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Flexural Behavior of Artificial Lightweight Aggregate Concrete Reinforced by Carpet Waste Fiber

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Abstract. Artificial lightweight aggregate (ALWA) can be used as a replacement for coarse aggregates to produce low-density lightweight concrete. It can reduce the total weight of structural members, and consequently, the seismic forces on the building can be minimized. When adding a certain amount of fibers to the concrete mixture, the concrete performance can be improved by enhancing bonding between the mortar matrix and aggregates. To find more robust results, the study of combining the ALWA and fibers needs to be investigated. This paper deals with the impact of carpet fiber on flexural strength and failure mode of ALWA concrete. The experimental work was conducted on 150x150x600 mm concrete beams with ALWA aggregates and a 0 to 1% carpet fiber fraction range. The test results show that the optimum flexural strength of the beam improves by 7.15% with a 0.47% carpet fiber addition. In contrast, the specimen's failure mode indicates that it does not happen suddenly, with the deflection quality experiencing a reduction of 24.32% due to the presence of fibers. The results offer valuable information on the progress of lightweight concrete and fiber concrete research, also will contribute to the future research of the ALWA concrete strengthened with fibers.

INTRODUCTION

Loading work on building structures, both in the vertical direction and horizontal loads or due to shrinkage and temperature changes, can cause bending and deformation of structural members. When the beam element is subjected to a gravitational load, compressive stress exists at the top of the beam whereas the tensile stress appears at the bottom part. Since its tensile strength is low [1], in an attempt to improve the ability of concrete to withstand tensile stress on already designed reinforced concrete frames, the frames can be laminated with fiber-reinforced polymer [2], steel wire rope [3], or bamboo fibers [4]. Nevertheless, the incorporation of fibers into the mixture may be taken into consideration for fresh concrete mixtures. Not only do the fibers slow the propagation of cracks, but

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they also hamper their onset [5–7]. In addition to reducing the width and the propagation of cracks, fibers can also increase the durability of concrete structures [7–8]. Currently, the investigation in improving the performance and preventing the failure of the concrete members has become a favorite issue [9].

Based on the study by Neville [10], lightweight concrete has a specific gravity below 2,000 kg/m^3, with ordinary concrete having 2,400 kg/m^3. This lightweight concrete is used primarily to reduce the weight of a structure and its heat transmission [11]. Due to its mild nature, Haryanto [12] argues that the use of lightweight concrete as a structural material can bring its advantages, namely reducing the load that the foundation will receive. Moreover, lightweight concrete has other properties such as not conducting heat and being flame retardant and easy to mix but being a less good sound-insulating material [13]. ALWA (artificial lightweight aggregate) is defined as artificial aggregates resulting from processing a type of clay that expands and splits at certain heating temperatures, resulting in lightweight concrete aggregates.

Furthermore, waste material by-products of the textile industry, mainly fabric containing 50–70% nylon and 15–25% polypropylene [14–16]. This promotes the need for using fiber-reinforced carpet waste. One possible use is in the material and structural engineering field. A carpet section consists of face yarn and main, adhesive and secondary layers [17], as shown in Fig. 1.

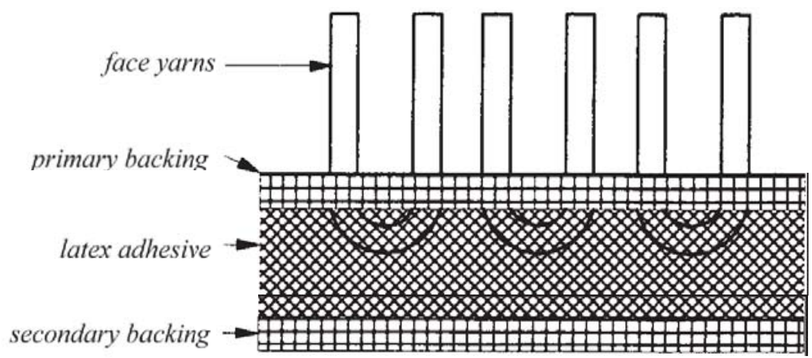

FIGURE 1. Carpet waste section illustration [17].

In an earlier study by Haryanto *et al*. [18], superplasticizers were stated to increase the workability of ALWA concrete with carpet waste fiber to a 19 cm slump value. ALWA concrete's compressive strength may rise to 14.73% with 0.46% carpet waste fiber fraction by volume, whereas the tensile strength of ALWA concrete can increase by 75.18% up to 0.85% fiber volume proportion. Since the effect of using ALWA results in a maximum of 1,940 kg/m^3 density, the concrete can be categorized as lightweight concrete. The ALWA materials have lower specific gravity than of conventional gravel, with specific gravity 1.43 compared to 2.4–2.9, respectively. The concrete density subsequently decreases as a result of increased pore density [18].

A study by Mohammadian *et al*. [19] clarified that in a concrete mixture, carpet waste fibers produced a low compressive strength but were accompanied by a significant increase in flexural strength and increased ability to absorb energy. The low compressive strength of carpet fiber concrete would limit its use to certain structural applications [19]. However, a study by Haniegal *et al*. [20] suggested that by adding 0.5% carpet waste fibers, the flexural strength could be increased by around 16%. A 17 and 1.8% increase in flexural strength with the addition of 0.5 and 1.0% carpet fibers, respectively, was also reported by Awal *et al*. [21], which was accompanied by a significant increase in tensile strength and a slightly higher shrinkage strain of normal concrete.

Although numerous studies have been carried out, they are still being performed on separate material usage; lightweight concrete and fiber concrete. Therefore, further experimental work on the combination of these two materials needs to be conducted to obtain more robust results. Thus, this study aims at analyzing the effect on the performance of ALWA lightweight concrete beams that incorporate carpet waste fibers. The discussion is focused on flexural strength, failure mode, and deflection measurement. This will provide important information on the development of lightweight concrete research.

EXPERIMENTAL METHOD

Materials

The experimental work was conducted on concrete specimens with ALWA and using 0, 0.25, 0.5, 0.75, and 1.0 volume percentages of carpet fiber from the concrete volume [18]. Concrete mixture materials include Portland Cement, fine sand aggregates, ALWA as coarse aggregates, carpet waste fiber, superplasticizer, and water. The ALWA aggregates produced in Cilacap City have a fine modulus of 6.48, a specific gravity of 1.43, a size between 5 mm and 40 mm, and are shown in Fig. 2. Meanwhile, carpet waste fibers have a 1.19 specific gravity, 50x3x2 mm dimensions [18], and are shown in Fig. 3. For this study, the carpet waste was obtained from the local manufacturer in Purwokerto City with one single brand and type. To improve concrete workability, a superplasticizer was applied at 2% of the cement weight. Table 1 shows the concrete mixture composition.

FIGURE 2. Artificial lightweight aggregates [18,22,23].

FIGURE 3. Carpet waste fibers [18,22,23].

TABLE 1. Concrete mixture compositions [18].

Volume fraction (%)	Carpet waste fiber (g)	Cement (g)	Sand (g)	Artificial lightweight aggregate (g)	Water (g)
0	0				
0.25	2,997.5				
0.5	5,995	375	750	525	81
0.75	8,992.5				
1	11,990				

Flexural Test

The specimens used in the flexural test include 3 beam specimens of each fiber percentage with 150x150x600 mm dimensions. The test was conducted on a flexural testing machine and the load was placed on every $\frac{1}{3}$ span of the specimen length, as shown in Fig. 4. The two supports can be classified into a simply-supported condition. For the test result where the fracture plane is in the central region, i.e. the $\frac{1}{3}$ area in the center part (Fig. 5a), the flexural strength is calculated according to Eq. (1). Whereas when the fracture plane is outside the central region but still inside in a 5% distance from the central region, as shown in Fig. 5b, Eq. (2) is used to calculate the flexural strength.

$$\sigma_l = \frac{P\,L}{A\,h^2} \tag{1}$$

$$\sigma_l = \frac{P\,a}{b\,h^2} \tag{2}$$

where:

σ_l = flexural strength (MPa)

P = maximum load (N)
a = distance between the crack line and specimen edge (N)
b = width of beam specimen (mm)
h = height of beam specimen (mm)

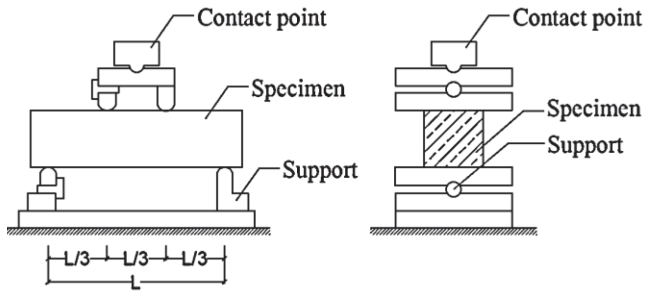

FIGURE 4. The flexural test set up [24].

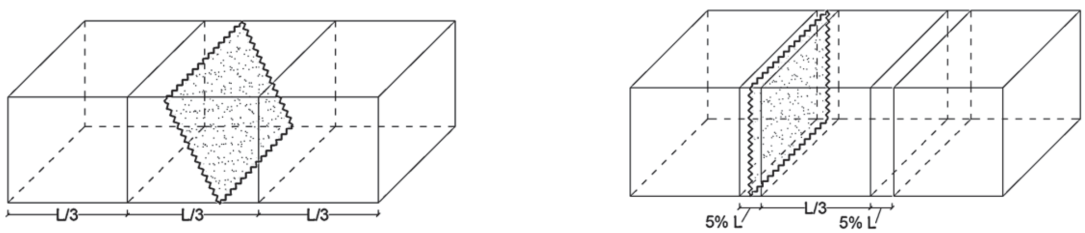

FIGURE 5. The fracture plane of the beam specimen obtained by flexural test [24]; (a) the plane is inside the central region; (b) the plane is outside the central region but still within 5% distance from the central region.

RESULTS AND DISCUSSION

Flexural Strength

The flexural strength results of the different carpet fiber percentage, ranging from 0% to 1%, can be shown in Table 2. From the previous study by Heniegal *et al.* [20] and Awal *et al.* [21], the incorporation of carpet fibers in certain amount to the normal-aggregate concrete appears to have a 16% higher flexural strength than the non-fiber concrete. However, as with the increasing amount of fiber, it can cause a flexural strength decreased from a certain value. This is in line with Fig. 6 in this study, which shows the impact of fiber percentage on ALWA concrete's flexural strength. With a 0.47% carpet waste fiber content, the optimal value can be reached, increasing the flexural strength to 7.15%. This is in accordance to the previous researches [25–26] that the maximum flexural strength of concrete was achieved by the 0.5% addition of carpet fibers.

Adding fiber can reduce the concrete workability so that the ALWA concrete will tend to become less dense and incompressible. The fibers will inhibit the spread of cracks and keep the concrete mixture stable in holding the load, even though it has cracked [12]. The phenomenon led to an increase in the value of the ALWA concrete flexural strength, as shown in the early stage of the flexural strength graph in Fig. 6. This result agrees with research studies by Hadi [27] and Paultre *et al*. [28]. It was found that the additional fibers on the concrete mix will strengthen the bonding between the mortar matrix and aggregates in an appropriate amount, then enhance the flexural strength, the energy absorption, the tension behavior, and the behavior of toughness [27–29].

TABLE 2. The flexural strength of the specimens.

Volume fraction (%)	Flexural strength (MPa)		
	Specimen 1	Specimen 2	Specimen 3
0	1.068	1.082	0.912
0.25	1.027	0.997	1.186
0.5	1.447	0.896	1.224
0.75	0.872	0.799	1.195
1	0.943	1.134	1.088

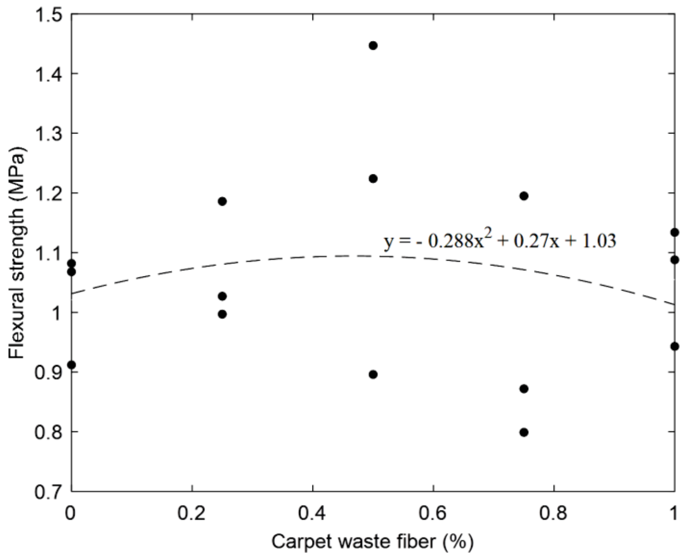

FIGURE 6. Fiber percentage vs flexural strength of ALWA concrete.

Failure Mode

The failure in flexural test specimens shows that the ALWA concrete specimens failed in flexural mode. Before reaching maximum load, cracks on the bottom part of beam specimens occur first. The beam was not broken into pieces, but only cracked and remained in one part. This is shown in Fig. 7. In contrast to ALWA non-fiber concrete, it did occur suddenly and can be categorized as a brittle failure. Cracks have been observed on the tensile side of the specimens before the maximum load was reached.

FIGURE 7. Failure mode on ALWA with fiber concrete occurred with the flexural failure mode in the beam's middle span.

The presence of fibers in ALWA concrete results in more flexibility and a more ductile failure mode of beam specimens. The minor cracks that occur can be prevented with the fibers, wherein the fiber will still hold the concrete part separated by the cracks. From the failure mode shown in Fig. 7, adding fibers can make the concrete beam more resistant to cracking and become impact resistance. The addition of fibers also adds to the ductility of lightweight concrete [11].

Deflection

ALWA concrete deflection measurement was performed to assess the beam concrete's stiffness. A dial gauge was placed under the beams at the midspan to monitor the final deflection. The final deflection was recorded as the difference between the vertical position of the beam from the loading started until the specimens failed. Table 3 indicates the results of the maximum deflection recorded. Figure 8 shows the relationship between the percentage of carpet waste fiber and deflection. It shows that the greater the level of fiber added to the concrete mixture, the deflection of the concrete specimen is lower.

In the conventional lightweight concrete with zero percent carpet fiber, the maximum deflection value is 0.465 mm. After the amount of fiber is increased, the deflection is also reduced. Due to the presence of the fiber, the bigger value of the deflection can be prevented. It can be seen from Fig. 8 that the non-fiber specimens had more deflection than the 1% content of the fiber. This is similar to study conducted by Wang [30]. The deflection from the addition of 0.47% carpet fiber content was recorded as 0.43 mm or reduce 10% from the deflection in ALWA concrete without carpet fiber. Yet, the minimum deflection reduction of ALWA concrete occurred in the 1% carpet fiber content, with the reduction of 24% from the non-fiber ALWA concrete. However, the failure mode for the fiber ALWA concrete are similar and showing more ductile behavior, compared to the non-fiber specimens.

TABLE 3. The maximum deflection of the specimens.

Volume fraction (%)	**Deflection (mm)**		
	Specimen 1	Specimen 2	Specimen 3
0	0.49	0.39	0.44
0.25	0.54	0.35	0.69
0.5	0.40	0.41	0.29
0.75	0.45	0.35	0.41
1	0.33	0.36	0.31

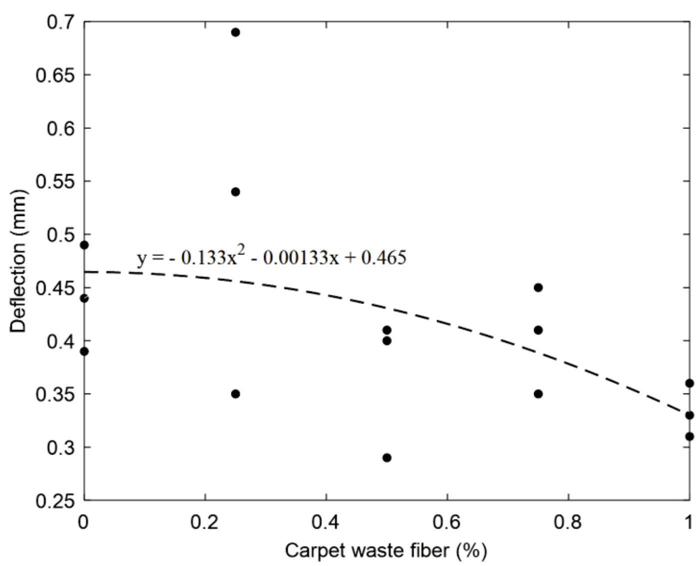

FIGURE 8. Fiber percentage vs ALWA concrete deflection.

Fibers in concrete can cause the stiffness to become higher due to the bridging mechanism provided by the fibers. It is useful for preventing cracks and making lightweight fibers concrete more ductile than ordinary lightweight concrete. This is in accordance with the result from Antonius [31], which proved that the concrete fracture process can be controlled using fibers.

CONCLUSIONS

The present study focused on the performance of ALWA concrete beams reinforced with carpet waste fibers subjected to flexural load. ALWA assists in reducing the density of the concrete, which then can be categorized as lightweight concrete. The inclusion of fibers in ALWA concrete results in the failure mode of beam specimens being more ductile and enabling the bridging mechanism in the concrete beams. The research found that by adding 0.47% carpet waste fibers, the flexural strength of ALWA concrete beams can be improved up to the optimum percentage of 7.15%. The presence of carpet fibers also prevents the concrete beams collapse from occurring suddenly, with the deflection value experiencing a reduction of up to 24.32%. For future study, the characteristics of carpet waster fiber should be measured and the total number of the specimens need to be increased to the sufficient amount.

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