The Flexural Strength of Post-Fire Concrete with the use of Waste Banner Fibers

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Abstract. The use of nylon fiber from the waste banner in this study was expected to be an alternative effort to reduce the negative impact of waste banner while improving the property of concrete that was a flexural strength as an effect of the character of nylon fiber that has high tensile strength. The purpose of this study was to determine the maximum value of the flexural strength of post-fire concrete resulting from the addition of waste banner fiber. 64 of beam samples in 150 mm of width, 150 mm of thickness, and 600 mm of length used to test the flexural strength of concrete. The variation of the waste banner fiber’s lengths was 30 mm, 60 mm and 90 mm while the combustion temperature used were 200 °C, 300 °C and 400 °C. The results of the study showed that 60 mm fiber’s length gave the highest flexural strength results compared to other fiber lengths. The higher the combustion temperature produces the decreasing of concrete’s flexural strength.

1. Introduction
Fiber Reinforced Concrete (FRC) has been successfully used in various civil engineering applications such as slabs [1], pre-cast products [2], lightweight concrete [3], structures in seismic regions [4], and many other applications. The main purpose of using FRP in concrete is to increase the energy absorption capacity and toughness of the material, as well as to increase the tensile and flexural strength of concrete [5]. Fibers of various shapes and sizes [6] produced from steel [7,8], polypropylene [9], glass [10], plastic [11] and natural materials [12] have been commonly used in FRC. With the increasing awareness of environmental conservation, the use of fibers made from waste material come to gain a lot of attention from the researcher as well as concrete industries. In this research, waste banner chosen as row material for fiber.

The banner sheet is consists of nylon fiber which covered by polyvinyl and used to called as Polyvinyl chloride (PVC) banner. PVC banner broadly used as momentary advertising media or an event’s backdrop. PVC is one of the plastic categories which generally made of thermoplastic resins [13]. The wastes of plastics have been becoming a serious problem in the world. Scientists estimate that during 1950 until 2015, approximately 6300 Mt plastic wastes were produced around the world, in which mostly (79%) was fill up the landfills or disposed in the environment [14]. The use of waste banner as fiber in FRC could be an alternative way to decrease the cumulation of plastic pollutant in a landfill as well as in the ocean.

The most severe hazards that may occur during the service life of a structure is fire. Many recent studies had reported the collapse of a structure due to fire. During 2017 there were 2055 building fire cases in Jakarta, Indonesia [15]. Most of the fire incidents caused the structure to collapse. Even if a
structure survives from a fire incident, the next question is whether or not the structure is safe to be used, and whether or not it needs repair. When the fire occurred in a structure made from fiber reinforced concrete, the uncertainties as to the remained strength would be higher because of the lack of knowledge on the performance of FRC reinforcing bars at high temperatures [16]. Since Polyvinil Chloride (PVC), banner’s raw materials, is a material with a very poor heat stability with maximum operating temperature around 140 °F (60 °C) when heat distortion begins to occur [17], so the assessment of the remaining strength of FRC with the waste banner after the fire is crucial to observe on the further use of the affected buildings and structures. The current study investigates the flexural strength of post-fire FRC with the use of waste banner as fiber.

2. Experimental
This study conducted by doing an experimental laboratory investigation of specimens prepared with various variations of fiber content for the flexural test.

2.1. Materials
Concrete main ingredients were fine aggregate, coarse aggregate, and Cement. The natural fine aggregate was used and taken from Merapi mountain’s quarry, which selected by sieving on sieves size and selected the fine gradation as shown in figure 1, while the physical properties of fine aggregate are listed in Table 1. This property confirmed with the standard from S-04-1989-F. The coarse aggregates were also taken from Merapi mountain’s quarry which crushed with the maximum size of 20 mm, and the physical properties of coarse aggregate are presented in Table 2. The Portland Cement Composite (PCC) manufactured by HOLCIM was used. It’s conformed to Indonesian specification of SNI 7064-2004 [18].

![Figure 1. The gradation of fine aggregates.](image)

| Characteristic       | Point | Standard from SNI | No. of SNI          |
|----------------------|-------|-------------------|---------------------|
| Water content        | 1.18% | 1-3%              | SNI 03-1970-1990    |
| Absorbtion           | 1.09% | <2%               | SNI 1970:2008 [19]  |
| Specific gravity     | 2.57  | 2.5-2.7           | SNI 1970:2008       |
| Fineness modulus     | 3.06  | 2.5-3.8           | SNI S-04-1989-F     |

Table 1. The Physical Properties of Fine Aggregates.
Table 2. The Physical Properties of Coarse Aggregate.

| Property       | Point | Standard from SNI       | No. of SNI               |
|----------------|-------|-------------------------|--------------------------|
| Specific gravity | 3.38  | 2.5 – 2.7               | SNI 1969:2008           |
| Absorbtion      | 1.07  | >3%                     | SNI 1969:2008           |
| Abration        | 9.32  | <50%                    | SNI 2417:2008           |
| Fineness modulus| 3.38  | 2.5-3.8                 | SNI 03-1968-1990        |

Waste banner used as fiber materials in a rectangular shape with a dimension of 2 mm in width and three variations lengths that were 30 mm, 60 mm, and 90 mm as shown in Figures 2.

Figure 2. Waste Banner Fiber.

2.2. Test specimens preparation
The dimension of specimens for the flexural test according to SNI 4154-2014 [20] was 150mm x 150mm for the cross section and 600mm for the length. Mix design concrete conducted according to SNI 7656:2012 [21]. Table 3 summarizes the result of mix design concrete.

Table 3. Mix design result.

| Materials      | Amount | Unit       |
|----------------|--------|------------|
| Cement         | 197.101| Kg/ m³     |
| Fine Aggregate | 874.883| Kg/ m³     |
| Coarse Aggregate | 988.393| Kg/ m³     |
| Water          | 204.523| Kg/ m³     |

Three variations of waste banner length, that were 30 mm, 60 mm, and 90 mm, added in the concrete mixture as much as 0.2% of concrete weight. The specimens prepared to be fired in three variation temperatures, that were 200 °C, 300 °C and 400 °C for one ours. Normal concrete with no fiber added nor firing also prepared as a control variable. Each variation consists of four specimens.

2.3. Castings of test specimens
Castings of beam concrete specimens were prepared to determine the flexural strength of waste banner FRC. The proses of concrete making start with mixing cement and natural sands together in the dry
state for about 3 minutes to obtain a uniform mixture. The next step was adding the water to the blend slowly and mixed into a homogeneous mixture. Then the coarse aggregates and waste banner fiber added, blend together till a uniform mixture was obtained. The mixing processes were performed using a 350-litre concrete mixer. The fresh concrete mixture then poured into the moulds and compacting using vibrator table.

After casting, the specimens were covered with wet burlap and left in the casting room at a temperature of (20±5) °C for a period of 24 h. The specimens were then de moulded and submerged in water for 26 days, and then placed in room temperature for a day before the specimens were burned in 200 °C, 300 °C, and 400 °C.

2.4. Testing
Four specimens of normal concrete and 60 specimens of waste banner FRC were tested to determine the residual flexural strength after exposure to high temperatures. All tests were performed at room temperature after the specimens had cooled down from the defined temperatures for each specimen. The flexural test using a simple beam with center-point loading was performed according to standard SNI 4154-2014 [20]. All concrete specimens were tested using Universal Testing Machine (UTM) with max capacity 50 Ton.

3. Results and Discussion
Table 4 summarizes the results of the residual flexural strength for all variations of waste banner length. The flexural strength data came from the average of four samples tested specimens for each type of concrete. The retained ratio in table 4 was calculated with respect to the flexural strength of concrete without combustion. The residual flexural strength of FCR with 60 mm length of waste banner fiber after combustion in 200 °C was higher than the other residual flexural strength of all variation of FRC which were observed in this study, that reached 3.58 N/mm². This point was approximately 76% and 7.8% greater than the retained strength of FCR with 30 mm and 90 mm length of the waste banner fiber, respectively. The retained ratio of all variation was above 50%. This result was in line with previous research which obtained that the strength of the concrete will be decreased to below 30% at 500 °C [16]. Hamdi & Kuba [22] from their research concludes that the mechanic degradations of normal concrete post-fired in 100 °C, 300 °C, and 600 °C were about 4%, 52%, and 65%, respectively. This degradation was caused by the decreasing in attachment between aggregates and cement paste, which is characterized by cracks and fragility of concrete or in the other word, concrete which is easily cracking.

Figure 3 shows the trend of the flexural ratio of all concrete variations in this study respect to the normal concrete as a variable control. From the figure noted that the higher the combustion temperature will reduce the flexural strength of the concrete, with the residual strength was around and above 50%. 
Table 4. Flexural strength test result.

| Waste banner length (mm) | Combustion Temperature (°C) | Flexural Strength (N/mm²) | Retained ratio |
|--------------------------|-----------------------------|---------------------------|----------------|
| 0                        | Without Combustion          | 4.72                      | 1.00           |
|                          | 200                         | 3.48                      | 0.74           |
|                          | 300                         | 2.73                      | 0.58           |
|                          | 400                         | 2.65                      | 0.56           |
| 30                       | Without Combustion          | 2.98                      | 1.00           |
|                          | 200                         | 2.03                      | 0.68           |
|                          | 300                         | 2.27                      | 0.76           |
|                          | 400                         | 2.32                      | 0.78           |
| 60                       | Without Combustion          | 4.39                      | 1.00           |
|                          | 200                         | 3.58                      | 0.82           |
|                          | 300                         | 2.80                      | 0.64           |
|                          | 400                         | 2.71                      | 0.62           |
| 90                       | Without Combustion          | 4.18                      | 1.00           |
|                          | 200                         | 3.32                      | 0.79           |
|                          | 300                         | 2.54                      | 0.61           |
|                          | 400                         | 2.32                      | 0.56           |

Figure 3. The ratio of flexural strength.
Fiber used as substitution material in the concrete mixture will shrink and lose ductility drastically if it is exposed to temperatures above 200 °C which causes the fiber material can no longer withstand the given flexural load. The resistance of FRC to high temperatures is lower than that of normal concrete. The decrease of the flexural strength of the beam in post-fire concrete is due to the water content that will evaporate when the concrete is heated. Tjokrodimulyo [23] said that the loose of strength occurs also due to gradual changes in chemical composition in the cement paste.

4. Conclusion
An experimental study has been carried out to investigate the flexural strength of post-fire FRC with the use of waste banner as fiber. 60 specimens prepared with three variations of waste banner length, that were 30 mm, 60 mm, and 90 mm, then fired in three variation temperatures, that were 200 °C, 300 °C and 400 °C. According to the experimental result, the variation in fiber length that produces the highest flexural strength of all variations used in this study was at 60 mm fiber length with a combustion temperature of 200 °C that was 3.58 Mpa.

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