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The Connection Model of Segmental Precast Concrete Beam Reinforced with Recycled Tyre

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Abstract. Segmental precast reinforced concrete with waste tyre as reinforcement is one method of simplifying and speeding up the installation of on-site concrete structures. This study determines the connections between segmental precast reinforced concrete and waste tyre as reinforcement. The dimensions of the specimens used in the experiment are 15 cm × 15 cm × 50 cm. The size of recycled tyre as reinforcement used is 10 mm x 10 mm in cross section view. One specimen is concrete beams with waste-tyre reinforcement as a standard test specimen. Four other specimens are in the form of segmental precast concrete beams with segmental connector lengths of 10 cm, 15 cm, 20 cm, and 25 cm. Furthermore, concrete beam specimens are tested to investigate their flexural capacity with a three-point loading method. The results show that the length of the reinforcement fitting does not significantly affect the flexural strength of the beam. The flexural strength capacity of concrete beams reinforced with recycled tyre with these connectors is approximately 10 kN.

INTRODUCTION

In recent decades, many types of solid waste materials are produced by human activities. Solid wastes include glass, plastic, tires, beverage bottles, demolished concrete, and demolished asphalt pavement. Recovery of waste is a good strategy and material for creating green buildings. Recycled concrete aggregate was studied in order to understand the commercial feasibility of those aggregates [1]. In the study, four simulation of business model are investigated. The production of recycling demolished concrete aggregate studied are set as 100 and 50 ton per hour constant supplied plant, and 100 and 50 ton per hour uncertain supplied plant. The results show that the constant supplied plant is the most profitable than others.

In line with the increase in demolished concrete waste, tyre wastes have also increased dramatically in every country around the world. One million, 3 million, and 4 million ton of tyre waste were produced by Japan, USA, and European Union. Even, the production of tyre waste is also very high in Indonesia as a developed country. This is driven by the growing number of vehicle usage. The number of vehicles in Indonesia is very large. Even after the Indonesian government issued a policy on low-cost green cars (LCGCs), car ownership in Indonesia increased dramatically. This has a linear impact on the use of tyres. As a result, the quantity of tyres waste jumped sharply. Fifty million tyres were produced in 2013. The domestic consumption of tyres is around 20 million tyres per year. Furthermore, the amount of tyre waste is equal to approximately 20 million tonne per year. This quantity will increase due to acceleration of vehicles production and ownership in Indonesia. Negative side effect emerges when tyre waste is disposed in open areas and a huge space is required to dispose them. A breakthrough is required to reuse tyres waste with a safe, cheap, and useful method [2]. Another research also investigate other waste materials such as mineral and slag wastes [3]. They obtained that flexural strength of concrete with mineral fibres increase expressively. The waste scrapped tire rubbers is utilized as a fine aggregate to produce Asphalt Concrete (AC)

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mixture. The results show that it increases the resistance of the pavement in high temperature and load, and at the same time, it escalates the resistance to permanent deformation caused by rusts.

The physical condition of old tyres soaked in sea water as deep as 24 m for 42 years was examined and determined in depth [4]. The tyres had not suffered serious damage. Pieces of tyre (tyre granulate) are very resistant to chemical attack in acidic environments, according to a study conducted by some researchers [5]. Pieces of tyre (tyre granulate) can ignite at temperatures above 322ºC [6]. The density of tyre pieces ranges from 1.8 to 1.27 t/m^3 [7-9]. Another reused of recycle tyre as powdered tyres is applied to replace sand in concrete [10]. Meanwhile, tyre chip contents of 2.5, 5, 7.5, and 10% are added and used in the mortar and discover that higher flexural strength is obtained compared to ordinary mortar [11]. Flexible pavement components made of waste scrapped tire rubbers is proposed as an alternative materials [12].

The difference in volume and in the size of scrap rubber from 0.9 to 0.29 mm in concrete also reduce the compression capacity of concrete [13]. The effect of additional waste rubber contents of 10, 15, 20, and 30% is investigated in order to determine the durability of concrete and the results show that concrete with waste rubber has a higher value in durability compared to normal concrete [14].

Furthermore, it states that the use of rubber made the concrete lighter and more impact resistant, tough, ductile, and soundproof [15]. Another research on rubber-modified concrete with particle sizes of 4.2 and 1.85 mm is conducted to describe the effect in the properties of concrete. The results show that there is a little influence on the compressive capacity, brittleness, and plasticity of rubber-modified concrete [16].

Research on tyre waste with greater size is conducted by previous researchers [17]. The dimension of tyre waste 10 x 15 x 920 mm is applied in the reinforced concrete to replace steel bar. The flexural capacity of concrete with waste tire is lower about 45% than concrete reinforced with steel bar. Unfortunately, the advantage of higher strain of the waste tire does not utilized in those study.

The corrosion crack in reinforced concrete is affected by pre-stressed force [18-20]. The idea of pre-stressed force contribution in the corrosion crack is applied in recycled tyre as reinforcement. The latest study on recycled tyre with pre-stressed usage in concrete is conducted and applied it in a simple beam. The recycled beam is stretched to 17% of its strain capacity and then jacked on the concrete [1]. The flexural strength of concrete reinforced with recycled tyre is higher than that of concrete without waste tyre reinforcement. This is because tyre waste transfers the pre-stressed force onto the beam. Consequently, the flexural strength increases. Unfortunately, the connection between segments of precast concrete with the recycled tyre as reinforcement has not been designed yet. This research aims to study the model of connections between segments of concrete beam.

EXPERIMENTAL METHODS

The experiment is performed at a laboratory scale. A preliminary test is done to investigate the quality of crushed stone and river sand. The characteristics considered are the specific gravity, density, clay content, and gradation of aggregate. Therefore, the concrete mix proportion is composed based on the preliminary aggregate test to meet the expected quality of concrete. The materials, equipment, procedure for making specimens, and type of testing are described in more detail below.

Materials and Equipment

The materials utilized in the study are cement type I, crushed stone, sand, water, recycled tyre, pipe with a diameter of 8 mm, pipe clamps, and steel rods with a diameter of 8 mm, and nuts. Figure 1 and 2 show the recycled tyre and pipe clamp. The equipment comprises a universal testing machine, concrete mixer, sieve, balance, slump test equipment, and mould for the concrete beam. Concrete with compressive strength of 15 MPa is considered. The mixed design of concrete is shown in Table 1.

TABLE 1. Mixed design of concrete, 15 MPa

Weight of materials (kg/m^3)			
Cement	**Crushed stone**	**Sand**	**Water**
360	1,070	775	205

FIGURE 1. Recycle tyre

FIGURE 2. Pipe clamp

Procedures of Making Specimen

The precast concrete moulds are set up. The form work is installed for the connection between the precast concrete segments. The form work is connected by a pipe with a diameter of 8 mm to another form work different precast concrete segments. The recycled tyres, and consisting of 10 pieces with dimensions of 10 mm × 10 mm, are inserted as reinforcement as can be seen in Fig. 3. The pipe clamps are installed at each end of the recycled tyre as shown in Fig. 4.a. Four cubic holes with size of 25 mm is made on the upper and lower layer of segmental beam as indicated in Fig. 4.b and 4.c. In order to make those cubic holes, form work from solid wood is installed in the form wok of concrete beam as presented in the Fig.5.

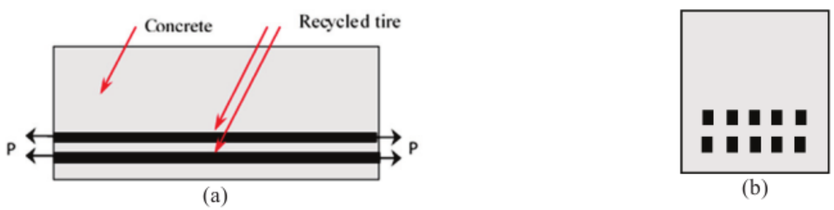

FIGURE 3. Process of stretching the recycle tyre, (a) long section, (b) cross section

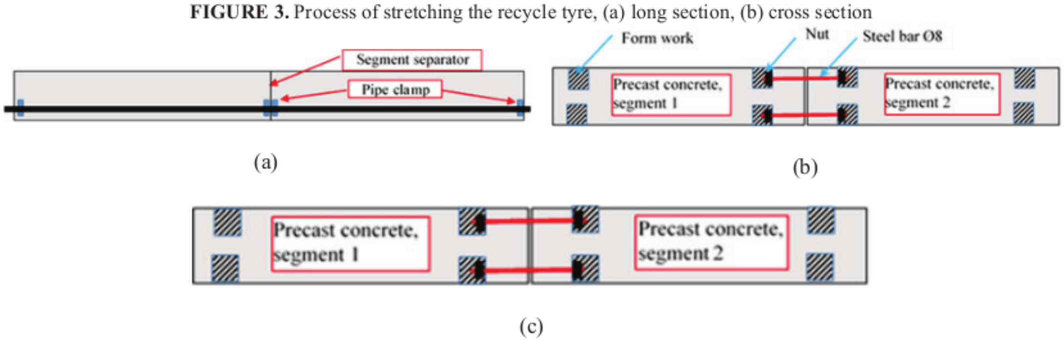

FIGURE 4. Connector between segments of precast concrete, (a) position of pipe clamp as anchorage, (b) top view of connection of precast concrete, (c) side view of connection of precast concrete

Hole for steel bar with 8 mm diameter is created by placing the Polyvinyl Chloride (PVC) pipe diameter 0.5 inch in the form work. The recycled tyre reinforcement is stretched until its length reaches 140% of the initial length. The scheme of tyre waste elongation can be seen in Fig. 3. The fig illustrates what happens when the recycled tyre is pulled by force, P. A scheme of the connector between segments of precast concrete beam is shown in Fig. 4. Figure 5 presents the real process of specimen preparation. The number of specimens used in this study are five pieces. One specimen has no connector between the segments of precast concrete. Four specimens have connectors between segments of precast concrete. The lengths of the connectors are 10, 15, 20, and 25 cm. The dimensions of the concrete beam are 15 cm × 15 cm × 100 cm.

After the preparation is completed, the fresh concrete is cast into the mould. The mould is removed when the concrete has aged for one day and finally the hardened concrete specimen is obtained. The next step is curing the specimen using a wet mattress for 28 days. After that, the segments of precast concrete with recycled tyre as reinforcement are ready to be connected with each other. The specimen with dimensions of 15 cm × 15 cm × 50 cm is connected with four pieces of steel rod with a diameter of 8 mm and stopped using a nut at the end of each side. The lengths of the connection rods are 10, 15, 20, and 25 cm. The hole in the location of the nut is then filled using mortar. Figure 6 shows the fixing of the nut at the connection between two specimens of precast segmental concrete. After the nuts are fixed, then the holes of nuts was covered by mortar. The mortar used is composed by cement, sand and water. The proportion is identic with mix proportion of concrete without crushed stone.

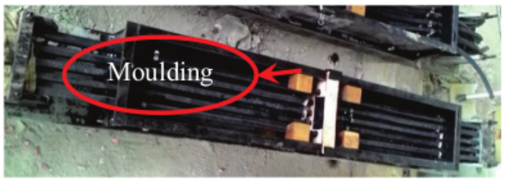

FIGURE 5. Setting up of segmental precast concrete in the experimental

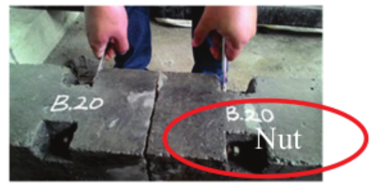

FIGURE 6. Fixing the nut on the connection of precast segmental concrete

Testing Procedures

This testing refers to [21], which is used to investigate the flexural capacity of the concrete beam. Figure 7 represents the flexural testing using three-point loading based on the standard. The following process is conducted. The load is placed on the two supports in contact with the surface of the specimen at the third point. The load is applied in range 3 and 6% of the estimated maximum load. The loading is burdened on the specimen slowly to avoid sudden load. The load is generated at a stable rate to the rupture point. When the failure is started in the tension layer within the middle third or the distance length, the modulus of rupture is calculated by Formula 1.

$$R = \frac{PL}{bd^2} \tag{1}$$

If the crack failure occurs in the tension layer located in the outer of the middle third of the distance by not more than 5% of the distance, the modulus of rupture is calculated by Formula 2.

$$R = \frac{3Pa}{bd^2} \tag{2}$$

In the equation, R is the modulus of rupture in MPa (Mega Pascals), P is the greatest applied load indicated Universal Testing Machine in N (Newton), L is the distance between two supports in millimetres, b is the width of the sample at the located failure in millimetres, d is the depth at the located crack in millimetres, and a is the average distance between the lines of the cracks and the closest support calculated on the surface tension of the beam sample.

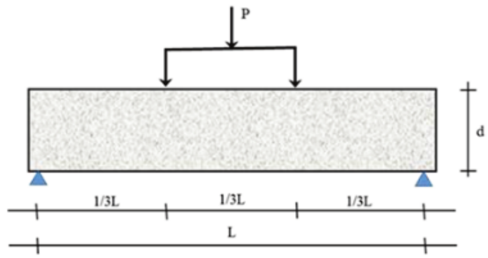

FIGURE 7. Set-up of flexural strength test

RESULTS AND DISCUSSION

Compressive Strength of Concrete

The testing of compression for concrete is performed in the laboratory by using Universal Testing Machine in order to confirm that the mix design of concrete as perform in the Table is in accordance to the initial design. A cylinder with diameter of 150 mm and height of 300 mm is employed based on SNI 03-2847-2002 [22]. The three samples are soaked in the fresh water for 28 days. The specimens should be placed in the temperature room for 3 hours prior to the compression test. The results of compressive strength are 16.75 MPa, 16.25 MPa, and 16.45 MPa. The average data of compression is 16.45 MPa. The initial designed of concrete is 15 MPa and can be achieved by compressive strength of those testing cylinder.

Crack Patterns

The rupture model or crack pattern of the specimen can be seen in Fig 8. Specimens with connectors 10, 15, 20, and 25 cm long and without connectors are shown as Figs 8.a–e, respectively. According to these figs, the cracks can be described as occurring in the middle third of the specimens. This means that the rupture is generated by the bending moment. The opening crack is initiated on the bottom side of the beam and then propagates to the top side of the beam. The simple reason for this is that the bottom side supports the highest tensile load during the testing. Most of the cracks also occur in the concrete around the end of the connector and are not followed by breakage of the steel bar.

Figure 8.a shows that the crack occurs on the left side connector of the beam. The crack only appears in one path, in which there is no branch of crack produced in specimen with connector length of 10 cm. Unlike Fig 8.a, the specimen with connector length of 15 cm, as shown in Fig 8.b, has branches of crack when the crack reaches around 4 cm from the bottom of the beam. Figure 8.c and 8.d have similar tendency of pattern with Fig 8.a. Only one crack is generated on the beam. The crack is located and occurs on the left side of connector for specimen with connector of 20 mm. On the other hand, for specimen with 25 cm connector, the crack is built up on the right side of the connector between two segmental beams as shown in Fig 8.d.

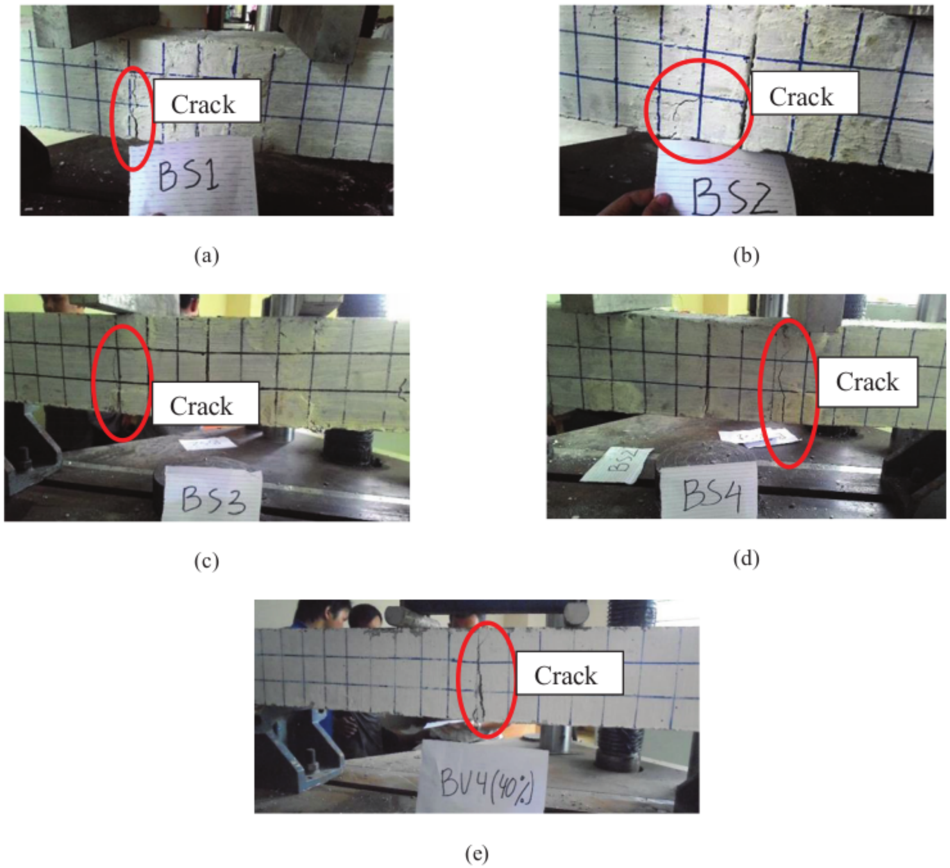

FIGURE 8. Crack pattern of the specimens, (a) specimen with connector length of 10 cm, (b) specimen with connector length of 15 cm, (c) specimen with connector length of 20 cm, (d) specimen with connector length of 25 cm, (d) specimen with connector length of 40 cm

Flexural Strength

Figure 9 shows the result of the flexural strength tests of specimens with connector lengths of 10, 15, 20, and 25 cm and without connectors, consecutively. These figs show the correlation between displacement on horizontal axis and load on vertical axis. The figs show that all the specimens with connectors have maximum loads of around 10 kN. This means that the length of the connector does not make a significant contribution to supporting the external load. After the initial crack occurs in the concrete, the capacity of the beam to support the external load suddenly decreases, but the beam does not collapse totally. It still retains the capacity to support a load of around 4–6 kN.

Even when the displacement of the beam reaches 5–6 mm, the concrete beams are constantly stable on the support. The phenomenon also occurs in the concrete beam without connectors. On the other hand, the deflection is higher with increasing length of segmental connection. When the maximum force is reached, the values of deflection are 2.4, 2.6, 5.5, 6.2, and 6.2 mm for beams without connectors and with connector lengths of 10, 15, 20, and 25 cm respectively.

The Modulus of Rupture (MOR) of the beam can be calculated according to Equation 1. The result is 0.475, 0. 528, 0.475, 0.475, 0.488 and 0.555 MPa for concrete beam with connector length of 10, 15, 20, 25 cm and without connector respectively. Based on those results, it shows that concrete beam with connector length of 15 cm has a maximum modulus of rupture. This modulus of rupture (MOR) value is still smaller than MOR value of precast concrete beam reinforced with recycled tyre without connector. However, the difference in value can be neglected because the difference is very small.

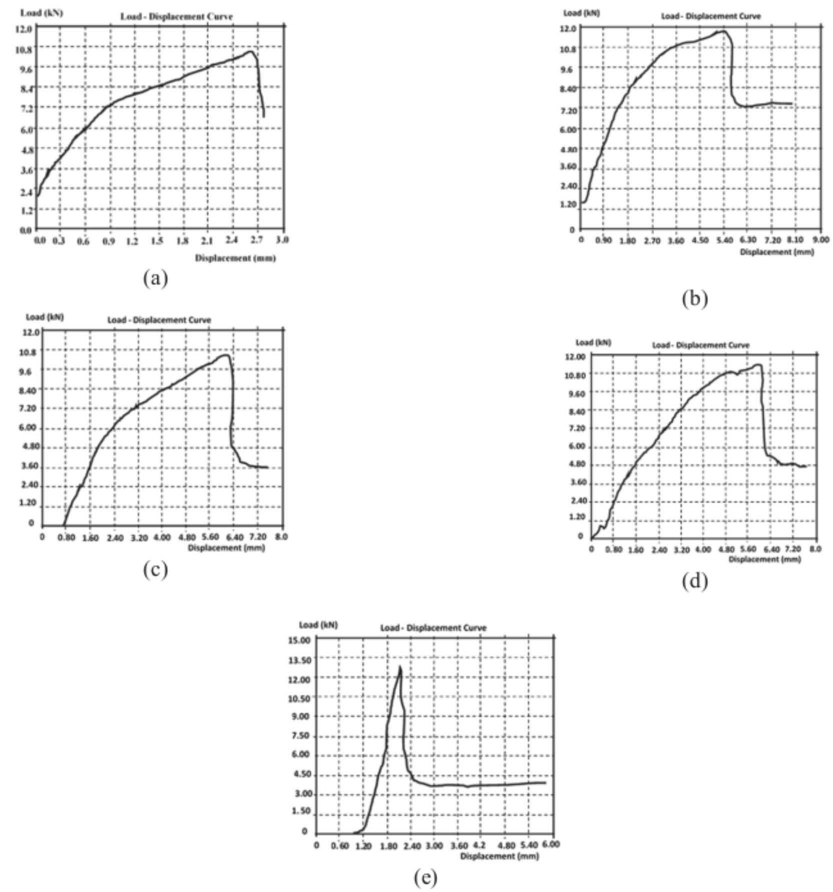

FIGURE 9. Relationship between load and displacement, (a) connector length of 10 cm, (b) Connector length of 15 cm, (c) Connector length of 20 cm, (d) Connector length of 25 cm, (e) Connector length of 40 cm

Another advantage of precast concrete beam reinforced with recycled tyre with connector is the fact that it has higher remain load after the occurrence of first crack if compared to concrete beam without connector. It can be observed based on Fig 9.a-e that the remain loads of concrete beams with connector length of 10, 15, 20 and 25 cm are 7.1, 7.2, 3.6 and 3.8 kN, respectively. On the other hand, concrete beam without connector has remain load of 3.2 kN.

CONCLUSIONS

According to the discussion in the previous section, the conclusions can be summarized as follow:

1. The length of the connector in segmental precast concrete beams reinforced with tyre waste does not make a significant contribution.
2. The length of the connector in the concrete beam affects only the amount of deflection when the maximum load is reached. The longer the connector, the higher the deflection.
3. A steel bar with a diameter of 8 cm is sufficiently robust to serve as a connector in segmental precast concrete beams reinforced with tyre waste.
4. The Modulus of Rupture (MOR) is 0.475, 0. 528, 0.475, 0.475, 0.488 and 0.555 MPa for precast concrete beam reinforced with recycled tyre and with connector length of 10, 15, 20, 25 mm and without connector respectively.
5. The remain load of precast concrete beam reinforced with recycled tyre and with connector length of 10, 15, 20 and 25 cm and without connector are 7.1, 7.2, 3.6, 3.8, and 3.2 kN, respectively.

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