Split tensile and flexural strength of concrete with artificial lightweight aggregate (ALWA) and steel-fiber

M Wulandari¹, M F Sofianto¹, Tavio²
¹Department of Civil Engineering, Faculty of Engineering, Universitas Negeri Surabaya, Indonesia, 60231
²Department of Civil Engineering, Institut Teknologi Sepuluh Nopember, Indonesia, 60111

meitywulandari@unesa.ac.id

Abstract. In this study, ALWA made from Styrofoam. Styrofoam is reprocessed by adding acetone solution. The use of acetone is to form styrofoam into hard grains so that it resembles coarse aggregates so that they can be used as substitutes for coarse aggregates in concrete mixtures. Hooked type steel fibers are also used as additives in this study. Steel fibers used are 0%, 0.75% and 1.5% of volume concrete while for the composition of ALWA Styrofoam were 0%, 15%, 50% and 100% for split tensile strength testing, respectively. Concrete composition for flexural strength testing is the optimum composition of the tensile strength test results. The results showed concrete with a mixture of 15% ALWA Styrofoam and 1.5% steel fiber was able to produce optimum split tensile strength, the most optimum tensile strength testing of 5.29 MPa and for the flexural strength test results of 9.47 MPa at maximum load. Addition of steel fibers with a mixture of ALWA Styrofoam is able to make concrete to be more resistant to cracking and more ductile.

1. Introduction
Artificial lightweight aggregate is an innovation to replace natural aggregates used as a concrete mixture. Research related to the manufacture of artificial lightweight aggregates (ALWA) has been carried out [1-4]. The materials used for the manufacture of artificial lightweight aggregates are very diverse. Natural materials such as clay are one of the natural ingredients that can be formed into ALWA [5-6]. In addition to utilizing natural materials, materials for producing ALWA can come from industrial wastes that cannot be recycled, one of which is Styrofoam. The advantage of using Styrofoam waste as an ingredient in making ALWA is one solution to reduce the impact of environmental pollution. [7].

Research related to the use of styrofoam in concrete mixes generally is a substitute for coarse aggregates and fine aggregates without changing the original shape of Styrofoam [8-11]. In this study, styrofoam was reprocessed by adding an acetone solution. The use of acetone is to form styrofoam into granules that are harder so that it resembles coarse aggregates. Mechanically the concrete has a low tensile strength, so to increase the tensile strength of the concrete other materials need to be added. Steel fiber is one material that can increase the tensile strength of concrete. The use of steel fibers not only increases tensile strength but can also increase bending capacity, restraining concrete to be more resistant to cracking [12] and increase ductility [13]. The mechanical properties of concrete with steel fiber added material are influenced by type and volume fraction, the volume classification of steel fibers that can improve the mechanical properties of concrete is divided into three, low (steel
fiber volume less than 1%), medium (steel fiber volume between 1 % and 2%) and very high (the volume of steel fiber is more than 2%) [14]. Also, tensile strength, flexural strength, and compression strength increased by 100%, 150-200%, and 10-25% respectively by adding 1-1.5% steel fiber to concrete. Concrete has brittle properties, but with the addition of steel fibers can make concrete more ductile [15-16].

Some studies use Styrofoam as an aggregate substitution material, while in this study Styrofoam is used as the main ingredient for making artificial lightweight aggregates (ALWA). Artificial lightweight aggregate which is a mixture of Styrofoam and acetone is used as substitution of coarse aggregate because it has a hard texture. This study also only focuses on testing the tensile strength and flexural strength, to increase the value of tensile strength and flexural strength plus other materials i.e. steel fibers.

2. Research Method

2.1. Material

Composition materials for concrete are included cement, coarse aggregates, fine aggregates, steel fibers, artificial lightweight aggregates, and water. The material in this study, using material available on the local market. Portland cement used is Portland Pozzolana Cement (PPC) [17], fine aggregate in the form of black sand which is included in the zone two categories. The following are the specifications (Table 1) and details of steel fibers (Figure 1).

| Specification of steel fiber |
|-----------------------------|
| **Type** | Hooked |
| **Length** | 60 mm |
| **Diameter** | 0.8 mm |
| **Aspect ratio (l/d)** | 75 |
| **Tensile strength** | 1254 n/mm |
| **Weight** | 0.22 gr |

Coarse aggregates used in this study were of two types i.e. split stone size of 20 mm (figure 2) and styrofoam of ALWA (figure 3). Step for making artificial lightweight aggregates (ALWA) can be seen in Figure 4.

![Figure 1. Shape and size of steel fiber](image1)

![Figure 2. Size of split stone is 20 mm](image2)

![Figure 3. Styrofoam of ALWA](image3)
Figure 4. Step for making Styrofoam ALWA

Styrofoam is dissolved with acetone, the ratio of styrofoam and acetone is 1:1.9

Styrofoam and acetone solutions are formed into granules with a size resembling coarse aggregates of about 10 to 20 mm.

Granules of Styrofoam ALWA beads are soaked for ±3 days so that the ALWA dries quickly and the texture becomes hard.

Styrofoam ALWA which has been soaked for ±3 days is aerated so that the Styrofoam ALWA dries.

Table 2. Mix design for splitting test

| Material                  | Percentage of styrofoam ALWA | Unit  |
|---------------------------|------------------------------|-------|
|                           | 0%              | 15%         | 50%         | 100%         |
| Cement                    | 700             | 700         | 700         | 700          | kg/m$^3$ |
| Fine aggregates           | 542             | 542         | 542         | 542          | kg/m$^3$ |
| Split stone               | 923             | 785         | 461         | 0            | kg/m$^3$ |
| Styrofoam ALWA            | 0               | 38          | 125         | 251          | kg/m$^3$ |
| Water                     | 210             | 210         | 210         | 210          | kg/m$^3$ |
| 0% SF*                    | 0               | 0           | 0           | 0            | kg/m$^3$ |
| 0.75% SF*                 | 52.13           | 52.13       | 52.13       | 52.13        | kg/m$^3$ |
| 1.5% SF*                  | 104.26          | 104.26      | 104.26      | 104.26       | kg/m$^3$ |
| Total of specimens        | 3               | 3           | 3           | 3            | -       |

*SF : steel fiber

Table 3. Mix design for flexural strength

| Composition of concrete                | 15%         |
|---------------------------------------|------------|
| Composition of Styrofoam ALWA         | 700 kg/m$^3$|
| Cement (kg/m$^3$)                     | 700        |
| Fine aggregates (kg/m$^3$)             | 542        |
| Coarse aggregates (kg/m$^3$)           | 785        |
| Water (kg/m$^3$)                       | 210        |
| Styrofoam ALWA (kg/m$^3$)              | 38         |
| 1.5% steel fiber (kg/m$^3$)            | 104.26     |
| Total of specimens                     | 2          |

2.2 Test method

Testing process starts from mixing concrete material. During the mixing process, Styrofoam ALWA is inserted first so that it is easy to bind to the other material while the steel fibers are evenly distributed with a random orientation so that balling effects do not occur. After the mixing process, fresh concrete is inserted into the cylinder and beam mold. Test specimens which were 24 hours old were then immersed for 28 days. Furthermore, the test material which has been 28 days old has been tested for split tensile strength which refers to the ASTM standard C 496/C 496-04 [18] and flexural strength.
testing which refers to the ASTM C 78 standard [19]. The tool used for testing is CTM (Compression Testing Machine) for testing the tensile strength and flexure testing machine for flexural strength testing. Test specimens for split tensile strength and flexural strength can be seen in figure 5 and figure 6.

![Figure 5. Specimen model for splitting test](image1)

![Figure 6. Specimen model for flexural strength](image2)

3. Test results

3.1. Split tensile strength test

Test results of the average split tensile strength can be seen in table 4.

| Percentage Styrofoam of ALWA | Split tensile test (MPa) |
|-----------------------------|-------------------------|
|                            | 0% SF | 0.75% SF | 1.5% SF |
| 0%                          | 3.13  | 5.50     | 6.05    |
| 15%                         | 2.61  | 4.80     | 5.29    |
| 50%                         | 1.94  | 3.97     | 4.41    |
| 100%                        | 1.24  | 3.31     | 3.54    |

Based on the test results of split tensile strength, the more Styrofoam ALWA composition used as coarse aggregate substitution, the value of split tensile strength decreases (figure 11). This is because the Styrofoam ALWA has a weak bond with cement paste. The rough surface of styrofoam ALWA is not able to increase the binding capacity with cement paste when the load reaches its maximum capacity then it cracks and splits into two parts, then ALWA Styrofoam is released from the cement paste bond. Concrete with a composition of 0% steel fiber is still brittle because during the testing process the concrete is very quickly split into two parts.

![Figure 7. Concrete with 0% styrofoam ALWA](image3)

![Figure 8. Concrete with 15% styrofoam ALWA](image4)

![Figure 9. Concrete with 50% styrofoam ALWA](image5)

![Figure 10. Concrete with 100% styrofoam ALWA](image6)
Concrete with the addition of steel fibers as much as 0.75% and 1.5% is more ductile. When the load has reached its maximum capacity, the concrete only has a crack in the middle and does not split into two parts (Figure 12). Adding steel fibers is also able to increase the tensile strength, based on Figure 12, it can be seen that the more steel fibers are added, the greater the tensile strength. The volume of steel fiber used in this research is still in medium limit, therefore value of the split tensile strength has not decreased as the amount of steel fiber increases.

3.2 Flexural strength test results
The results of flexural testing were carried out to determine the flexural strength of concrete using ALWA Styrofoam and steel fibers. The loading used for flexural strength testing is a third point loading. The test material used for flexural strength testing is Styrofoam ALWA concrete and steel fiber which has maximum compressive strength, namely concrete with a composition of 15% ALWA Styrofoam and 1.5% steel fiber (B15F1.5). From the results of the flexural strength test, the $P_{cr}$ value is obtained when the beam has the first crack and $P_{max}$ when the beam reaches the maximum load. The ability of concrete beams with ALWA Styrofoam and steel fiber to withstand maximum loads can be seen in Table 5 and Table 6 below:

| Specimens code | Dimension of beam | $P_{cr}$ | $M_{c}$ | $f$ |
|----------------|------------------|----------|---------|-----|
|                | b (mm) x h (mm) x L (mm) | y (mm) | (N)    | (N.mm) | (MPa) |
| B15F1.5 - 01   | 150 x 150 x 600 | 75      | 35690  | 3569007 | 6.34  |
| B15F1.5 - 02   | 150 x 150 x 600 | 75      | 36694  | 3669385 | 6.52  |
| Average        |                 |         | 36192  | 3619196 | 6.43  |
Figure 13. specimen 1 for flexural strength testing

Figure 14. specimen 2 for flexural strength testing

Based on Table 5 and Table 6 it can be seen that when the first crack load ($f_{cr}$) is obtained the average value of $f_r$ (modulus of rupture) is 6.43 while when reaching the maximum load the average value of $f_r$ (modulus of rupture) is 9.47 MPa. A crack pattern of the beam occurs in the middle of the span then vine vertically upward until it reaches the maximum load. The use of ALWA Styrofoam and steel fibers are able to hold the beam because the beam does not split into two parts.

4. Conclusions
Based on research and discussion of findings that have been presented previously, the following conclusions can be drawn:

- Concrete with ALWA Styrofoam without the addition of steel fiber is not able to increase the tensile strength because the binding with the paste is weak.
- Concrete without the addition of steel fibers, the concrete is still brittle and is very easily crack into two parts as the Styrofoam ALWA composition increases.
- Adding steel fibers between 0.75% and 1.5% can increase the tensile strength of concrete and can make concrete more ductile.
- The use of ALWA Styrofoam and steel fibers can restraint beams because the beam is not split into two parts when testing flexural strength.

References

[1] F. C. Chang, M. Y. Lee, S. L. Lo, and J. D. Lin, “Artificial aggregate made from waste stone sludge and waste silt,” *J. Environ. Manage.*, vol. 91, no. 11, pp. 2289–2294, 2010.
[2] V. Jagadish and R. Jagadeesan, “A Feasibility Study on Artificial Aggregates Using Waste Materials,” vol. 2, no. 3, pp. 292–296, 2015.
[3] K. Srinivasan, M. Mutharasi, R. Vaishnavi, S. Mohan, and V. Logeswaran, “An Experimental Study on Manufacture of Artificial Aggregates Incorporating Flyash, Rice Husk Ash and Iron Ore Dust,” *Int. J. Sci. Eng. Technol. Res.*, vol. 5, no. 1, pp. 163–168, 2016.
[4] J. Thomas, “Concrete made using cold bonded artificial aggregate,” *Am. J. Eng. Res.*, no. 1, pp. 2320–847, 2013.
[5] D. Rumšys, D. Bačinskas, E. Spudulis, and A. Meškenas, “Comparison of Material Properties
of Lightweight Concrete with Recycled Polyethylene and Expanded Clay Aggregates,”
*Procedia Eng.*, vol. 172, pp. 937–944, 2017.

[6] M.-H. Zhang, X. Liu, and L.-S. Chia, “High-Strength High-Performance LightWeight Concrete- A Review,” *Proc. 9th Int. Symp. High Perform. Concr.*, no. March 2014, p. 16, 2011.

[7] M. Kekanović, D. Kukaras, A. Čeh, and G. Karaman, “Lightweight concrete with recycled ground expanded polystyrene aggregate,” *Teh. Vjesn.*, vol. 21, no. 2, pp. 309–315, 2014.

[8] T. T., “Partial Replacement of Coarse Aggregates By Expanded Polystyrene Beads in Concrete,” *Int. J. Res. Eng. Technol.*, vol. 3, no. 2, pp. 238–241, 2015.

[9] M. H. Ahmad, Y. L. Lee, N. Mohd Noor, and S. H. Adnan, “Strength Development of Lightweight Styrofoam Concrete,” *Int. Conf. Civ. Eng. (May 2008)*, pp. 1–6, 2008.

[10] D. Patel, U. Kachhadia, M. Shah, and R. Shah, “Experimental Study on Lightweight Concrete with Styrofoam as a Replacement for Coarse Aggregate,” vol. 1, pp. 103–96, 2018.

[11] T. Pavlu, K. Fortova, J. Divis, and P. Hajek, “The utilization of recycled masonry aggregate and recycled EPS for concrete blocks for mortarless masonry,” *Materials (Basel).* vol. 12, no. 12, 2019.

[12] G. F. Peng, W. W. Yang, J. Zhao, Y. F. Liu, S. H. Bian, and L. H. Zhao, “Explosive spalling and residual mechanical properties of fiber-toughened high-performance concrete subjected to high temperatures,” *Cem. Concr. Res.*, vol. 36, no. 4, pp. 723–727, 2006.

[13] Y. Ding and W. Kusterle, “Compressive stress-strain relationship of steel fibre-reinforced concrete at early age,” *Cem. Concr. Res.*, vol. 30, no. 10, pp. 1573–1579, 2000.

[14] P. Kumar Mehta; Paulo J. M. Monteiro, *Concrete microstructure properties and materials*, Third Edit., no. c. California: New York: McGraw - Hill.

[15] M. J. Shannag, R. Brincker, and W. Hansen, “Pullout behavior of steel fibers from cement-based composites,” *Cem. Concr. Res.*, vol. 27, no. 6, pp. 925–936, 1997.

[16] W. Gramling and T. Nichols, “Steel-Fiber-Reinforced Concrete,” *Transp. Res. Board Spec. Rep.*, no. 148, pp. 108–116, 1974.

[17] H. Mortar, H. Cement, A. P. Apparatus, and H. Cements, “Standard Specification for,” vol. 14, pp. 1–7.

[18] C. C. Test, T. Drilled, C. Concrete, and B. Statements, “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete,” pp. 1–5.

[19] C. C. T. Speci-, T. D. Cores, and C. C. T. Speci-, “Standard Test Method for Flexural Strength of Concrete ( Using Simple Beam with,” pp. 1–3.