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Mechanical properties of lightweight aggregate concrete reinforced with soda can waste fibre

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Abstract. The use of lightweight concrete as building construction material can reduce the building's self-weight and its vulnerability to earthquakes. This paper presents an experimental study on the mechanical properties of lightweight aggregate concrete reinforced with soda can waste fibre. The addition of the fibres may help prevent environmental damage. Twenty-four concrete cylinder specimens with a height of 300 mm and a diameter of 150 mm were cast. The volume fraction of the fibre was varied between 0, 0.3, 0.6, and 0.9%. To facilitate the casting process, superplasticizer was added in a content of 2% by cement weight. We found that the fibrous concrete produced can be categorized as lightweight concrete with a density below 2000 kg/m^3. The mechanical property that experienced the highest improvement, amounting to 61.00%, was the split tensile strength. The optimum fibre volume fraction for better performance in terms of strength is 0.3%.

1 Introduction

Satyarno [1] reported that earthquakes are one of the natural disasters that always come suddenly without any prior warning signs. It cannot be predicted when, where, and with what strength an earthquake will occur. Compared to other natural disasters, earthquakes generally occur in a short period of time of just a matter of seconds, but they can cause damage to building constructions and other infrastructures. Finally, they endanger lives, as shown by the high number of casualties [2, 3]. For example, as reported by GIZ-International Services [4], an earthquake occurred on 4 April 2011, in the early morning at 3:06 am, located about 300 km southwest of Cilacap. The Indonesian National Board for Disaster Management (BNPB) released information about the earthquake on its official website [5]. It was recorded that the earthquake had a magnitude of 7.1 RS at a depth of 10 km. It was found that the damage to houses included 445 collapsed houses, 801 seriously damaged ones, and 1,446 slightly damaged ones. The heaviest damage was found in Bojongsari village, where 102 houses collapsed, 103 were seriously damaged, and 71 were slightly damaged. The number of refugees reached 6043 inhabitants, and the financial losses came to Rp 31.5 billion.

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One of the main causes of the buildings' vulnerability to earthquakes is the use of heavy-weight materials, which can even worsen the performance of the structure [6]. Therefore, lightweight concrete is considered as a solution to reduce the weight of the structure. Lightweight concrete has many and varied applications including multi-storey building frames and floors, bridges, offshore oil platforms, and prestressed or precast elements [7]. It also solves durability problems in buildings and exposed structures. Lightweight concrete has a strength comparable to that of normal weight concrete, but typically 25 to 35% lower, and offers design flexibility and substantial cost savings by providing less dead load, improved seismic structural response, longer spans, better fire ratings, thinner sections, decreased storey height, smaller-size structural members, a need for less reinforcing steel, and cheaper foundation costs. Lightweight concrete precast elements incur lower transportation and placement costs [8]. Many types of aggregates that are classified as lightweight are available, and their properties cover wide ranges. Elastic properties, compressive and tensile strength, time-dependent properties, durability, fire resistance, and other properties of lightweight concrete are dependent on the type of lightweight aggregate utilized in the concrete [9].

Lightweight concrete is defined as concrete with a density of 200–2000 kg/m^3 [10]. Structural lightweight concrete is defined as concrete using lightweight aggregate or a mixture of lightweight coarse aggregate and sand and it has been specified that it should not exceed a maximum density of 1850 kg/m^3 and should meet the requirements regarding compressive strength and tensile strength of lightweight concrete for structural purposes [11, 12]. Generally, lightweight aggregate consists of natural lightweight aggregate and artificial lightweight aggregate. Examples of natural lightweight aggregates include pumice and scoria. Artificial lightweight aggregate is an aggregate created by expanding materials through a heating process, such as slag from the smelting of iron, clay, diatoms, shale, clay stone, perlite, and vermiculite. Akmaluddin [13] argued that because pumice is a natural material of volcanic origin produced by the release of gases during the solidification of lava, it is quite hard in nature and does not deteriorate easily once bound in concrete. Furthermore, he reported that lightweight concrete with pumice aggregate can achieve a compressive strength of 26.6 MPa.

Concrete is the most widely used construction material. However, it has low tensile strength and low energy absorption [14]. An effective method of enhancing the mechanical properties of concrete is by adding a small fraction of short fibres to it [15–17]. Mohammadian and Haghi [18] explained that increasing the amount of fibres in the matrix tends to reduce the compressive strength but provides a substantial increase in flexural toughness and enhances the ability to absorb energy. Furthermore, the reduction in compressive strength of mixtures with fibres may limit their use in some structural applications. With regard to the use of steel fibres, Sivakumar and Sounthararajan [19] found that increasing the addition of steel fibres to concrete mixture led to reasonable improvements in tensile strength thanks to the bridging action of the fibres under tension. Heniegal et al. [20] concluded that the addition of 0.5% fibres to concrete increased the indirect tensile strength by about 8–18%. Awal et al. [21] reported that the addition of 0.5 and 1.0% fibres increased the flexural strength by 17 and 1.8% respectively, as well as increasing the split tensile strength significantly and increasing the shrinkage strain slightly compared to normal concrete.

The aim of this work is to present an experimental study of the mechanical properties of lightweight aggregate concrete reinforced by soda can waste fibre. Recent data reveal that over one trillion aluminium soft drink and beer cans have been thrown in the trash rather than the recycling bin [22]. It is estimated that 1,010,000,000,000 (equal to 1 trillion, 10 billion) cans have been wasted since 1972, when the industry started keeping records. Stacked end-to-end, these wasted cans would extend 76 million miles, a distance equivalent

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to 158 round trips to the moon. A trillion wasted cans weigh in at 17.5 million tons, a quantity of scrap aluminium worth about USD 21 billion at today's market prices. The cumulative environmental damage from the failure to recycle this metal is the real issue. A previous study by Haryanto [23] concluded that the addition of 0.75% aluminium fibres increased the impact resistance of lightweight concrete with artificial lightweight aggregate by 250% for the first crack conditions. Further studies using carpet waste fibres found that the split tensile strength of lightweight aggregate concrete increased up to 75.18% while the flexural strength increased by 7.15% [24, 25]. Utilization of other waste materials to improve the performance of concrete has also been implemented previously [26, 27].

2 Experimental programme

2.1 Material properties

Multipurpose cement was used in this study. A saturated surface dry river sand having a mud content of 3.25% and water absorption of 6.63% was used as a fine aggregate. The fineness modulus and specific gravity of the sand were found to be 3.55 and 2.50 respectively. Artificial lightweight aggregate made from expanded shale [28] with a density of 1050 kg/m^3 having 13.82% water absorption was used as coarse aggregate, as can be seen in Figure 1. The fibres used were obtained from soda can waste (Figure 2) and were 50 mm in length, 2 mm in width, and 0.1 mm in thickness. A control specimen of plain lightweight concrete (PLC) without any soda can waste fibres was also made for comparison. Three fibre volume fractions, V_f, of 0.3, 0.6, and 0.9% were employed in this study. Superplasticizer was added in a content of up to 2% by cement weight to facilitate the casting process.

Fig. 1. Artificial lightweight aggregate made from expanded shale. [25]

Fig. 2. Soda can waste fibres.

2.2 Casting and testing of concrete specimens

The workability of concrete mixes was measured by the slump test in accordance with SNI 1972: 2008 [29]. Compressive strength and split tensile strength tests were conducted on 24 cylinder specimens with a height of 300 mm and diameter of 150 mm at the age of 28 days in accordance with SNI 1974: 2011 and SNI 03-2491-2002, respectively [30, 31]. The modulus of elasticity was measured in accordance with SNI 03-4169-1996 [32]. The compressive strength and modulus of elasticity data were obtained from the same cylinder specimen test simultaneously as presented in Figure 3. Figure 4 shows the concrete cylinder being tested under splitting.

Fig. 3. Compressive strength and modulus of elasticity test. [24]

Fig. 4. Split tensile test. [24]

The compressive strength is determined by Equation 1 while the split tensile strength is determined by Equation 2.

$$f_c^{'} = \frac{P}{A} \quad (1)$$

$$f_t = \frac{2}{\pi}\frac{P}{ld} \quad (2)$$

where:

$f_c^{'}$ = Compressive strength (MPa)
f_t = Split tensile strength (MPa)
A = Area of specimen (mm^2)
P = Maximum load (N)
l = Length of specimen (mm)
d = Diameter of specimen (mm)

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3 Results and discussion

3.1 Workability

The fresh concrete properties in terms of workability are presented in Figure 5. As expected, the workability of concrete containing soda can waste fibres in all mixes decreased, with slump values ranging from 1 cm to 4.5 cm. The sturdy fibre–matrix bond and the absence of superplasticizer would have caused this reduction in the slump value of concrete [19]. The addition of superplasticizer affects the slump value significantly because superplasticizer is a water-reducing additive that is effective in improving the workability without having to increase the water content. The range of slump values in all mixes with superplasticizer is 12 to 19 cm.

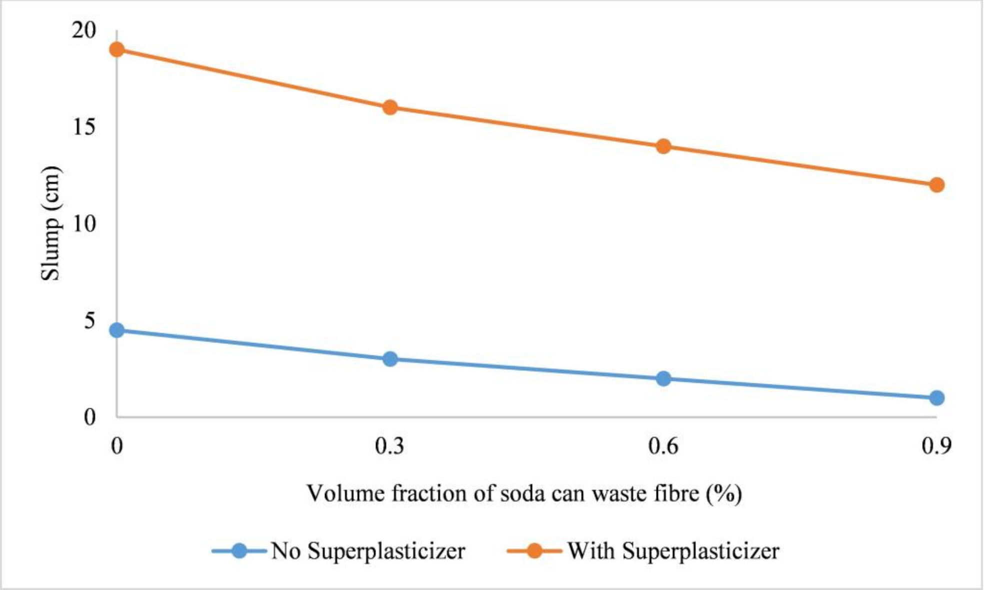

Fig. 5. Workability.

3.2 Density

The use of artificial lightweight aggregate can cause the density of concrete to reach a maximum value of 1940 kg/m^3, so it can be categorized as a lightweight concrete [10]. The addition of soda can waste fibres affects the density of the concrete values. As the addition of the soda can waste fibre increases, the density of concrete increases until it reaches a maximum value. After that, the density of the concrete will drop because the volume fraction of fibre is too high, and as a result the concrete is not solid anymore and contains many pores. The results of the concrete density measurements can be seen in Figure 6.

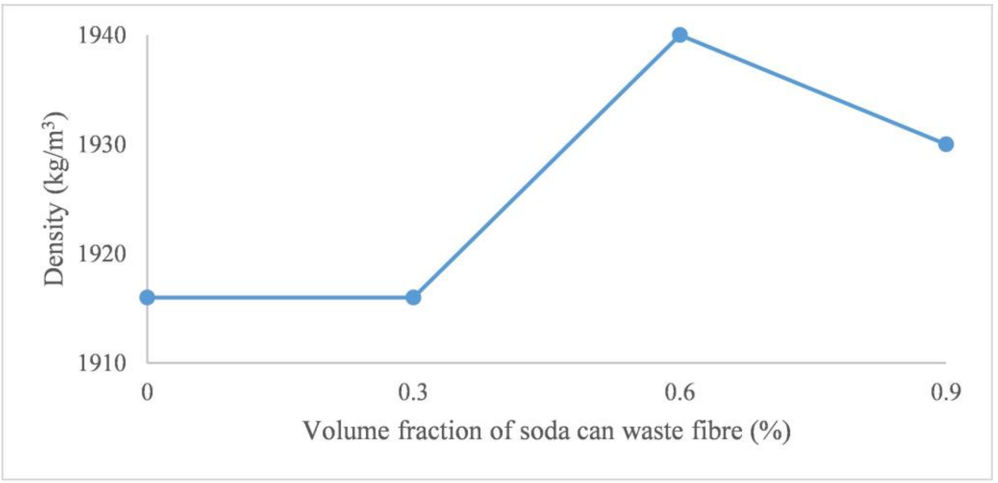

Fig. 6. Density.

3.3 Compressive strength

The test results for concrete at 28 days showed that the compressive strength of lightweight concrete with soda can waste fibre tends to be higher than that of plain lightweight concrete. As can be seen in Figure 7, the maximum compressive strength of 17.36 MPa was found for a 0.3% volume fraction, and this strength value is 37.34% higher than that of plain lightweight concrete. This is caused by the behaviour of the fibre, which can improve the bond between the aggregate and cement-matrix. However, the increase in the volume fraction decreases the workability of the concrete as it tends to become porous, which, in turn, decreases the compressive strength of the lightweight concrete.

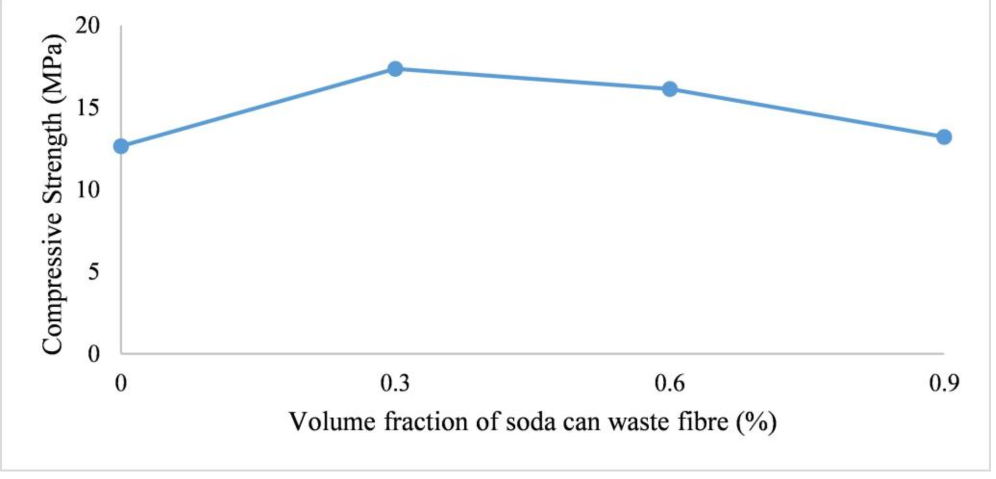

Fig. 7. Compressive strength.

3.4 Modulus of elasticity

The modulus of elasticity is essentially a measurement of the stiffness of a material. The modulus of elasticity of concrete is a key factor for estimating the deformation of buildings

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and members, as well as a fundamental factor for determining the modular ratio, m, which is used for the design of sections of members subjected to flexure [32]. The modulus of elasticity is often used in sizing reinforced and unreinforced structural members, establishing the quantity of reinforcement, and computing the stress for observed strain values and is especially important in the design of pre-stressed concrete members. So, the modulus of elasticity of concrete is a very important parameter reflecting the ability of concrete to deform elastically. The results obtained indicated that the modulus of elasticity of lightweight concrete increases with the addition of soda can waste fibres to concrete, as shown in Figure 8. The addition of a volume fraction equal to 0.3% gave the maximum value of the modulus of elasticity of lightweight concrete of 14685.50 MPa, representing an increase of 45.50% compared to plain lightweight concrete.

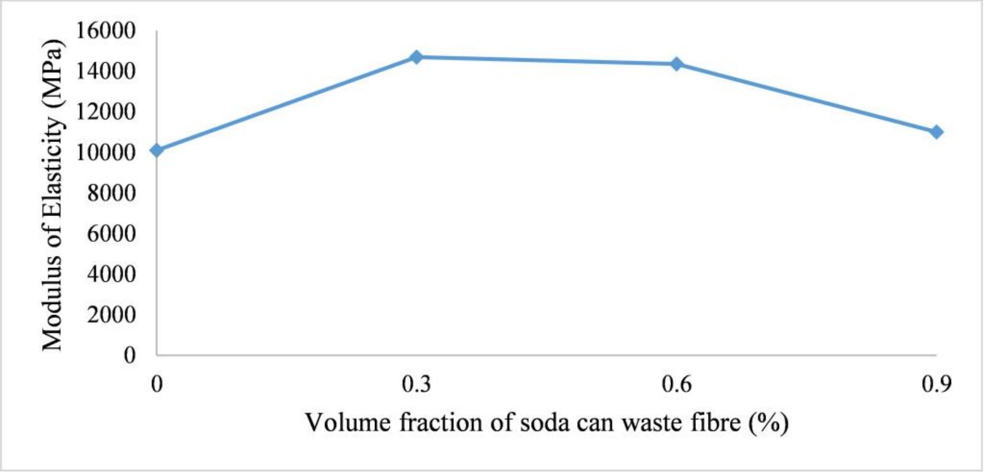

Fig. 8. Modulus of elasticity.

3.5 Split tensile strength

Figure 9 shows that the maximum split tensile strength of 1.98 MPa occurred with the addition of a volume fraction of 0.3%, an increase of 61.5% compared with plain lightweight concrete. In the plain lightweight concrete, the failure occurs suddenly and is not preceded by the early signs. The specimen fracture (Figure 10) was accompanied by a loud explosion. This is very different from the failure of lightweight aggregate concrete reinforced with soda can waste fibre. The specimen did not undergo fracture but only suffered from cracking and remained in one piece (Figure 11). The soda can waste fibres help to bridge and arrest the cracks and restrict the growth of flaws in the matrix, preventing them from becoming enlarged, under stress, into cracks that eventually cause failure.

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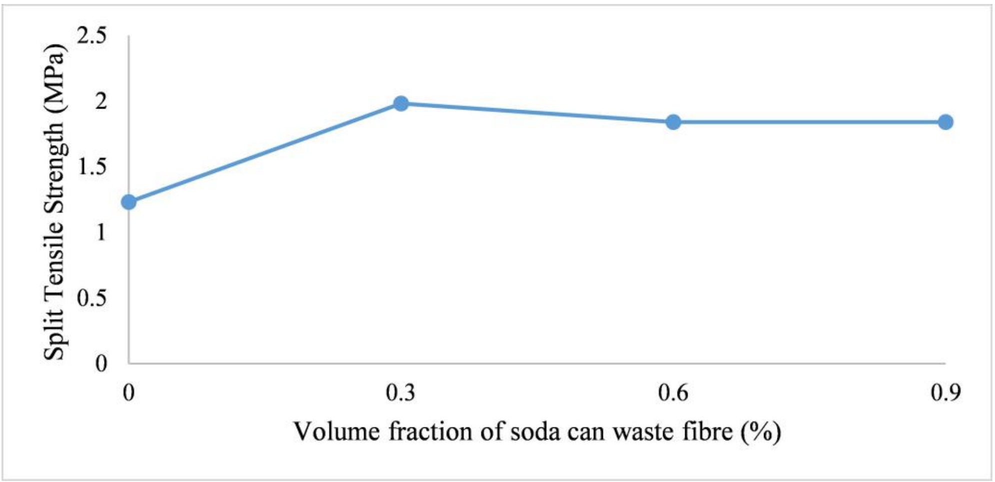

Fig. 9. Split tensile strength.

Fig. 10. Failure of plain lightweight aggregate concrete.

Fig. 11. Failure of lightweight aggregate concrete reinforced with soda can waste fibre.

4 Conclusion

From this experimental study, it can be concluded that the concrete produced can be categorized as a lightweight concrete. The mechanical properties of lightweight concrete are significantly improved by soda can waste fibres. The optimum fibre volume fraction for better performance in terms of strength is 0.3%. The mechanical property that experienced the highest improvement, which amounted to 61.00%, was the split tensile strength. The soda can waste fibres help to bridge and arrest the cracks and restrict the growth of flaws in the matrix, preventing their enlargement, under stress, into cracks, which eventually cause failure.

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