Mechanical properties of crumb rubber-rice husk ash concrete as a rigid pavement material

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Abstract. Waste tyres accumulate very quickly in a landfill as a result of the fast development of the transport industry, and mainly automobiles. The polymeric waste has limited usage and is rarely employed in a highly economic and viable product. A rigid pavement material needs to have high mechanical properties and durability when exposed to aggressive environments. In this research, a combination of waste tyre with rice husk ash and Portland Cement Composite (PCC) as a primary binder was designed to produce concrete that meets the requirements of flexural strength value of the rigid pavement based on the Indonesian Standard from Bina Marga 2018. Eight mixes with a variety of water/cement ratio (0.30-0.40), crumb rubber (2.5-7.5%), and rice husk ash (7.5-10%) were designed in this research. The control mix was PCC concrete. The crumb rubber substituted the fine aggregate content, while the rice husk ash replaced the cement content in concrete. The specimens were cast and subsequently cured in water pond up to 28 days. The mechanical properties of concrete, namely compressive strength and flexural strength were determined for all variations. Based on the results, Mix 1 with w/c ratio of 0.30, crumb rubber of 5%, and rice husk ash of 10%, performed both the highest compressive strength and flexural strength values of 36.38 MPa and 4.53 MPa, respectively, after 28 days. Both values fulfilled the requirements of the Indonesian Standard Bina Marga 2018. It can be concluded that an appropriate combination of crumb rubber and rice husk ash improves the mechanical properties of the concrete and has potential as a rigid pavement material.

1. Introduction

The rigid pavement is another type of road pavement which uses concrete as the primary construction material. The rigid pavement is more competitive as a road construction material because it has long term service life because of its higher strength, better durability, and lower maintenance cost than the asphalt pavement [1]. Since concrete is a brittle material, the rigid pavement cannot withstand a huge tensile load, and in time fine cracks gradually occur in the concrete. Rigid pavement is required to have a flexural strength of minimum 4.5 MPa, according to the Directorate General of Highway Construction and Maintenance (Bina Marga) General Specification 2018 [2]. Instead of using steel reinforcement, an addition of fibre-shaped material could be an alternative to increasing the toughness and elastic properties such as tensile and flexural strength of the concrete [3].
Waste tyres have been accumulating in the landfill as a result of the fast development of the automobile industry. Based on Central Bureau of Statistics data (BPS), an increase in vehicles in the Riau Province, Indonesia by around 8.8% per year, from 104,118,969 units in 2013 to 114,209,266 units in 2014 [4]. Various tyres from cars, trucks, motorbikes, and bicycles are made of rubber, which seems more suitable as fine aggregate replacement in concrete due to its high-performance product and recycling opportunities [5]. Tyre waste in many forms, such as ash, chip, shredded, crumb, fibre, and particles were studied by many researchers [6-10]. Thomas & Gupta [11] and Gupta et al. [12] have listed the effects of adding rubber material to concrete. The rubber could decrease the compressive strength, increase flexural strength as the percentage of rubber fibres in concrete increases, decrease density and workability, decrease modulus of elasticity, increase flexibility, increase chloride ions and acid resistance, and improve high-temperature environmental resistance. Strength loss in concrete indicates poor adhesion between the cement matrix and the rubber, and also weaker or more elastic crumb rubber as aggregate replacement than the natural aggregate [13].

Furthermore, crumb rubber with an average particle size between 0.075 to 4.75 mm has been used as an additive in concrete mixtures since it could withstand sudden cracks and the separation of the concrete after the failure due to the impact load [14]. Crumb rubber increases the flexural strength values of the concrete because of its high elastic properties, though the difficulties encountered during the compaction of fresh concrete decreases concrete density and the corresponding strength [10, 15]. However, this material promises to improve rigid pavement performance under tensile loads on soft or problematic soil with low-bearing capacity and continuous loading that causes wide and accumulated cracks in the long term.

The incorporation of pozzolanic materials from solid industrial waste such as fly ash and waste tyre in concrete aims to reduce waste accumulation in the landfill and improve permeation properties [10]. The pozzolanic reaction caused by the waste is also a reason for a subsequent increase of the compressive strength. Rice husk ash as the pozzolanic materials has a high silicate content, are mainly used to replace cement to provide a beneficial reaction for concrete tightness. Rice husk ash from rice husk combustion in rice mills has silica content of more than 80% [16]. According to one study, the mechanical properties of concrete decreases as the rice husk ash content increases [17]. The rice husk ash replaced the cement by 0, 2, 4, 6%, and the crumb rubber content as a sand replacement was constant at 10%.

Abdurrahman et al. [15] in his previous study highlighted the optimum crumb rubber and rice husk ash proportion. The optimum proportion was 30% and 10% with the average flexural strength of 3.1 MPa. However, the result does not comply with the Bina Marga General Specification 2018 for the rigid pavement design [2]. Hence, in this research, the effects of various combinations of crumb rubber and rice husk ash by evaluating their mechanical properties to obtain the optimum mixture composition that meets the specification of Bina Marga 2018 were investigated.

2. Materials and methods

Portland Cement Composite (PCC) from Padang, West Sumatra, Indonesia, was used as the main binder. The rice husk ash was taken from Kampar Regency, Riau. Chemical composition of PCC and the rice husk ash are displayed in table 1. Coarse and fine aggregates had a specific gravity of 2.59 and 2.55, respectively. Water absorption of both coarse and fine aggregates were 0.28% and 3.62%, respectively.

In this research, a range of parameters was set to obtain an optimum mixture composition of the crumb rubber concrete. The parameters were water/cement (w/c) ratio, crumb rubber percentage, and the rice husk ash percentage. The parametric study to obtain the optimum mixture was set to identify the effects of different variables by varying each variable and leaving the other variable fixed. As shown in table 2, the w/c (water to cement) ratio ranged between 0.3-0.4, the amount of crumb rubber added had a variation of 2.5%, 5%, 7.5% by fine aggregates volume, and the amount of RHA was 7.5%, 10%, 12.5% by cement volume. Those values were determined based on previous studies [15]. The three range sizes of crumb rubber, i.e. 2-4.75 mm, 0.6-2 mm, and 0.075-0.6 mm, were mixed in
specific percentages of 25%, 35% and 40%, respectively, to ensure a homogeneous composition of the concrete mixture. Plain PCC concrete samples without crumb rubber and rice husk ash were manufactured as a control mix.

Table 1. Chemical compositions (wt %) of cement and waste used in this study.

| Oxides (%) | Portland Composite Cement (PCC) [18] | Rice Husk Ash (RHA) |
|------------|--------------------------------------|---------------------|
| SiO₂       | 23.04                                | 86.92               |
| Al₂O₃      | 7.40                                 | 1.41                |
| Fe₂O₃      | 3.36                                 | 0.48                |
| MgO        | 0.63 [19]                            | 1.01                |
| CaO        | 57.38                                | 1.77                |
| Na₂O       | -                                    | 0.05                |
| K₂O        | -                                    | 0.98                |
| Na₂O+0.658K₂O | 0.52 [19]                             | -                   |
| P₂O₅       | -                                    | -                   |
| SO₃        | 1.78 [19]                            | 0.46                |
| LOI        | -                                    | 7.63                |
| Others     | 5.89                                 | -                   |

Table 2. Parameters used in this research.

| Mix | w/c ratio | Crumb rubber | RHA |
|-----|-----------|--------------|-----|
| 1   | 0.3       | 5%           | 10% |
| 2   | 0.35      | 5%           | 10% |
| 3   | 0.4       | 5%           | 10% |
| 4   | 0.3       | 2.5%         | 10% |
| 5   | 0.3       | 7.5%         | 10% |
| 6   | 0.3       | 5%           | 7.5%|
| 7   | 0.3       | 5%           | 12.5%|
| Control | 0.3     | 0%           | 0%  |

Table 3. Mixture composition for each mix variation.

| Mix | Coarse agg. (kg) | Fine agg. (kg) | Cement (kg) | Water (kg) | Crumb rubber (kg) | RHA (kg) | Superplasticizer (kg) | Slump (mm) |
|-----|------------------|---------------|-------------|------------|-------------------|----------|-----------------------|-----------|
| 1   | 38.50            | 22.87         | 27.80       | 8.56       | 0.30              | 0.20     | 0.28                  | 80        |
| 2   | 38.50            | 26.18         | 23.82       | 8.46       | 0.34              | 0.16     | 0.24                  | 205       |
| 3   | 38.50            | 28.64         | 20.86       | 8.70       | 0.36              | 0.14     | 0.21                  | 240       |
| 4   | 38.50            | 22.87         | 27.80       | 8.56       | 0.15              | 0.20     | 0.28                  | 95        |
| 5   | 38.50            | 22.87         | 27.80       | 8.56       | 0.45              | 0.20     | 0.28                  | 65        |
| 6   | 38.50            | 22.87         | 27.80       | 8.56       | 0.30              | 0.15     | 0.28                  | 110       |
| 7   | 38.50            | 22.87         | 27.80       | 8.56       | 0.30              | 0.24     | 0.28                  | 55        |
| Control | 38.50     | 22.87        | 27.80       | 8.56       | 0.00              | 0.00     | 0.28                  | 150       |

The concrete samples were designed with a target compressive strength of 35 MPa and a flexural strength of 4.5 MPa. The mixture composition of all the mixes studied are shown in table 3. Superplasticizer was added by 1% of cement weight to increase the workability of those mixes. Specimens for compressive strength test were produced using 105x210mm cylinders and
150x150x600mm for the flexural strength test. Triplicate samples were used for each variation. The specimens were cast and subsequently treated in the water pond for 28 days. A slump test was conducted using the Indonesian National Standard (SNI) 03-1972-1990. Strength tests were conducted as per SNI 03-1974-2011 for the compressive strength, and per SNI 03-4431-2011 for the flexural strength.

3. Results and discussion

3.1. The effect of the w/c ratio on mechanical properties

Figure 1(a) displays the effect of the w/c ratio on compressive and flexural strength at 28 days. In general, as the w/c ratio decreases, the compressive strength increases since there is less water in the mixture [20, 21]. In the case of the control mix, the compressive strength at 28 days was 4% less than the target strength of 35 MPa. It was quite challenging to attain a target strength of 35 MPa at 28 days since the PCC concrete usually had a slow strength gain in early age. Mix 1 with w/c ratio of 0.30 performed the highest compressive strength of 36.38 MPa compared to other mixes. The mix contains 5% crumb rubber and 10% RHA which influences its workability (table 3) and the corresponding strength at 28 days.

The flexural strength of the concrete with a different w/c ratio at 28 days is shown in figure 1(b). Following the norm, as the w/c ratio increases, the flexural strength also increases for both mixes 1 and 3. However, mix 2 showed a different result since it had the lowest flexural strength compared to the other combinations. The mix had a high slump value (table 3), but the flexural strength had significant plummeted maybe due to a very poor interlocking between all the elements in the mixture. The control mix had a flexural strength of 4.27 MPa, which was lower by 5.1% than that of Mix 1 with the same w/c ratio. The flexural strength of the control mix followed the compressive strength trend, a slow strength gain of the PCC concrete (control) without any additive at 28 days. Based on this study, it is recommended to use a w/c ratio of 0.3 since as compressive strength increases, flexural strength also increases.

3.2. The effect of crumb rubber on mechanical properties

Figure 2 shows the influence of crumb rubber on compressive and flexural strength of the concrete. In figure 2(a), the compressive strength increased with the crumb rubber quantity but decreased after reaching its optimum value of 5%. The results indicate a lack of adhesion between the cement paste and the crumb rubber with an increase of the crumb rubber content to 7.5% in concrete. Similar findings were also reported in previous studies with a different maximum percentage of crumb rubber.
According to Ganjian et al. [22], a decrease of compressive strength with an increase in crumb rubber content in the mixes could be due to several reasons, i.e. soft cement paste containing rubber particles, different constituent materials, and ununiform distribution of rubber particles in the concrete. Furthermore, the crumb rubber was added in the mixture by volume of the fine aggregates; hence, the mix becomes not workable with very low slump ash as shown in table 3.

Elastic properties such as tensile and flexural strength are important measurements to show how stiff or flexible the material is under a compressive load. Based on figure 2(b), the flexural strength increases with crumb rubber contents as opposed to the compressive strength. Mix 5 performed a higher flexural strength of 8.56% than that of the control mix at 28 days. A high strength gain could be due to the filler effect of the crumb rubber that improves the stress resistance of the beam. Su et al. [24] reported the rubber particle sizes affected the strength gain/loss of the flexural beam. The smaller the particles, the lesser the strength loss due to improved strength and reduced likelihood of fracture in the samples. Other findings explained the role of crumb rubber as reinforcement to prevent immediate failure when a crack develops in concrete during flexural strength test [25-26]. Based on the laboratory results, the Mix 1 has satisfied Bina Marga 2018 requirements for both strength values; then it is recommended to use 5% crumb rubber as a pavement material in concrete.

![Figure 2. The effect of crumb rubber on (a) compressive and (b) flexural strength values at 28 days.](image)

### 3.3. The effect of rice husk ash (RHA) on mechanical properties

The rice husk ash as a pozzolanic material has an impact on improving the strength and density of the concrete in the long term. A correlation between the compressive strength and rice husk percentage is shown in figure 3(a). There was an increase in the strength by 7.94% of 10% rice husk ash (RHA) concrete than the control mix at 28 days. However, a slight decrease of strength was observed for concrete with 12.5% of RHA. The RHA was reported to improve the concrete’s strength in a certain percentage [25-28]. Inclusion of rice husk ash above the optimum value could reduce workability, thus increasing porosity and reducing the compressive strength. In this study, the optimum value of the RHA was 10%, which shows a proportionate amount of this additive for the concrete mixed with crumb rubber.
Figure 3. The effect of rice husk ash (a) compressive and (b) flexural strength values at 28 days.

3.4. The optimum mixture based on values of the mechanical properties

It is also interesting to notice the effect of RHA content in the concrete. Mix 4 with 2.5% crumb rubber and 10% RHA performed smaller strength level than Mix 1 that had more crumb rubber and similar rice husk ash content in the mix. In one study, concrete using crumb rubber only without RHA showed a reduction of the compressive strength [17]. A proportional mixture combination of crumb rubber and RHA leads to a better distribution of the materials in the concrete matrix, improving porosity and thus producing a better compressive strength than other mixes.

A rigid pavement undergoes repetitive loading from vehicles and cracks usually develop later in the structure. A high strength rigid pavement concrete is beneficial as it can overcome the external load and reduce the possibility of immediate cracks developing in the early stages of its service life. To obtain the optimum crumb rubber and RHA content, the compressive and flexural strength for each mix must not exceed the minimum requirement for rigid pavement design by the Indonesian Standard Bina Marga 2018 [2]. As shown in table 4, Mix 1 produces compressive and flexural strength values at 28 days that comply with the National Indonesian Standard. Thus, the optimum mixture obtained from this research and suitable for rigid pavement material was Mix 1 with a w/c ratio of 0.3, 5% crumb rubber, and 10% rice husk ash.
Table 4. Compressive and flexural strength values for all mixtures at 28 days.

| Mix | W/C Ratio | Crumb Rubber | Rice Husk Ash | Compressive Strength | Flexural Strength |
|-----|-----------|--------------|---------------|----------------------|------------------|
|     |           |              |               | Compressive Strength | Flexural Strength |
|     |           |              |               | according to Bina Marga 2018 [2] | Flexural Strength according to Bina Marga 2018 [2] |
| 1   | 0.3       | 5%           | 10%           | 36.38 MPa            | 4.53 MPa         |
| 2   | 0.35      | 5%           | 10%           | 30.03 MPa            | 4.00 MPa         |
| 3   | 0.4       | 5%           | 10%           | 24.64 MPa            | 4.33 MPa         |
| 4   | 0.3       | 2.5%         | 10%           | 26.75 MPa            | 4.47 MPa         |
| 5   | 0.3       | 7.5%         | 10%           | 23.67 MPa            | 4.67 MPa         |
| 6   | 0.3       | 5%           | 7.5%          | 31.76 MPa            | 4.20 MPa         |
| 7   | 0.3       | 5%           | 12.5%         | 33.88 MPa            | 4.60 MPa         |
| Control | 0.3 | 0% | 0% | 33.49 MPa | 4.27 MPa |

4. Conclusions

Waste tyre in the form of crumb rubber and rice husk ash was included in the concrete mixes to study their mechanical properties. The values were also assessed if they meet rigid pavement requirements as per Indonesian National Standard Bina Marga 2018. Eight concrete mixes were designed, cast and tested for their compressive and flexural strength values at 28 days. The parameters tested were w/c ratio of 0.30-0.45, crumb rubber percentage to replace sand by volume of 2.5-7.5%, and rice husk ash percentage as a cement replacement material from 7.5 to 12.5%. The control mix used was PCC concrete without crumb rubber and RHA content. The experimental study shows that the Mix 1 with a w/c ratio of 0.3, crumb rubber of 5% and rice husk ash of 10% has compressive and flexural strength values of 36.38 MPa and 4.53 MPa, respectively, at 28 days. Both values fulfilled the compressive and flexural strength rigid pavement requirements according to the Indonesian Standard Bina Marga 2018. From this research, it can be concluded that a proportionate combination of crumb rubber-rice husk ash contributes to the improvement of mechanical properties of concrete as a rigid pavement material.

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