

THE EFFECTS OF STEEL FIBERS EXTRACTED FROM WASTE TYRE ON CONCRETE CONTAINING PALM OIL FUEL ASH

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ABSTRACT: Waste tyres have been an increasing problem every year due to the increase in vehicle sales. In Indonesia, more than 50 million waste tyres were generated every year. However, materials in waste tyre such as textile and steel fibers, actually, can be used to improve the mechanical properties of the concrete. Recently, some researchers have been devoted to the utilization of steel fibers extracted from the waste tyre (SFEFWT) on the concrete. This study focuses on the investigation of SFEFWT effect on the concrete containing palm oil fuel ash (POFA). Steel fibers were extracted from waste tyres by manually cutting process and being cut to 1 inch (25.4 mm) length. A number of cylindrical and beam specimens of concrete containing 15% palm oil fuel ash by being partially replaced the weight of cement, with addition 0.25%, 0.50%, 0.75% and 1% SFEFWT were cast and tested. The mechanical properties such as compressive, tensile and flexural strengths at the age of 28 days are studied for having prepared the concrete. The results show that the addition of SFEFWT on the concrete containing POFA improves the concrete strengths, particularly the tensile and flexural strengths. The more percentage of SFEFWT content on the POFA concrete results in the higher increase in tensile and flexural strengths. In addition, the presence of SFEFWT contributes to give higher bonding on concrete to control the crack opening on the POFA concrete.

Keywords: Steel fibers extracted from the waste tyre, Palm oil fuel ash, Compressive strength, Splitting tensile strength, Flexural strength.

1. INTRODUCTION

Concrete is one of the most versatile building materials. It can be cast to fit any structural shape from ordinary rectangular beam or column to a cylindrical water storage tank in a high-rise building [1]. However, the concrete has some deficiencies such as low tensile strength, low post cracking capacity, brittleness and low ductility, limited fatigue life, not capable of accommodating large deformations and low impact strength [2]. Concrete is characterized by 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 fibers (steel, glass, synthetic and natural) and it can be practiced among others that remedy weaknesses of concrete, such as low growth resistance, high shrinkage cracking, low durability, etc. [3]-[4]. The strength and durability of concrete can be changed by making appropriate changes in its ingredients like cementitious material, aggregate and water and by adding special ingredients [5].

The addition of steel fibers to concrete considerably improves its mechanical properties such as tensile and flexural strengths, ductility, and flexural toughness [6]-[8]. Steel fiber has the ability to excellent tensile strength, flexural

strength, shock resistance, fatigue resistance, ductility and cracks arrest. Steel fibers influence the mechanical properties of concrete and mortar in all failure modes, especially those that induce fatigue and tensile stress, e.g., direct tension, bending, impact, and shear [9]-[10]. With the inclusion of hooked end fiber improve the mechanical properties of concrete [11]-[12].

Palm Oil Fuel Ash (POFA) as the product of burning palm oil husk and palm kernel shell in the palm oil mill has been studied as cement replacement materials (CRM) in the concrete [13]. The use of POFA is limited to a cement replacement material, ranging from 0-30% by weight of cement in the production of concrete, which has a beneficial effect on the general properties of concrete and will help to reduce the construction cost [14]-[15]. The addition of POFA in the concrete mixes can increase the resistance of the concrete toward sulphate and acid attack [16].

The Waste tyre as a solid waste material has been proposed to be used in concrete in recent years. In Indonesia, there are more than 50 million waste tyres has been produced every year. The Waste tyre is one of the cheap, economical, easy and abundantly available sources for producing high tensile strength steel fibers, which can be used in the concrete mix. The use steel fibers extracted from the waste tyre in concrete, it would be the best

way to make it more economical. It is environmental friendly besides enhancing concrete properties.

Some studies have been carried to investigate the utilization of steel fiber from the waste tyre on normal concrete [17]-[19]. However, it needs more research to prove the outcomes such as the utilization of steel fiber from the waste tyre on concrete containing POFA.

This study focuses on investigation the effect of steel fibers extracted from the waste tyre (SFEFWT) on concrete containing POFA.

2. MATERIALS AND METHODS

2.1 Material Used

2.1.1 Cement

Cement used in this experimental work is Ordinary Portland Cement (OPC) produced by Padang Cement Factory, West Sumatera-Indonesia.

2.1.2 Fine aggregate

Locally available sand conforms to grade aggregate of maximum size 4.75 mm as per ASTM C 128-07a. Specific gravity and fineness modulus of fine aggregate are 2.57 and 3.11, respectively, as shown in Table 1.

Table 1 Properties of fine aggregate

No.	Property	Value
1	Specific Gravity	2.57
2	Fineness Modulus	3.11

2.1.3 Coarse aggregate

Locally available crushed stones conform to grade aggregate of nominal size 20 mm as per ASTM C 136-06. Specific gravity and fineness modulus of coarse aggregate are 2.68 and 6.44, respectively, as shown in Table 2.

Table 2 Properties of coarse aggregate

No.	Property	Value
1	Specific Gravity	2.68
2	Fineness Modulus	6.44

2.1.4 Water

Fresh potable water free from acid and organic substances was used for mixing and curing concrete.

2.1.5 Steel fiber extracted from waste tyre

In this experimental work, steel fibers were extracted from waste car tyres by the manually cutting process, as shown in Figures 1, 2 and 3. The maximum cut length of fibers was 1 inch (Figure 4).

The average diameter of fibers was 0.28 mm keeping aspect ratio (Length/Diameter) equal to 90. The different proportion of steel fiber from waste tyre from 0 to 1% with increment 0.25% by concrete volume was used to prepare the different concrete mixes.

2.1.6 Palm oil fuel ash

Palm Oil Fuel Ash is the product of burning palm oil husk and palm kernel shell in the palm oil mill. POFA obtained from Palm Oil Factory, in Sangir Dharmasraya, West Sumatera-Indonesia was used as cement replacement material on concrete.

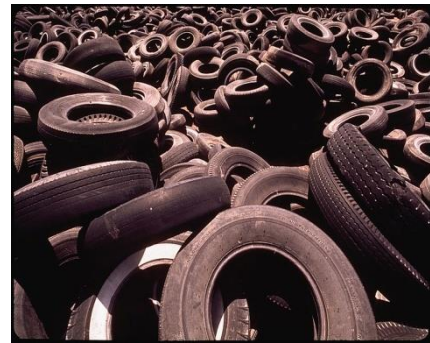


Fig. 1 Waste tyres



Fig. 2 Cutting process of waste tyre to obtain extracted steel fibers

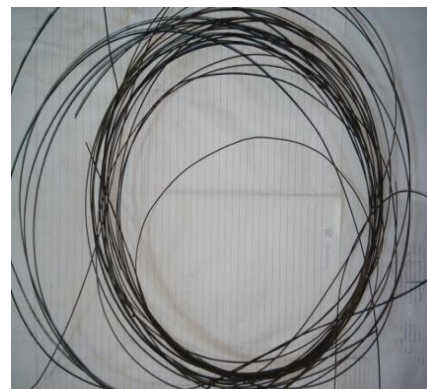


Fig. 3 Steel fibers extracted from waste tyre



Fig. 4 Steel fibers in 1 inch cut length



Fig. 5 Palm oil fuel ash

Table 3 Chemical composition of POFA

Chemical Composition	Formulae	Content (%)
Silicon Dioxide	SiO ₂	62.84
Aluminium Trioxide	Al ₂ O ₃	2.19
Iron Oxide	Fe ₂ O ₃	0.00
Lime	CaO	9.57
Magnesium Oxide	MgO	3.48
Potassium Oxide	K ₂ O	-
Loss of Ignition	LOI	-

The specific gravity of palm oil fuel ash was 2.30. The chemical composition of POFA was tested in Indarung II, Padang Cement Factory and the result was given in Table 3. Figure 5 shows the Palm Oil Fuel Ash.

3. EXPERIMENTAL STUDY

3.1 Mix Proportions of Concrete

Concrete containing POFA for the M26 grade was prepared based on Indonesian National Standard (SNI). A mix proportion of 1:2.18:3.28 with 0.52 water cement ratio to get a characteristic strength of M26 was considered for this study. Six mixture proportions were made. The first is control

mix (concrete without POFA and steel fiber), and the other five mixes are POFA concrete with the addition of steel fiber with percentage 0%, 0.25%, 0.5%, 0.75%, 1% of concrete volume. The Ordinary Portland Cement (OPC) is partially replaced by 15% POFA of concrete weight. The mix proportions of concrete are given in Table 4.

Table 4 Mix proportions of concrete

Sample ID	SF 0	SF 0.25	SF 0.50	SF 0.75	SF 1.00
Cement (kg/m ³)	332.3	332.3	332.3	332.3	332.3
Water (kg/m ³)	205	205	205	205	205
F.A. (kg/m ³)	725.6	725.6	725.6	725.6	725.6
C.A. (kg/m ³)	1088	1088	1088	1088	1088
SFEFWT (%)	0	0.25	0.50	0.75	1.00
POFA (kg/m ³)	58.65	58.65	58.65	58.65	58.65

3.2 Casting of Specimens

There are 45 specimens were cast, consist of 30 cylinders specimens for compressive and splitting tensile strength tests and 15 beam specimens for the flexural strength test.

Cylindrical moulds of 150 mm diameter and 300 mm length are used for casting the specimen for compressive and splitting tensile strength tests, respectively. For flexural strength test, beam specimen with the size of 100 x 100 x 500 mm is cast. The specimens are cast with 0%, 0.25%, 0.5%, 0.75% and 1% content of SFEFWT on concrete containing palm oil fuel ash. All specimens were cured for 28 days.

3.3 Testing of Specimens

Compressive, splitting tensile and flexural strengths of each specimen was determined using SNI 1974:2011, ASTM C 496-86 and ASTM C 293-08, respectively. Figures 6 and 7 show the cylindrical specimens under compressive and splitting tensile testing, respectively, and Figure 8 shows beam specimens under flexural testing in the laboratory.

4. RESULTS AND DISCUSSION

4.1 Compressive Strength

Table 5 and Figure 9 show the test result of the compressive test on POFA concrete with different percentage of steel fibers tested on the 28th day.



Fig. 6 Compressive test on cylindrical specimens



Fig. 7 Splitting tensile test on cylindrical specimens



Fig. 8 Flexural test on beam specimens

As shown in Table 5 and Figure 9, the compressive strength of POFA concrete reinforced with SFEFWT slightly increases as well as SFEFWT content. The percentage increases in the

compressive strength for the cylinder with steel fibers 0.25%, 0.50%, 0.75% and 1% compared to the cylinder without steel fibers are 4.54%, 7.57%, 10.22% and 12.5%, respectively. The maximum compressive strength with the addition 1.0% of SFEFWT in concrete containing POFA is 29.70 N/mm².

Table 5 Test result for compressive strength

No	POFA Content (%)	SFEFWT Content (%)	Comp. Strength (N/mm ²)	Increase (%)
1	15	0	26.40	-
2	15	0.25	27.60	4.54
3	15	0.50	28.40	7.57
4	15	0.75	29.10	10.22
5	15	1.00	29.70	12.5

*SFEFWT: Steel Fiber Extracted From Waste Tyre

*POFA: Palm Oil Fuel Ash

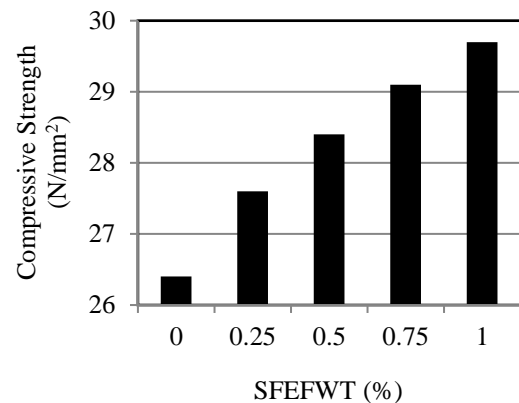


Fig. 9 Compressive strength vs. percentage SFEFWT content

It also can be seen from Table 5 that the higher percentage increases from every percentage in the compressive strength between 0% and 0.25%. The presence of SFEFWT contributes to give higher bonding; it increases the compressive strength of the POFA concrete.

4.2 Splitting Tensile Strength

The results of splitting tensile strength of POFA concrete mixed with SFEFWT measured on the 28th day are given in Table 6 and Figure 10. The results presented in Table 6 and Figure 10 show that the splitting tensile strength of the POFA concrete increases by rising SFEFWT content. The maximum increase 22.85%, i.e., 2.85 N/mm² as compared to concrete without having SFEFWT POFA; in addition, 1.0% SFEFWT is observed.

Table 6 Test result for splitting tensile strength

No	POFA Content (%)	SFEFWT Content (%)	Tensile Strength (N/mm ²)	Increase (%)
1	15	0	2.32	-
2	15	0.25	2.50	7.76
3	15	0.50	2.61	12.5
4	15	0.75	2.71	16.81
5	15	1.00	2.85	22.85

*SFEFWT: Steel Fiber Extracted From Waste Tyre

*POFA: Palm Oil Fuel Ash

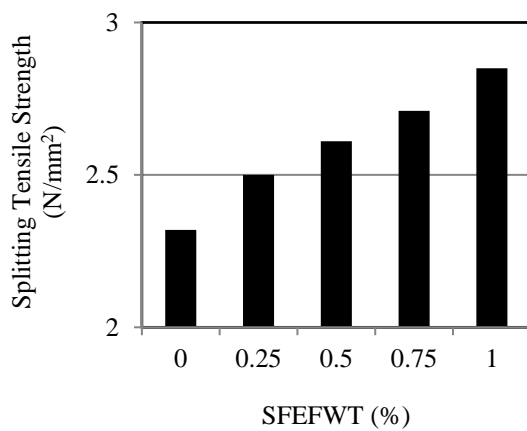


Fig. 10 Splitting tensile strength vs. percentage SFEFWT content

The splitting tensile strength in POFA concrete increase due to the inclusion of SFEFWT might be attributed to the mechanism of steel fibers in arresting crack progression. The presence of fibers in concrete restrains the development of internal micro-cracks and thus contributes to an increased tensile strength. Therefore, the increase in SFEFWT content leads to an increase in the tensile strength of concrete.

4.3 Flexural Strength

The results of flexural strength test at 28 days given in Table 7 and Figure 11 show the increase of flexural strength for different percentage of SFEFWT. The result indicates that the effect of SFEFWT on flexural strength of POFA concrete is very clear and it shows the benefit of SFEFWT to improve the flexural strength of POFA concrete. The flexural strength increases with rising in SFEFWT percentages on the specimen. The maximum flexural strength 5.50 N/mm² is obtained by the addition 1.0% SFEFWT, in which the maximum percentage increase the flexural strength is 31.27%.

Table 7 Test result for flexural strength

No	POFA Content (%)	SFEFWT Content (%)	Flexural Strength (N/mm ²)	Increase (%)
1	15	0	4.19	-
2	15	0.25	4.46	6.44
3	15	0.50	5.06	20.76
4	15	0.75	5.32	26.97
5	15	1.00	5.50	31.27

*SFEFWT: Steel Fiber Extracted From Waste Tyre

*POFA: Palm Oil Fuel Ash

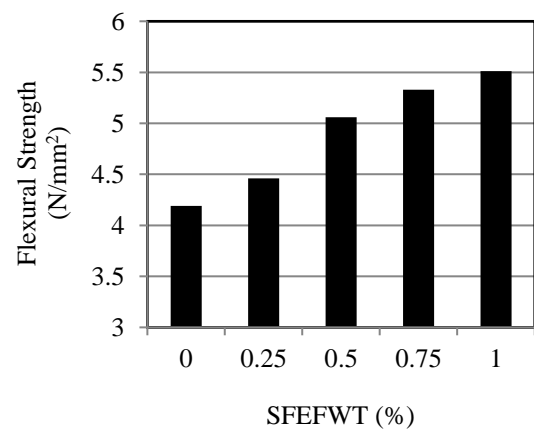


Fig. 11 Flexural strength vs. percentage SFEFWT content

The increase of flexural strength might be due to the superior performance in flexural strength for the specimen with SFEFWT arises from the improving fiber-matrix bond provided by using SFEFWT. In addition, the higher flexural strength of POFA concrete with SFEFWT is mainly attributed to the role of steel fibers in releasing fracture energy around crack tips, which is required to extent crack growing by transferring it from one side to another.

In this study, it is also observed that the addition of SFEFWT controls cracks opening on the POFA concrete during the flexural test. The load to fail the beam specimen has to be increased to cause more crack for the failure of POFA concrete with SFEFWT content. The more the steel fiber amount in concrete, the higher increase in flexural strength and bonding of POFA concrete so that it will control the crack opening width.

Figure 12 shows the beam specimen of POFA concrete containing SFEFWT after flexural strength testing. It is clearly seen from the figure that the steel fiber from waste tyre bridges across the cracked matrix, which will provide the higher bonding on the POFA concrete.



Fig. 12 Crack opening in POFA concrete with SFEFWT

5. CONCLUSION

- The addition of SFEFWT from 0.25% to 1% improves the compressive, splitting tensile and flexural strengths of POFA concrete.
- The maximum compressive strength with the addition 1.0% of SFEFWT in concrete containing POFA is 29.70 N/mm², which is 12.5% increment as compared to the POFA concrete without having SFEFWT.
- By adding 1% SFEFWT on POFA concrete, the maximum increase of splitting tensile test 22.85%, i.e., 2.85 N/mm² is observed as compared to the concrete without having SFEFWT.
- The maximum increase of flexural strength 31.27%, i.e., 5.50 N/mm² as compared to concrete without having SFEFWT; in addition 1.0% SFEFWT of concrete contains POFA.
- The addition of SFEFWT controls the crack opening on POFA concrete. The more the steel fiber amount in concrete results in the higher bonding on POFA concrete to restrain the development of internal micro-cracks.

6. ACKNOWLEDGEMENTS

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