Compressive stress-strain behavior of concrete with artificial lightweight aggregates and steel-fibers

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Abstract. Artificial lightweight aggregate used in the concrete mix is able to reduce the volume of concrete so that when applied to structural concrete it will reduce the weight of the structure. To be used in the structural concrete mix, the compressive strength produced must be able to meet the minimum requirements of structural concrete compressive strength. The addition of steel fibers to concrete with artificial lightweight aggregate can provide a good behavior change to its mechanical properties. This research was conducted experimentally which investigated compressive stress-strain behavior, the main ingredients used to make artificial lightweight aggregate were Styrofoam and acetone with the composition of 0% -100% of coarse aggregate and to increase the compressive strength of steel fibers by 0% -1.5% from the specimen volume. The specimen used was a 100x200 mm cylinder tested using a Universal Testing Machine, the output obtained was the value of stress and strain. The test results show that the stress-strain of the concrete increases with increasing steel fiber composition. Strain value increased by 23% from normal concrete strain. The compressive strength produced from concrete with a mixture of lightweight artificial aggregates and steel-fibers is able to reach the minimum concrete compressive strength requirements.

1. Introduction
Innovations to make artificial lightweight aggregate (ALWA) from waste that cannot be recycled have been done a lot, this is one solution to reduce the impact on the environment and can also minimize the use of natural resources as a mixture of concrete [1-3]. Artificial lightweight aggregate which is able to produce minimum compressive strength for structural concrete is very effective to be used as one of the concrete mix materials because it is able to reduce the dimensions of structural components in a building so that the safety of the structure due to earthquake shear forces becomes safer. Research on concrete using lightweight artificial aggregates is able to achieve a compressive strength of 29.4 MPa [4]. Composition of 100% artificial lightweight aggregate which is used as coarse aggregate is also able to attain the minimum compressive strength requirements of structural lightweight concrete that is equal to 18.55 MPa [5].

Styrofoam with Expanded Polystyrene (EPS) type is a waste that can be used as an aggregate substitution in a concrete mixture [6,7]. Styrofoam waste is easily obtained from small and large industries. Styrofoam can not only be directly applied as a substitute for coarse aggregate but can also be reprocessed so that the properties and characteristics of Styrofoam can resemble coarse aggregate. In
this study, Styrofoam was reprocessed so that its characteristics resembled more coarse aggregates so that the texture of Styrofoam, which was originally soft, became harder.

Artificial lightweight aggregate used in concrete mixture is not able to significantly increase the compressive strength of concrete so that other materials are needed as added material to achieve the expected compressive strength. One material that is able to increase the compressive strength is steel-fiber. The addition of steel-fibers by 1-2% is known to be able to improve the mechanical properties of concrete in the medium level and become a high level when added by 2% [8]

Concrete is known to become more ductile when added with steel-fibers [9,10]. If the concrete ductility increases, it will greatly affect the stress-strain value [11,12] so that in this study steel-fibers between 0-1.5% are used. The aim of this study was to determine the effect of the use of artificial lightweight aggregate made from Styrofoam with the addition of steel-fibers on the compressive stress-strain behavior in concrete.

2. Methods

2.1. Material
In this study, divided into three types of test specimens, the first is normal concrete, the second is concrete mixed with artificial lightweight aggregate, and the third is concrete mixed with artificial lightweight aggregate and steel-fiber. Therefore, the materials used in this study are Portland Pozzolana Cement (PPC) according to C595/C595M-18 standard, coarse aggregate with a size 1-2 cm, artificial lightweight aggregate, fine aggregate in zone 2 categories, steel-fibers, and water.

Artificial lightweight aggregate must have lightweight characteristics so that the main ingredient used is Styrofoam. This lightweight artificial aggregate is made by going through several stages and using acetone solution so that the texture becomes hard like a coarse aggregate [13]. The form of coarse aggregate and artificial lightweight aggregate can be seen in Figure 1. The results of the specific gravity of each aggregate can be seen in Table 1.

![Figure 1. Coarse aggregates (a) and artificial lightweight aggregate (b).](image)

Table 1. Material properties.

| Materials         | Density | Unit   |
|-------------------|---------|--------|
| Coarse aggregate  | 2620 kg | kg/cm³ |
| Artificial aggregate lightweight | 710 kg | kg/cm³ |
| Fine aggregate    | 2660 kg | kg/cm³ |

The type of steel fiber used as additional material is hooked-end (Figure 2). This steel fiber has a tensile strength of 1254 MPa, a diameter of 0.8 mm and a length of 6 cm. The amount of steel fiber used is in accordance with the fiber content and the volume of the test specimen.
2.2. Mix design
The process for making specimen mix designs must be calculated correctly. This is because the artificial light aggregate has a lightweight, so the calculation of the amount of coarse aggregate is not based on weight but based on volume. The sample used is a cylinder with a size of 100 mm x 200 mm. The results of the mix design calculation can be seen in Table 2.

Table 2. Mix design.

| Composition of artificial lightweight aggregate (%) | Materials | Coarse Aggregates (gr/cm³) | Artificial lightweight aggregate (gr/cm³) | Fine aggregate (gr/cm³) | Water (gr/cm³) | 0% Steel-fibers (gr/cm³) | 0.75% Steel-fibers (gr/cm³) | 1.5% Steel-fibers (gr/cm³) |
|-----------------------------------------------------|-----------|-----------------------------|------------------------------------------|------------------------|-------------------|------------------------|------------------------|------------------------|
| 0                                                   | 0.70      | 0.923                       | 0                                        | 0.542                  | 0.210             | 0                      | 0.052                  | 0.104                  |
| 15                                                  | 0.70      | 0.785                       | 0.038                                    | 0.542                  | 0.210             | 0                      | 0.052                  | 0.104                  |
| 50                                                  | 0.70      | 0.461                       | 0.125                                    | 0.542                  | 0.210             | 0                      | 0.052                  | 0.104                  |
| 100                                                 | 0.70      | 0                        | 0.251                                    | 0.542                  | 0.210             | 0                      | 0.052                  | 0.104                  |

2.3. Test equipment and procedure
Stress-strain values are obtained from compressive strength test results. Compressive strength testing is done after the concrete age reaches 28 days and is already in dry condition after soaking. The equipment used for compressive strength testing is Universal Testing Machine (UTM) with type HT-2101. The maximum load capacity of this testing machine is 2000 kN. The testing phase is in accordance with American Standard Testing and Material, namely ASTM C39M. The surface of the sample that is compressed must be flat so that there is no difference in the results of the compressive strength. The loading process is carried out until the concrete is destroyed and stopped when the loading rate decreases. The outputs obtained from the results of this test are not only stress numbers but this machine also produces strain values so that stress-strain behavior can be analyzed.

3. Results and discussion
The output of the compressive strength test results is stress and strain values so that the stress-strain behavior in this study is analyzed. Some things that need to be considered in stress-strain behavior are the influence of the use of artificial lightweight aggregate and steel-fibers to the stress-strain value when it reaches maximum conditions and when it collapses. Compressive strength test specimen can be seen in Figure 3.

In this analysis to determine the increase in the strain that occurs in each composition used two references. First, at the initial stress and strain, where the curve is linear and begins to collapse when the stress and strain reach 0.85f′c after the peak stress. Second, the collapse occurs when the stress and strain reach 0.5f′c after the peak stress. Then the strain value taken for the stress and strain relationship curve is the strain that occurs when the peak stress (f′c_maks) and the strain at 0.85f′c after the peak stress and the strain at 0.5f′c after the peak stress.
Figure 3. Concrete with artificial aggregate and steel-fibers.

The results of compressive stress-strain in normal concrete and concrete with the use of artificial lightweight aggregate can be seen in Table 3.

Table 3. Stress-strain for normal concrete and concrete with artificial lightweight aggregate.

| Sample code | Stress ($f'_c$) | Strain ($\varepsilon$) |
|-------------|-----------------|-----------------------|
|             | $f'_{cmaks}$    | 0.85$f'_c$ | 0.5$f'_c$ | unit | $\varepsilon_{fcmaks}$ | $\varepsilon_{0.85f'_c}$ | $\varepsilon_{0.5f'_c}$ |
| C-0         | 33.49           | 28.46       | 16.74     | MPa  | 0.00142         | 0.00166        | 0.00184         |
| CA-15       | 22.49           | 19.12       | 11.25     | MPa  | 0.00135         | 0.00168        | 0.00232         |
| CA-50       | 14.96           | 12.72       | 7.48      | MPa  | 0.00119         | 0.00170        | 0.00248         |
| CA-100      | 11.88           | 10.10       | 5.94      | MPa  | 0.00109         | 0.00171        | 0.00250         |

Figure 4. Stress-strain curves for normal concrete and concrete with artificial lightweight aggregate.

Based on Table 3 it can be seen that in normal concrete (C-0) it produces maximum stress. While concrete with a composition of 100% ALWA Styrofoam has the lowest stress, but the strain at $0.85f'_c$ after the peak strain increased by 2.6%. At the time of $0.5f'_c$ strain after the peak concrete strain with a composition of 100% ALWA Styrofoam (CA-100) increased by 35% from normal concrete (C0). Visually the increase in strain can also be seen in Figure 4, when the curve lines have passed the peak stresses that decrease appear steeper, this indicates that concrete without the composition of ALWA Styrofoam is more brittle. Concrete curves with ALWA Styrofoam composition of 15% (CA15), 50% (CA50) and 100% (CA100) seen be more strength than normal concrete. This indicates that concrete using ALWA Styrofoam has more ductile behavior.
The relationship of stress and strain in concrete with a mixture of Styrofoam ALWA and 0.75% steel-fibers can be seen in Table 4 and Figure 4.

**Table 4.** Stress-strain for Concrete with Artificial Lightweight Aggregate and 0.75% Steel-Fibers.

| Sample code | Stress ($f'_c$) | Strain ($\varepsilon$) |
|-------------|-----------------|------------------------|
| Henry        | $f'_c$ maks     | 0.85$f'_c$ | 0.5$f'_c$ | $\varepsilon$ fcmaks | $\varepsilon$ 0.85$f'_c$ | $\varepsilon$ 0.5$f'_c$ |
| C0-F75      | 36.29           | 30.84       | 18.14      | 0.00159            | 0.00178            | 0.00269            |
| C15-F75     | 27.20           | 23.12       | 13.60      | 0.00162            | 0.00184            | 0.00272            |
| C50-F75     | 19.37           | 16.46       | 9.68       | 0.00143            | 0.00187            | 0.00278            |
| C100-F75    | 13.54           | 11.51       | 6.77       | 0.00130            | 0.00150            | 0.00282            |

In Table 4 it can be seen that in concrete without the use of ALWA Styrofoam and the addition of 0.75% steel fiber (C0-F75) produces maximum stress. Whereas concrete with a composition of 100% ALWA Styrofoam and 0.75% steel fiber has a minimum stress, but strain at 0.5$f'_c$ after the peak strain of concrete with a composition of 100% ALWA Styrofoam and 0.75% steel fiber (C100-F75) increased by 4.5% of concrete with a mixture of 0% ALWA Styrofoam and 0.75% steel fiber (C0-F75). The relationship of stress and strain in concrete with a mixture of ALWA Styrofoam and 1.5% steel fiber can be seen in Table 5 and Figure 5.

**Table 5.** Stress-Strain for Concrete with Artificial Lightweight Aggregate and 1.5% Steel-Fibers.

| Sample code | Stress ($f'_c$) | Strain ($\varepsilon$) |
|-------------|-----------------|------------------------|
| Henry        | $f'_c$ maks     | 0.85$f'_c$ | 0.5$f'_c$ | $\varepsilon$ fcmaks | $\varepsilon$ 0.85$f'_c$ | $\varepsilon$ 0.5$f'_c$ |
| C0-F15      | 42.13           | 35.81       | 21.06      | 0.00165            | 0.00195            | 0.00295            |
| C15-F15     | 28.48           | 24.21       | 14.24      | 0.00163            | 0.00202            | 0.00297            |
| C50-F15     | 26.15           | 22.23       | 13.07      | 0.00152            | 0.00203            | 0.00354            |
| C100-F15    | 18.76           | 15.95       | 9.38       | 0.00142            | 0.00208            | 0.00364            |

**Figure 5.** Stress-strain curves for concrete with artificial lightweight aggregate and 0.75% steel-fibers and 1.5% steel-fibers.

Based on Table 5 it can be seen that the concrete with a composition of 100% ALWA Styrofoam and 1.5% steel fiber has a minimum stress whereas concrete without the use of ALWA Styrofoam and the addition of 1.5% steel fiber (C0-F15) produces maximum stress. But based on the strain value, the strain at 0.85$f'_c$ after the peak strain increased by 0.6% while the strain at 0.5$f'_c$ after the concrete peak strain with a composition of 100% ALWA Styrofoam and 1.5% steel fiber (C100-F15) increased by 19.15%
of concrete with 0% ALWA Styrofoam and 1.5% steel fiber (C0-F15). Based on the test results it can be concluded that the addition of steel fiber to the mixture of ALWA Styrofoam further increases the strain of the concrete so that the concrete becomes more ductile.

4. Conclusions
The compressive strength produced from concrete with a mixture of artificial light aggregate as much as 100% and 1.5% steel-fibers are able to reach the minimum requirements of the compressive strength of structural concrete that is equal to 18.76 MPa. The test results show that the stress and strain of the concrete increases with increasing steel fiber composition. Concrete strain value with a mixture of artificial light aggregate and steel-fibers increased by 23% from the normal concrete strain.

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References
[1] Patel D, Kachhadia U, Shah M and Shah R 2018 Experimental Study on Lightweight Concrete with Styrofoam as a Replacement for Coarse Aggregate 1 103–96
[2] Srinivasan K, Mutharasi M, Vaishnavi R, Mohan S and Logeswaran V 2016 An Experimental Study on Manufacture of Artificial Aggregates Incorporating Flyash, Rice Husk Ash and Iron Ore Dust Int. J. Sci. Eng. Technol. Res. 5 163–8
[3] Thomas J 2013 Concrete made using cold bonded artificial aggregate Am. J. Eng. Res. 2320–847
[4] Chang F C, Lee M Y, Lo S L and Lin J D 2010 Artificial aggregate made from waste stone sludge and waste silt J. Environ. Manage. 91 2289–94
[5] Dimension C E 2018 Effect of the Use of Metakaolin Artificial Lightweight Aggregate on the Properties of Structural Lightweight Concrete 19 86–92
[6] Pavlu T, Fortova K, Divis J and Hajek P 2019 The utilization of recycled masonry aggregate and recycled EPS for concrete blocks for mortarless masonry Materials (Basel). 12
[7] Thomas Tamut 2015 Partial Replacement of Coarse Aggregates By Expanded Polystyrene Beads in Concrete Int. J. Res. Eng. Technol. 03 238–41
[8] P. Kumar Mehta; Paulo J. M. Monteiro Concrete microstructure properties and materials (California: New York: McGraw - Hill)
[9] Journal I, Engineering O F, Fiber S and Concrete R 2017 International journal of engineering sciences & research technology steel fiber reinforced concrete a review 6 130–3
[10] Journal I, Engineering O F, Of P, With C, Of A and Fibers S 2018 International journal of engineering sciences & research technology performance of concrete with adding of steel fibers 7 290–308
[11] Han B and Xiang T 2017 Axial compressive stress-strain relation and Poisson effect of structural lightweight aggregate concrete Constr. Build. Mater. 146 338–43
[12] Liu X, Wu T and Liu Y 2019 Stress-strain relationship for plain and fibre-reinforced lightweight aggregate concrete Constr. Build. Mater. 225 256–72
[13] Wulandari M, Tavio, Raka I G P and Puryanto 2018 Compressive Strength of Steel-Fiber Concrete with Artificial Lightweight Aggregate ( ALWA ) 4 2011–22