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Stress-strain and absorption of lightweight concrete with artificial lightweight aggregate from diatomaceous earth

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Stress-strain and absorption of lightweight concrete with artificial lightweight aggregate from diatomaceous earth

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Abstract. Lightweight concrete can be produced by using artificial lightweight aggregate (ALWA). Diatomaceous earth has extremely low density therefore can be used as a raw material to make ALWA. It is important to understand a stress-strain relationship of materials before they can be used as structural members. This paper presents the stress-strain of lightweight concrete with ALWA from diatomaceous earth based on the experimental observation. In addition, the relationship between the absorption of the lightweight concrete and the immersion time is also presented. Two types of ALWA were produced which are the ALWA made of diatomaceous earth only and the ALWA with the addition of 5% sawdust. A polynomial model of the stress-strain curve was proposed for lightweight concrete containing a different type of ALWA. The absorption of lightweight concrete with ALWA containing sawdust was higher than that of diatomaceous earth only.

1. Introduction

A deposit of 40,353,700 tons of weight diatomaceous earth in Aceh Besar District, Indonesia has been reported [1]. Some studies on the utilizing of diatomaceous earth from Aceh Besar District on supplementary cementing material have been conducted [2-6]. Due to the low density of diatomaceous earth, there is possible to make artificial lightweight aggregate (ALWA) from diatomaceous earth [7-9] and consequently lightweight concrete. The advantage of using lightweight concrete for both structural and non-structural elements is the reduction of the dead load-carrying by the members which causes the low earthquake load working on the structures as well as the low forces transfer to the soil by the foundation.

In this study lightweight concrete with ALWA from diatomaceous earth originated from Aceh Besar District was developed. For the stress analysis of existing structures as well as the design of new structures, the understanding of the stress-strain relationship of concrete is essential [10-15]. Therefore, as a new material, developing a stress-strain model of this lightweight concrete is necessary. Since diatomaceous earth is a porous material then the understanding of absorption of the developed lightweight concrete is also necessary.

The purpose of this study is to develop the stress-strain model of lightweight concrete with artificial lightweight coarse aggregate based on the experimental data. This model can be used in the designing of reinforced concrete structures using lightweight concrete as a structural material. The other aim of this study is to propose the relationship between the absorption of lightweight concrete with the immersion time.



2. Experimental program

The lightweight concrete in this study was produced by mixing cement, fine aggregate, coarse aggregate, and water in concrete mixer and mixed for about 5 minutes. The concrete specimens were cast in the steel mould. The specimens used for the stress-strain test were cylinder with a diameter of 100 mm and a height of 200 mm while those for absorption test were cube with a size of 50 mm. After 24 hours of casting, the molds were removed and the specimens were cured in water. The stress-strain and absorption tests were conducted when the specimens reached the age of 28 days.

Ordinary Portland Cement (OPC) with a specific gravity of 3.16 was used as cement material. River sand and artificial lightweight aggregate (ALWA) were used as fine and coarse aggregate, respectively. ALWA was made from diatomaceous earth, which is originated from Beureunut Village, Aceh Besar District. Two types of ALWA were made. For the first type, only diatomaceous earth was used as the raw material. For the second type, 5% of sawdust was added on the diatomaceous earth. The diatomaceous earth was ground and sieved by sieve #200. The diatomaceous earth powder was mixed with 5% sawdust to produce the second type of ALWA. The water was added on the diatomaceous earth powder little by little and pellets with the size ranging from 5 mm to 19 mm were made by hand. Later the pellets were roasted at the temperature of 100°C for 24 hours and burned at the temperature of 650°C for 5 hours in the brick burning furnace. The produced ALWA is shown in Figure 1.

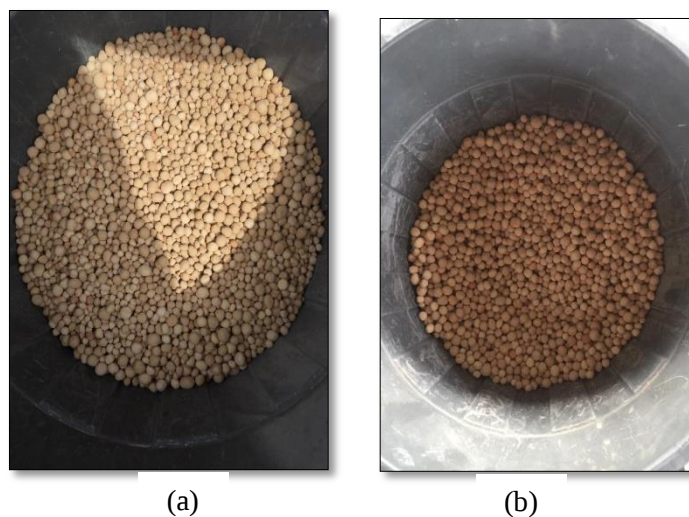


Figure 1. ALWA: (a) made of diatomaceous earth only; (b) made of diatomaceous earth and 5% sawdust.

Table 1. Physical properties of aggregate.

Physical Properties	River Sand	ALWA Type 1	ALWA Type 2
Bulk density (kg/litre)	1.684	0.724	0.623
Specific gravity (oven dry)	2.575	1.461	1.360
Specific gravity (saturated surface dry)	2.518	1.645	1.516
Absorption (%)	2.272	11.499	13.253
Fineness modulus	2.879	6.665	6.874

The bulk density, specific gravity, absorption, and fineness modulus of aggregate were tested according to ASTM C29/C29M-17a, ASTM C127-15, ASTM C128-15, and ASTM C136/C136M-14, respectively [16-19] and the results are shown in Table 1. The concrete mix proportion was designed based on ACI 211.2-98 [20] and shown in Table 2.

Table 2. Mix proportion of concrete for 1 m³ volume.

Materials	ALWA Type 1	ALWA Type 2
Cement (kg)	448.271	448.271
Sand (kg)	718.961	778.309
ALWA (kg)	623.163	536.230
Water (kg)	201.722	201.722
w/c	0.45	0.45

To obtain the stress-strain curve of lightweight concrete, a compression load was applied on the cylinder specimens according to ASTM C39/39M-18 [21] through an actuator until the specimens failed as shown in Figure 2. The deformation of the specimens was recorded by placing 2 transducers on the frame which was connected to the specimens while the load increment was recorded by the load cell. The data of load and deformation was transferred to a data logger and the stress and strain were then calculated.

**Figure 2.** Stress-strain test on concrete specimens.

The absorption of lightweight concrete was tested on the 50 mm cube specimens. The specimens were first roasted at the temperature of 100°C for 24 hours and the weight of the specimens was measured. The specimens were again roasted at the temperature of 100°C for 24 hours and the weight of the specimens was again measured. This process was repeated until the weight of the specimens gets constant. The specimens then were immersed in the water and the weight was measured. At the first 30 minutes of the immersion, the weight of the specimens was measured every 5 minutes. In the second 30 minutes of the immersion, the weight of the specimens was measured every 10 minutes. At the third 30 minutes of the immersion, the weight of the specimens was measured every 15 minutes. In this stage, the weight of the specimen became relatively constant. The immersion was continued until the weight of the specimens gets constant.

3. Results and discussion

3.1. Stress-strain relationship

Stress-strain relationships of 5 specimens of lightweight concrete with ALWA type 1 and ALWA type 2 are plotted in Figure 3 and 4, respectively. Those figures show that the stress-strain curve of

lightweight concrete is nonlinear even at the beginning of the application of loading. This nonlinear of stress-strain curve is due to the slip of aggregate from the cement paste and the close of void in the concrete when the loading is applied. The stiffness of the concrete decreases with the increase of applied stress due to the initiation and propagation of a crack in the concrete. Therefore, in this study, the non-linear stress-strain models for lightweight concrete with ALWA made from diatomaceous earth were developed.

To develop the stress-strain model, the stress data in Figure 3 and 4 was normalized with maximum stress while the strain data was normalized with strain at peak stress. By using the polynomial regression analysis and considering the initial condition of the material before loading (strain is zero at zero stress), then the stress-strain models of lightweight concrete with ALWA made from diatomaceous earth can be written as follows:

For lightweight concrete with ALWA type 1:

$$\sigma_c' = f_c' \left[2.2 \left(\frac{\varepsilon_c'}{\varepsilon_{co}'} \right) - 1.2 \left(\frac{\varepsilon_c'}{\varepsilon_{co}'} \right)^2 \right] \quad (1)$$

$$R^2 = 0.96$$

For lightweight concrete with ALWA type 2:

$$\sigma_c' = f_c' \left[1.8 \left(\frac{\varepsilon_c'}{\varepsilon_{co}'} \right) - 0.8 \left(\frac{\varepsilon_c'}{\varepsilon_{co}'} \right)^2 \right] \quad (2)$$

$$R^2 = 0.98$$

where: σ_c' = concrete stress; ε_c' = concrete strain; f_c' = concrete compressive strength; and ε_{co}' = concrete strain at peak stress. Since the concrete compressive strength and concrete strain at peak stress are material properties, the stress-strain curve of concrete can be drawn once those two parameters are known. The stress-strain curves of lightweight concrete tested in this study calculated by equations (1) and (2) are also plotted in Figure 3 and 4. A good correlation between presented models and experimental results proves the applicability of the models.

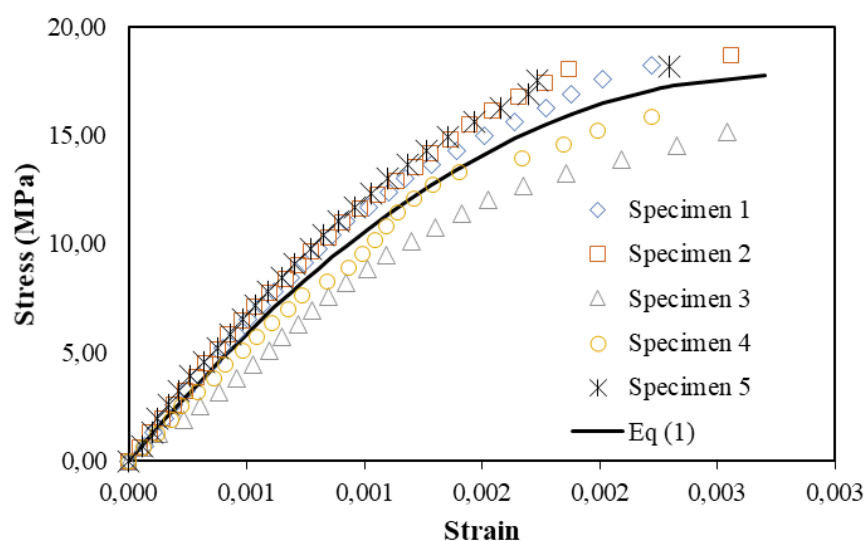


Figure 3. Stress-strain relationship of lightweight concrete with ALWA type 1.

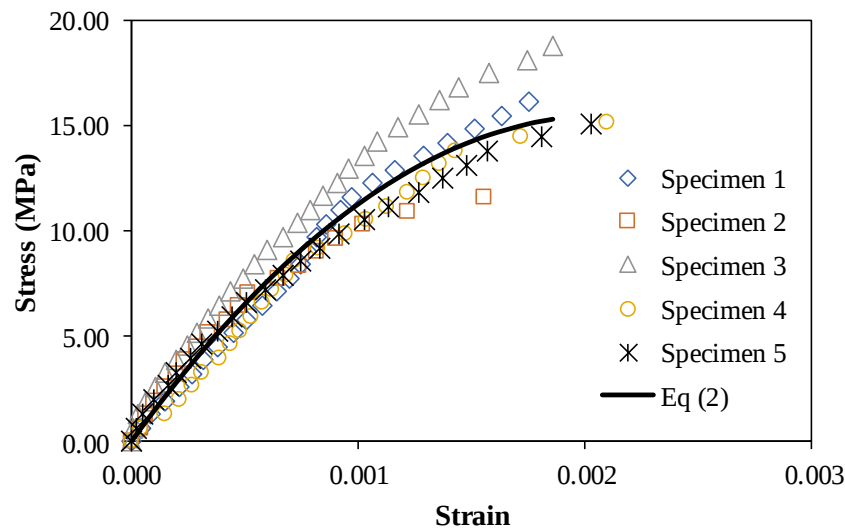


Figure 4. Stress-strain relationship of lightweight concrete with ALWA type 2.

3.2 Absorption

The absorption of 5 lightweight concrete cube specimens with ALWA type 1 and ALWA type 2 as a function of immersion time is shown in Figure 5. Since after 105 minutes of immersion the absorption became constant, only the absorption of lightweight concrete until 105 minutes of immersion is shown in Figure 5. This figure shows that the absorption of lightweight concrete with ALWA type 2 had higher absorption. This is because of the presence of sawdust in the ALWA type 2 so that can absorb more water. As shown in Table 1 the ALWA type 2 had higher absorption compared to ALWA type 1 resulted in higher absorption of lightweight concrete with ALWA type 2. Using the regression analysis, the relation between the absorption of lightweight concrete with ALWA from diatomaceous earth can be written as follows:

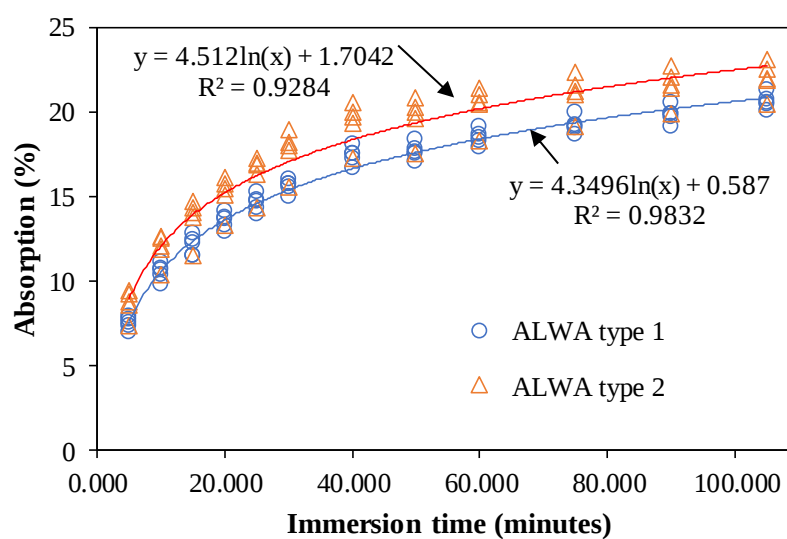


Figure 5. Absorption of lightweight concrete with ALWA from diatomaceous earth.

For lightweight concrete with ALWA type 1:

$$y = 4.350 \ln(x) + 0.587 \quad (3)$$

$$R^2 = 0.98$$

For lightweight concrete with ALWA type 2:

$$y = 4.512 \ln(x) + 1.704 \quad (4)$$

$$R^2 = 0.93$$

where y = absorption (%) and x = immersion time (minutes).

4. Conclusions

Based on the results in this study the following conclusions can be drawn:

1. A two-degree polynomial stress-strain model of lightweight concrete with artificial lightweight coarse aggregate (ALWA) was developed by using regression analysis. Two types of ALWA were produced which are ALWA made from diatomaceous earth only and ALWA made from diatomaceous earth with the addition of 5% sawdust. The model for concrete with the two different types of ALWA was the same as the difference is only in the regression constants.
2. The absorption of lightweight concrete with artificial lightweight coarse aggregate (ALWA) increased with the immersion time until 105 minutes. After 105 minutes of immersion in the water, the absorption became constant. The absorption of concrete with ALWA containing sawdust had higher absorption.

5. Acknowledgement

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