Effect of lightweight aggregates prepared from fly ash on lightweight concrete performances

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Abstract. Lightweight aggregates were prepared from fly ash of by-products from the paper industry. The influence of the ratio of clay to fly ash and processing conditions on lightweight aggregates properties were investigated. It was found that the amount of fly ash directly affected to porosity of lightweight aggregates. Lightweight aggregates with the ratio of clay to fly ash at 80:20 wt% using the sintering temperature at 1210°C exhibits bulk density of 1.66 g cm^{-3}, compressive strength of 25 MPa and water absorption of 0.55%. The replacement of coarse aggregates with lightweight aggregates at 100 wt% for concrete production showed the ultimate properties of concrete with density of 1780 g cm^{-3}, water absorption of 3.55%, compressive strength of 40.94 MPa and thermal conductivity of 0.77 W $m^{-1}K^{-1}$. The concrete had more than 25% weight reduction while keeping a similar compressive strength to an ordinary concrete. This is revealed that lightweight aggregates could be applied into structural concrete because it was able to reduce work load and increase safety factor of construction.

1. Introduction

Fly ash is an industrial waste of by-products from the power plant that needs to be disposed of in an environmental friendly way. Fly ash contains high content of silica and alumina which is suitable for using as a pozzolanic material in concrete [1]. The properties, classification and determining possible areas of usage of fly ash have attracted for many applications. Depending on the properties of fly ash, many year areas of application mainly in sectors of cement, ceramic, paint, plastic, agriculture, environment and construction are suggested in relevant literatures [2]. Fly ash is widely used in production of cement, concrete, cellular concrete, bricks, lightweight construction aggregate and soil stabilization. Fly ash contains aluminates and amorphous silicate minerals. Pozzolanic ash has the ability to react with slaked lime and water. The reaction occurring between lime and silica occurs based upon CaO-SiO_2-H_2O (C-S-H) formulation [3]. Hydration reactions can also take place to form CaO-Al_2O_3-SiO_2-H_2O (C-A-S-H) phases contributing to the strength of the final product [4]. These properties of fly ash provide an important advantage for the utilization of fly ash in production of construction materials. The use of fly ash in construction materials and concrete production is relatively low in Turkey when compared to that of Germany, the Netherlands, United Kingdom, United States and China [5]. Recently, lightweight concrete is attracted which possess significantly lower bulk density (<1900 kg m^{-3}) than standard concrete, but good strength (30-80 MPa) [6, 7]. Advantages of lightweight concretes are lighter structure, smaller, easier for handling and transporting

[8]. Fly ash can be produced lightweight aggregates by adopting pelletization which results in product light weight due to the presence of pores [9].

In this study, the influence of the ratio of clay to fly ash on lightweight aggregates properties were investigated. The performance of lightweight concretes were determined in terms of microstructure, density, thermal conductivity, water absorption and compressive strength.

2. Experimental

Fly ash used in lightweight aggregates production is an unused by-products from paper industry. The chemical composition of fly ash and clay were performed by X-ray fluorescence spectrometer (XRF). The chemical composition of fly ash are SiO_2 (2.17%), Al_2O_3 (0.51%), Fe_2O_3 (0.70%), CaO (68.00%), MgO (5.06%), K_2O (7.09%), SO_3 (6.40%), P_2O_5 (4.89%) and Na_2O (0.20%). For the chemical composition of clay are SiO_2 (60.55%), Al_2O_3 (23.50%), Fe_2O_3 (7.95%), CaO (0.99%), MgO (1.44%), K_2O (3.26%), SO_3 (0.11%), P_2O_5 (0.18%) and Na_2O (0.92%). Lightweight aggregates were produced by ball-milling the mixing of clay and fly ash for 1 h. The ratios of clay to fly ash were 90:10, 80:20, 70:30 and 60:40 wt%. A pelletizer disc was used forming lightweight weight aggregates. Then lightweight aggregates were dried at 60°C for 24 h and sintered at 1190, 1200 and 1210°C. The compressive strength of lightweight aggregates was performed on pellets placed between two plates of a hydraulic pressure machine and loaded diametrically until the failure occured. Lightweight aggregates were tested in oven dry condition utilizing shoveling and rodding procedure to determine the loose and rodded bulk densities according to ASTM C 29-09. The microstructure of lightweight aggregates was observed by optical microscopy (OM). Lightweight aggregates were partially used as a replacement of the coarse aggregate in concrete. The ratios of lightweight aggregate to coarse aggregate were 0:100, 50:50 and 100:0 wt%. Using the proportions of cement, sand and coarse aggregate is equal to 1:1:2 by weight. Then the microstructure of lightweight aggregates was observed by scanning electron microscopy (SEM). The physical properties, density, thermal conductivity, water absorption and compressive strength of lightweight concrete were investigated.

3. Results and discussion

The bulk density and compressive strength of lightweight aggregates with various ratios of clay to fly ash using the sintering temperature of 1190, 1200 and 1210°C are presented in figure 1. It can be seen that lightweight aggregates was low bulk density and high compressive strength at 70:30 and 80:20 wt% using the sintering temperature at 1210°C (figure 1(c)). For the water absorption of lightweight aggregates are shown in table 1. The lightweight aggregates was lowest water absorption at 80:20 wt% using the sintering temperature of 1210°C. The high quality of lightweight aggregates were low density, high compressive strength and low water absorption. As the results, the lightweight aggregates at 80:20 wt% using the sintering temperature of 1210°C exhibited lowest bulk density, high compressive strength and low water absorption with 1.66 g cm^{-3}, 25 MPa and 0.55%, respectively.

The properties of lightweight aggregates such as bulk density, water absorption and compressive strength depends on the microstructure of lightweight aggregates in the ratio of sintering temperature. Figure 2 shows the microstructure of lightweight aggregate at 80:20 wt% using the sintering temperature of 1190, 1200 and 1210°C. The external structure of the lightweight aggregates showed the surface glaze orange peel of sintering temperature range. During the molten glaze will occur bubble up inside. The bubbles will increase size and volume by trying to push out to the surface. The glaze is very viscous, it can be difficult pushed out air bubbles to the surface. This is due to mainly calcium oxide (CaO) in large quantities of fly ash. Therefore, the viscosity of the glaze is reduced by changing the sintering temperature. The silica (SiO_2) and calcium oxide (CaO) cause glaze which can reduce the viscosity of glaze during sintering. The silica content increases, the density of the microstructure decreases. The calcium oxide (CaO) affects to carbon dioxide (CO_2) reaction which produces gas and air bubbles. This is confirmed to the pore structure of lightweight aggregates. The optimum condition of lightweight aggregates is 80:20 wt% using the sintering temperature of 1210°C.

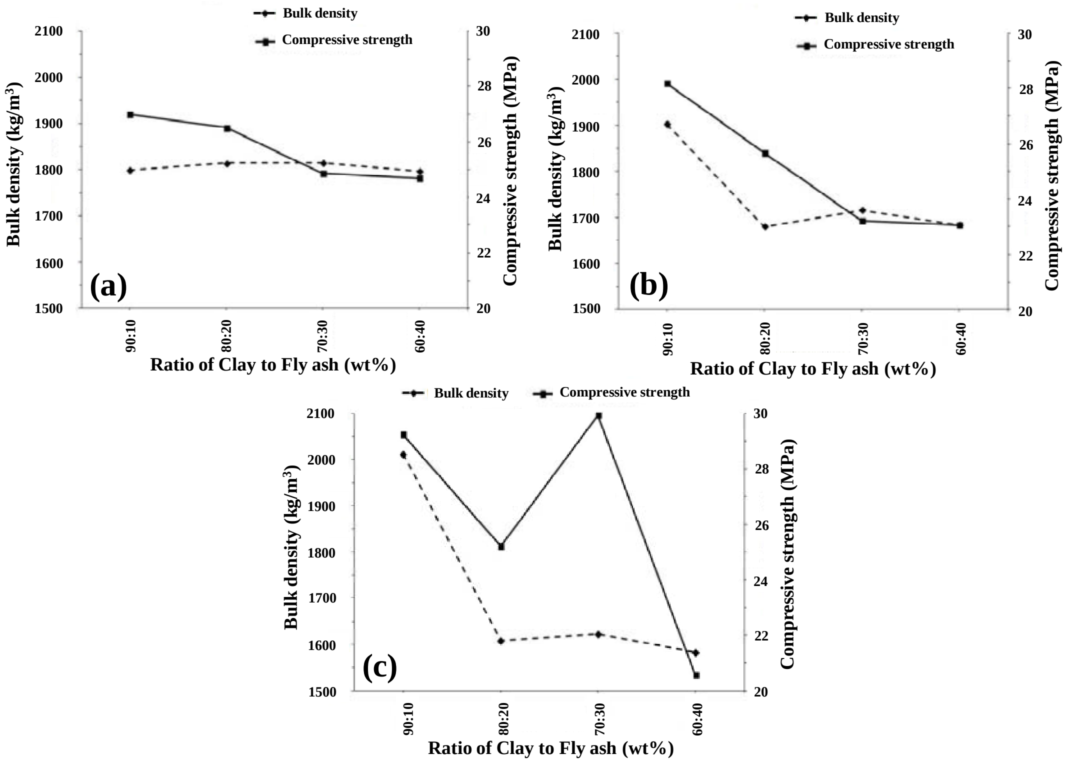

Figure 1. Bulk density and compressive strength of lightweight aggregates with various ratios of clay to fly ash using sintering temperature of (a) 1190, (b) 1200 and (c) 1210°C.

Table 1. Water absorption of lightweight aggregates.

Temperature (°C)	Water absorption (%)			
	90:10	80:20	70:30	60:40
1190	2.63	0.36	2.24	2.33
1200	1.58	0.43	2.63	2.81
1210	1.03	0.55	3.48	4.32

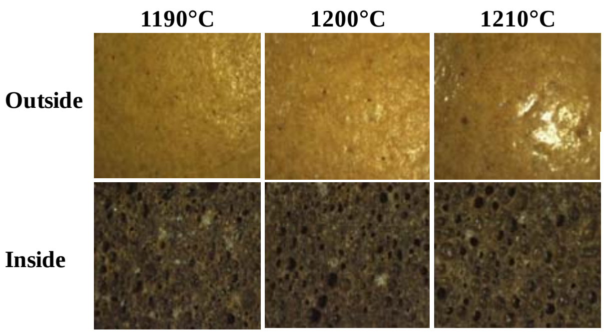

Figure 2. Microstructure of lightweight aggregates (outside and inside) at 80:20 wt% using the sintering temperature of 1190, 1200 and 1210°C.

The microstructure of concrete containing lightweight aggregates at 80:20 wt% using the sintering temperature of 1210°C is shown in figure 3. The microstructure of concrete exhibites reactive pozzolan and phase of C-S-H handles together to close with pore structure of lightweight aggregates. The properties of lightweight concretes such as weight, density, water absorption, compressive strength and thermal conductivity are shown in table 2. The replacement of coarse aggregates with lightweight aggregates were 0, 50 and 100 wt%. With the increasing of lightweight aggregates, the properties such as weight, density and thermal conductivity of lightweight aggregates decrease. The water absorption increases with the increasing of replacement of lightweight aggregates. The use of lightweight aggregates instead of coarse aggregates in concrete production decreased the weight, density and thermal conductivity due to the high porosity and highly water absorption. The replacement of coarse aggregates with lightweight aggregates at 100 wt% showed the density of 1780 g cm^{-3}, water absorption of 3.55%, compressive strength of 40.94 MPa and thermal conductivity of 0.77 W $m^{-1}K^{-1}$. The concrete had more than 25% weight reduction. Therefore, lightweight aggregates with the ratio of clay to fly ash at 80:20 wt% using the sintering temperature of 1210°C promotes appropriate properties for structural concrete. The lightweight concrete is significantly lower density than standard concrete (<1900 kg m^{-3}) and good strength.

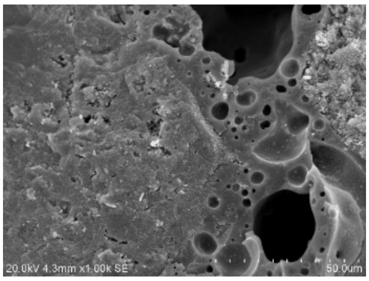

Figure 3. Microstructure of concrete contains lightweight aggregates at 80:20 wt% using the sintering temperature of 1210°C.

Table 2. Properties of lightweight concretes.

Replacement (%)	Weight (g)	Density (kg m^{-3})	Water absorption (%)	Compressive strength (MPa)	Thermal conductivity (W $m^{-1}K^{-1}$)
0	2228	2210	1.08	42.34	60.55
50	2081	2030	1.54	41.79	23.50
100	1822	1780	3.55	40.94	0.92

4. Conclusions
Lightweight aggregates were prepared by the ratios of clay to fly ash of 80:20 wt% using the sintering temperature of 1210°C provided low bulk density, high compressive strength and low water absorption. The bulk density and compressive strength were 1.66 g cm^{-3} and 25 MPa, respectively. The use of lightweight aggregates instead of coarse aggregates in lightweight concrete production provided significantly lower density than standard concrete and good strength. The replacement of coarse aggregates with lightweight aggregates at 100 wt% showed the density of 1780 g cm^{-3}, water absorption of 3.55%, compressive strength of 40.94 MPa and thermal conductivity of 0.77 W $m^{-1}K^{-1}$.

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