive and tensile strength.
2. The maximum compressive strength in HSC containing POFA and RHA concrete occurred in the addition of 2.0% fiber steel that is 64.82 MPa and 52.52 MPa, respectively, which increase 26.62% and 21.60%, respectively, compared with the mixture without SFWT content.
3. The addition of 2% SFWT in HSC containing POFA and RHA reached the maximum tensile strength of 6.07 MPa and 5.23 MPa, respectively, in which the increase of the tensile strength is around 37.59% and 23.34%, respectively, in comparison with the mixtures without steel fiber.
4. HSCP 5% with the addition of 2% SFWT shows the best engineering concrete properties among the other HSC mixtures investigated in this study.

6. ACKNOWLEDGEMENTS

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