International Journal of GEOMATE, June 2019, Vol.16, Issue 58, pp.14 - 19
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2019.58.4772
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

# EXPERIMENTAL STUDY ON THE EFFECT OF STEEL FIBER WASTE TYRE ON HIGH STRENGTH CONCRETE

*Fauzan[1], Ruddy Kurniawan[2], Oscar Fitrah N[3], Claudia Lovina A. N[4], and Zev Al Jauhari[5]

[1,2,3,4] Engineering Faculty, Andalas University, Indonesia; [5] Bengkalis State Polytechnic, Indonesia

*Corresponding Author, Received: 19 Nov. 2018, Revised: 30 Dec. 2018, Accepted: 14 Jan. 2019

**ABSTRACT:** High strength concrete (HSC) is defined as concrete with a specified compressive strength of 40 MPa or greater. High strength concrete is basically a brittle material, with low tensile strength. One way to improve the brittle and weak concrete properties towards tensile strength is by utilizing fiber. The utilization of steel fiber from waste tyres (SFWT) in high strength concrete can be used as an alternative to improve the mechanical properties of the concrete and also has benefit to reduce the waste of used tyres that increase every year. This research was carried out to investigate the effect of the addition of SFWT on HSC and high strength concrete containing silica fume (HSCSF). The SFWT is obtained from steel wires that are removed from used tyres and then, cut into 4 cm length. The cylindrical specimen with a diameter of 15 cm and height of 30 cm, and beams with dimension 10x10x50 cm are cast. The content of silica fume on HSC is 10% by replacing the cement weight. The addition of SFWT in both HSC and HSCSF are 0%, 0.5%, 1.0%, 1.5%, and 2%. The properties of high strength concrete: compressive strength, splitting tensile strength, and flexural strength are tested at 28 days after casting. The results show that the addition of SFWT increases the mechanical properties of HSC and HSCSF. The increase of SFWT content results in the higher mechanical properties of the HSC and HSCSF. In addition, the presence of SFWT in the high strength concrete delays the crack width of the concrete and prevents the brittle collapse.

*Keywords: High strength concrete, Steel fiber waste tyre, Silica fume, Concrete properties*

## 1. INTRODUCTION

Concrete is the single most widely used material in the world. In general, the strength and performance of concrete before the 20th century is still low, and then, it is developed to the high strength concrete (HSC). The high strength concrete is concrete with compressive strength implies 40 MPa or greater. Concrete with higher compressive strength can reduce the size of structural elements such as columns and beams [1].

HSC can be produced by reducing the water-cement ratio of the concrete. The reduction of the water-cement ratio results in a decrease in porosity and refinement of capillary pores in the matrix so the mechanical properties will increase. However, it will affect the workability of concrete. An alternative to make HSC is by using pozzolanic admixtures such as silica fume. Silica fume is a by-product of producing silicon metal or ferrosilicon alloy that is very reactive. It has been proved that the addition of silica fume on HSC increases the compressive strength, flexural strength, and durability. The highest increase of these concrete properties was found at the concrete containing 10% and 15% silica fume [2].

High strength concrete is inherently a brittle material, with low tensile strength and limited ductility. The cracks of HSC will also easily occur due to the tensile stress. One way to improve the brittle and weak concrete tensile strength is by utilizing fiber. Fibers help to improve the post-peak ductility performance, pre-crack tensile strength, impact strength, fatigue strength, and eliminate temperature and shrinkage cracks [3]. Several studies have proved that the use of fiber in HSC can improve the concrete properties, especially its tensile and flexural strength [4-8].

The utilization of special steel fiber from the used tyre, known as steel fiber waste tyre (SFWT) on HSC can be an alternative to produce HSC with high tensile strength. A large number of used tyres production results in the huge number of SFWT, which is the potential to be used to improve the mechanical properties of HSC. This research focused on the investigation of the effect of SFWT addition on HSC and high strength concrete containing silica fume (HSCSF).

## 2. MATERIALS

### 2.1 Cement

The cement used in this research is Ordinary Portland Cement (OPC) type I produced by cement manufacture in Padang, Indonesia.

### 2.2 Fine Aggregate

Locally available fine aggregate, with a maximum size of 4.75 mm is used in this study. The properties of the fine aggregate such as specific gravity, absorption, fineness modulus, and water content are shown in Table 1.

Table 1 Properties of fine aggregate

| No | Property | Value |
|---|---|---|
| 1 | Specific gravity | 2.44 |
| 2 | Absorption | 3.6 % |
| 3 | Fine Modulus (FM) | 3.4 |
| 4 | Water content | 0.94 % |

### 2.3 Coarse Aggregate

The locally coarse aggregate is used with the size of 5-10 mm. Table 2 shows the properties of the coarse aggregate such as specific gravity, absorption, fineness modulus, and water content.

Table 2 Properties of coarse aggregate

| No | Property | Value |
|---|---|---|
| 1 | Specific gravity | 2.51 |
| 2 | Absorption | 2.8 % |
| 3 | Fine Modulus (FM) | 4.97 |
| 4 | Water content | 1.06 % |

### 2.4 Water

Potable tap water which is free form acid and organic substance is used in mix preparation and curing concrete.

### 2.5 Steel Fiber Waste Tyre

The steel fibers were obtained from steel wires that were removed from used tyres (Figs. 1 and 2). The removal of the wires was carried out by a manual cutting process using specialized knives [9, 10]. Then, the wires were cut to 4 cm length to be added in the concrete mix (Fig. 3). Table 3 shows the geometric characteristics of the SFWT. The proportion of SFWT in the concrete mix varies from 0 to 2% with an increment of 0.5% by the concrete volume.

### 2.6 Silica Fume

Sika Fume produced by Sika Factory was used as silica fume material in this study. This material meets the technical requirements in accordance with ASTM C 1240-00.

### 2.7 Superplasticizer

Viscocrete-1003 superplasticizer manufactured by Sika Factory was used as a high range water reducer agent (HRWA) in the high strength concrete mix. This superplasticizer is in accordance with ASTM C 494-92 Type F.

Fig.1 Production of Used tyres

Fig.2 Steel wires from used tyres

Fig.3 Steel fiber waste tyre with 4 cm length

Table 3 Properties of steel fiber waste tyre

| Characteristics of steel fiber | Description |
|---|---|
| Form | irregular, sharp |
| Surface texture | invisible |
| Size | diameter 0.5 mm and length 40 mm |
| Aspect ratio | 80 |
| Density | 7850 kg/m$^3$ |
| Tensile strength | 500-2000 N/mm$^2$ |

## 3. EXPERIMENTAL WORK

### 3.1 Mix Design

The mix designs of HSC and HSCSF are calculated according to the ACI 211.4R-93. There are two variations of high strength concrete namely, high strength concrete and high strength concrete containing silica fume. The addition of silica fume in the concrete mixture is 10% of the cement weight, in which the silica fume serves as a cement replacement material. The amount of steel fibers added in the concrete mixture is based on the total volume of the commonly referred concrete volume fraction. The mix proportions of HSC and HSCSF with different percentages of SFWT are shown in Tables 4 and 5.

Table 4 Mix proportions of HSC

| Material | SF 0 | SF 0.5 | SF 1.0 | SF 1.5 | SF 2.0 |
|---|---|---|---|---|---|
| Cement (kg/m$^3$) | 561.5 | 561.5 | 561.5 | 561.5 | 561.5 |
| Sand (kg/m$^3$) | 638.7 | 638.7 | 638.7 | 638.7 | 638.7 |
| Split 5/10 (kg/m$^3$) | 902.6 | 902.6 | 902.6 | 902.6 | 902.6 |
| Water (kg/m$^3$) | 214.8 | 214.8 | 214.8 | 214.8 | 214.8 |
| SF (%) | 0.0 | 0.5 | 1.0 | 1.5 | 2.0 |
| Viscocrete 1003 (%) | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 |

Note: SF = steel fiber

Table 5 Mix proportions of HSCSF

| Material | SF 0 | SF 0.5 | SF 1.0 | SF 1.5 | SF 2.0 |
|---|---|---|---|---|---|
| Cement (kg/m$^3$) | 505.3 | 505.3 | 505.3 | 505.3 | 505.3 |
| Sand (kg/m$^3$) | 638.7 | 638.7 | 638.7 | 638.7 | 638.7 |
| Split 5/10 (kg/m$^3$) | 902.6 | 902.6 | 902.6 | 902.6 | 902.6 |
| Water (kg/m$^3$) | 214.8 | 214.8 | 214.8 | 214.8 | 214.8 |
| SF(%) | 0.0 | 0.5 | 1.0 | 1.5 | 2.0 |
| Silica Fume (kg/m$^3$) | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 |
| Viscocrete 1003 (%) | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 |

Note: SF = steel fiber

### 3.2 Specimen Preparation

Totally 80 specimens were fabricated, which consist of 30 cylinders for compressive tests, 30 cylinders for splitting tensile tests, and 20 beams for flexural tests. The number of test specimens is shown in Table 6.

Table 6 Number of test specimens

| Type of concrete | Number of concrete specimens | | |
|---|---|---|---|
| | Comp. | Tensile | Flexural |
| High strength concrete | 15 | 15 | 10 |
| High strength concrete with Silica Fume 10% | 15 | 15 | 10 |
| Total | 30 | 30 | 20 |

Cylindrical molds of 150 mm diameter and 300 mm height are used for casting the specimen for compressive and splitting tensile strength tests, respectively. For the flexural strength test, the beam specimens with a size of 100 x 100 x 500 mm are cast. The specimens are cast with 0%, 0.5%, 1%, 1.5%, and 2% contents of SFWT on the high strength concrete with and without silica fume. All specimens were moist cured in a humidity controlled room after casting. The curing of the concrete specimens was performed for 28 days.

### 3.3 Testing of Specimens

The compressive test on cylindrical specimens was performed in accordance with Indonesian standard SNI 03-1972-2011, while the splitting tensile test of the cylinders was carried out based on SNI 2491:2014. Both tests were conducted by using a Universal Testing Machine (UTM) at the Concrete Laboratory of Semen Padang Factory (SPF), as shown in Figs. 4 and 5.

Flexural testing on beams was performed based on SNI 4154:2014 using a flexural test device at the concrete laboratory, as shown in Fig. 6.

## 4. RESULTS AND DISCUSSION

### 4.1 Compressive Strength

The results of the compressive tests performed on HSC and HSCSF with different percentages of steel fibers tested on the 28$^{th}$ day are shown in Table 7 and Fig. 7. As seen in Table 7, the compressive strength of HSC and HSCSF containing SFWT increases with the increase of SFWT content. In HSC, the percentage increases in the compressive strength for the cylinders with 0.5%, 1%, 1.5% and 2% SFWT addition are 0.42%; 2.59%; 22.86%; and 24.56%, respectively. The highest compressive strength of 73.38 MPa was obtained on HSC with 2% SFWT addition.

Fig.4 Compressive test on the cylindrical specimen

Fig.5 Splitting tensile test on the cylindrical specimen

Fig.6 Flexural test on the beam specimen

Table 7 Test result of compressive strength

| No | SFWT (%) | Compressive strength (MPa) | | Percentage of increase (%) | |
|---|---|---|---|---|---|
| | | HSC | HSCSF | HSC | HSCSF |
| 1 | 0.0 | 58.91 | 69.87 | - | - |
| 2 | 0.5 | 59.15 | 73.41 | 0.42 | 5.08 |
| 3 | 1.0 | 60.44 | 74.36 | 2.59 | 6.43 |
| 4 | 1.5 | 72.38 | 77.00 | 22.86 | 10.21 |
| 5 | 2.0 | 73.38 | 78.54 | 24.56 | 12.42 |

For HSCSF, meanwhile, the highest value of compressive strength occurred in the addition of SFWT by 2% that is 78.54 MPa, which is around 12.4% increase in compressive strength compared to those without SFWT. Percentage increase of compressive strength with 0.5%; 1.0%; 1.5%; and 2% SFWT addition are 5.08%; 6.43%; 10.21%; and 12.24%, respectively. The comparison of compressive strength between HSC and HSCSF with variation SFWT content is shown in Fig. 7.

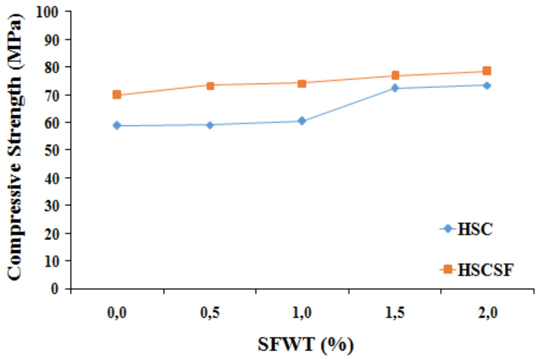


Fig.7 Comparison of compressive strength between HSC and HSCSF with different SFWT contents

It can be seen in Fig. 7, the increase in compressive strength between HSC and HSCSF has a different tendency. The compressive strength of HSCSF was higher than those of HSC in each SFWT content. This indicates that the presence of silica fume results in the higher compressive strength of the high strength concrete.

### 4.2 Tensile Strength

The splitting tensile strength test results on HSC and HSCSF with different contents of SFWT are shown in Table 8 and Fig. 8. The results show that the tensile splitting strength increases as the increase the SFWT content on both HSC and HSCSF from 0% to 0.5%, 1%, 1.5%, and 2%. This might be in consequence of the strong mechanical interlocking force in the concrete due to the presence of SFWT.

Table 8 Test result of splitting tensile strength

| No | SFWT (%) | Tensile strength (MPa) | | Percentage of increase (%) | |
|---|---|---|---|---|---|
| | | HSC | HSCSF | HSC | HSCSF |
| 1 | 0.0 | 3.85 | 5.61 | - | - |
| 2 | 0.5 | 4.77 | 5.65 | 23.87 | 0.76 |
| 3 | 1.0 | 4.87 | 6.10 | 26.32 | 8.83 |
| 4 | 1.5 | 7.61 | 7.75 | 97.55 | 38.27 |
| 5 | 2.0 | 8.27 | 9.14 | 114.69 | 62.99 |

For HSC, it is found that the maximum splitting tensile strength by adding 2% SFWT is 8.27 MPa, which is a 114.69% increase as compared to HSC without SFWT. In HSCSF, on the other hand, the maximum percentage increase of the tensile strength at 2% SFWT content is less than those in HSC, that is 62.99% (9.14 MPa).

Fig. 8 shows the comparison of tensile strength between HSC and HSCSF with variation SFWT content.

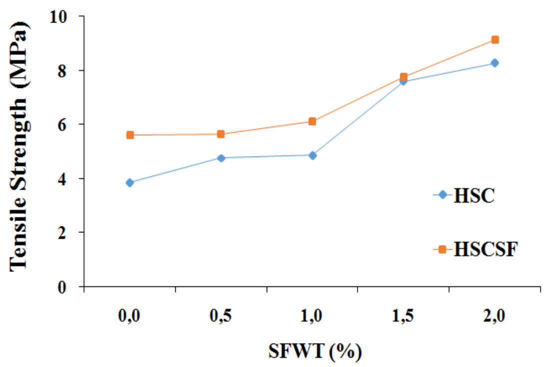


Fig.8 Comparison of tensile strength between HSC and HSCSF with different SFWT contents

Compare to HSCSF, the increase of tensile strength for HSC is more significant at each SFWT content. However, both HSC and HSCSF show almost similar increment on tensile strength from 0.5% to 1% SFWT content. In general, the tensile strength of HSCSF is higher than those of HSC at each SFWT content.

### 4.3 Flexural Strength

The results of the flexural strength tests performed on HSC and HSCSF at different percentages of SFWT content is shown in Table 9 and Fig. 9. From Table 9, it can be seen that in general, there is an increase in flexural strength from the addition of 0.5%, 1%, 1.5% and 2% SFWT to both HSC and HSCSF. The presence of SFWT improves the high strength concrete flexural strength. The highest content of fibers gives the maximum increase of the strength. The highest percentage of increase in flexural strength was observed with the addition of 2% SFWT content, which is 72.2% and 62.7% for HSC and HSCSF, respectively. The increases of the concrete flexural strength with the presence of SFWT might be due to the influence of concrete bonds with added materials in the form of SFWT. The maximum flexural strength on HSC and HSCSF are 10.73 MPa and 11.68 MPa, respectively.

Table 9 Test result of flexural strength

| No | SFWT (%) | Flexural strength (MPa) | | Percentage of increase (%) | |
|---|---|---|---|---|---|
| | | HSC | HSCSF | HSC | HSCSF |
| 1 | 0.0 | 6.23 | 7.18 | - | - |
| 2 | 0.5 | 6.89 | 8.10 | 10.47 | 12.85 |
| 3 | 1.0 | 7.27 | 8.57 | 16.61 | 19.44 |
| 4 | 1.5 | 8.33 | 9.18 | 33.57 | 27.90 |
| 5 | 2.0 | 10.73 | 11.68 | 72.20 | 62.70 |

The tendency of increase in flexural strength is almost similar for both HSC and HSCSF at each SFWT content, as shown in Fig. 9.

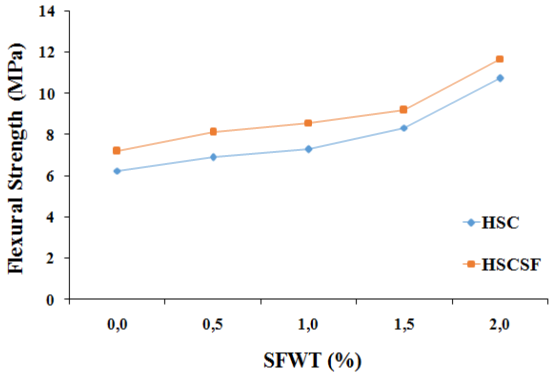


Fig.9 Comparison of flexural strength between HSC and HSCSF with different SFWT contents

Fig. 10 shows the illustration of cracks development in HSC without fiber. As seen in the figure, cracks in high strength concrete can pass through aggregates and matrix. This is because the mechanical properties of aggregates and matrix in high strength concrete are very similar (equally strong).

The presence of SFWT increases resistance to cracking. It is clearly seen from Fig. 11 that the steel fiber from waste tyre bridges across the cracked matrix, which will provide higher bonding on the HSC. As a result, the spreading of concrete cracks can be reduced. This indicates that the higher the SFWT content on the high strength concrete, the less crack occurred in the HSC, and test objects can receive a greater load. In addition, SFWT increases ductility, in which the steel fiber is still able to bind cracks in the HSC, so it can prevent the brittle collapse.

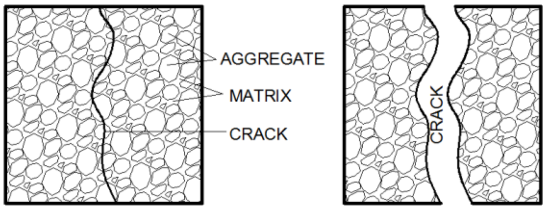


Fig.10 Illustration of cracks in high strength concrete without SFWT

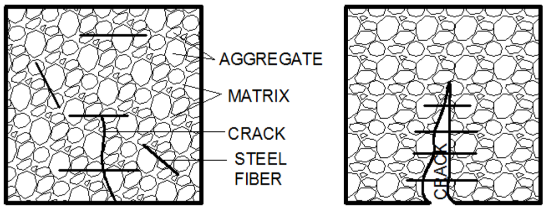


Fig.11 Illustration of cracks in high strength concrete with the addition of SFWT

## 5. CONCLUSION

1. The addition of SFWT from 0.5% to 2% in HSC and HSCSF increases the compressive strength, tensile strength, and flexural strength. The increase of these properties is due to the contribution of the fiber to bond the concrete, reduce the cracks and prevent a brittle collapse.
2. In HSC, there is no significant increase of compressive strength with 2.0% SFWT addition that is only 24.56%, while the significant increases are observed on the tensile and flexural strength that is 114.7% and 72.2%, respectively.
3. For HSCSF, the replacement of 10% cement weight by silica fume results in higher of the concrete strength compared with HSC at each SFWT content. The maximum percentage increase of the compressive, splitting tensile and flexural strength for HSCSF was observed on 2% SFWT addition that is 12.4%; 73.0%; and 62.7%, respectively.

## 6. ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support from Andalas University under contract no. 32/UN.16.17/PP.PGB/LPPM/2018.

## 7. REFERENCES

[1] Rashid, Abdur M., and Mansur M. A., Considerations in producing high strength concrete, Journal of Civil Engineering (IEB), Vol. 37(1), 2009, pp. 53-63.

[2] Amarkhail and Nasratullah, Effects of Silica Fume on Properties of High-Strength Concrete, International Journal of Technical Research and Applications e-ISSN: 2320-8163.

[3] Mhaske, Vijay M., Rahul D. P., and Wadekar A. P., Study on Behavior on High Strength Crimped Steel Fibre Reinforced Concrete for Grade M90, IJRET: International Journal of Research in Engineering and Technology eISSN: 2319-1163, ISSN: 2321-7308.

[4] Zhao, Qingxin., et. al., Effect of Fiber Types on Creep Behavior of Concrete, Construction and Building Materials, Vol. 105,2016, pp. 416–422

[5] Raikar V.R., Karjinni V.V., and Gundakalle V. D., Study on Strength Parameters of Steel Fiber Reinforced High Strength Concrete, International Journal of Applied Sciences and Engineering Research, Vol. 1, Issue 4, 2012, ISSN 2277 – 9442

[6] Velayutham G., and Cheah C. B., The Effects of Steel Fibre on the Mechanical Strength and Durability of Steel Fibre Reinforced High Strength Concrete (SFRHSC) Subjected to Normal and Hygrothermal Curing, MATEC Web of Conferences 10, 02004, 2014.

[7] Ashwani, To Study the Effect of Steel Fibers on Strength of Concrete with Partially Replaced Marble Dust, International Journal of Science and Research (IJSR), ISSN (Online): 2319-7064.

[8] Aydın and Serdar, Effects of Fiber Strength on Fracture Characteristics of Normal and High Strength Concrete, Rperiodica polytechnic, Civil Engineering, Department of Civil Engineering, Dokuz Eylül University, Buca 35160, Izmir, Turkey.

[9] Fauzan, Ismail F. A., Sandi R., and Jauhari Z. A., The influence of steel fiber extracted from the waste tyre on properties of concrete containing fly ash, International Journal on Advanced Science, Engineering and Information Technology, Vol. 7 (6), 2017, pp. 2232-2236.

[10] Fauzan, Ismail F. A., Sandi R., Syah N., and Melinda A. P., The effects of steel fibers extracted from the waste tyre on concrete containing palm oil fuel ash, International Journal of GEOMATE, Vol. 14, Issue 44, April 2018, pp. 142-148.