Fly Ash Based Lightweight Geopolymer Concrete Using Foaming Agent Technology

MOHD MUSTAFA AL BAKRI ABDULLAH[1,2]*, MUHAMMAD FAHEEM MOHD TAHIR[3], KAMARUDIN HUSSIN[1,3], MOHAMMED BINHUSSAIN[4], IOAN GABRIEL SANDU[5], ZARINA YAHYA[3], ANDREI VICTOR SANDU[2,5]*

[1]Faculty of Engineering Technology, Universiti Malaysia Perlis (UniMAP), P.O. Box 77, D/A PejabatPosBesar, Kangar, Perlis 01000, Malaysia

[2]Faculty of Technology, Universitas Ubudiyah Indonesia (UUI), JlnAlue Naga DesaTibang, Banda Aceh, Indonesia

[3]Center of Excellence Geopolymer & Green Technology (CeGeoGTech), School of Material Engineering, Universiti Malaysia Perlis (UniMAP), P. O. Box 77, d/a Pejabat Pos Besar, 01000 Kangar, Perlis Malaysia.

[4]King Abdul Aziz City Science & Technology (KACST), P.O Box 6086, Riyadh 11442, Kingdom of Saudi Arabia

[5]Gheorghe Asachi Technical University of Iasi, Faculty of Materials Science and Engineering, 71 D. Mangeron Blv., 700050, Iasi, Romania

This paper presents the mechanical properties of a lightweight geopolymer concrete synthesized by the alkali-activation of a fly ash source (FA) produced by mixing a paste of geopolymer with foam produced by using NCT Foam Generator. Two curing conditions are used, curing at room temperature and curing in an oven with a constant temperature which is 60°C. Bulk density showed that fly ash-based geopolymer lightweight concrete is light with the density of 1225 kg/m^3 - 1667 kg/m^3 with an acceptable compressive strength of 17.60 MPa for the density of 1667 kg/m^3.

Keyword: geopolymer, lightweight concrete, foaming agent technology, fly ash

Foam concrete produced by using either cement paste or mortar in which air in large numbers is trapped by using foaming agents. Foam concrete has high thermal flow capacity, low density, uses the minimum aggregate, controlled low strength, and has good thermal insulation properties [1]. Foam concrete can be produced either through the pre-foaming or foaming mixtures [1]. In the pre-foaming method, a suitable foaming agent is mixed with water and foam combined with a paste or mortar. Meanwhile, in the mixed foaming method, foaming agent is added to the paste mixture, and the mixture is brought to stable mass densities required [1].

Production of stable foam concrete mix depends on many factors such as the selection of foaming agent, the method used to prepare the foam to obtain uniform distribution of air pores, choice of materials, mix design strategies, and the processing of foam concrete [2]. Various foaming agents have been used to produce foam concrete, including detergents, hydrolyzed proteins, such as keratin materials and so on. [3].

Normally, ordinary Portland cement foam, concrete and Portland cement quick drive was used [4-6], along with high alumina and calcium sulfoaluminat [7], in order to reduce the setting time and increase early strength. Foam concrete production costs can be reduced by replacing Portland cement with fly ash (De Rose & Morris, 1999) and blast furnace slag sand (GGBS) [7] in quantities between 30 - 70% and 10 - 50%. With this replacement, the long-term strength of concrete foam is improved and heat of hydration is reduced. In addition, the strength of the concrete can be increased by 10% by replacing Portland cement with silica fume [8].

According to Nehdi [9], typically a trial and error method was adopted to achieve concrete foam with the desired properties. For the mix and density are given, based on the rational proportion of solid volume calculation was proposed by McCormick [10]. Based on this research, design assistance ACI 523 [11] with the plastic density and compressive strength, the use of either cement or water-cement ratio can be selected for the strength and density of which was granted. ASTM C796 [12] giving a method of calculating the volume of foam required to make a cement slurry that has been known to water-cement ratio and the density of the target. Kearsley and Mostert [13] proposed a set of equations (the density and volume of foam concrete), written in terms of the composition of the mixture, in order to calculate the volume of foam and cement. Kearsley and Wainright [3] used cement ratio of 1:1 based on the foam volume method.

For the compressive strength on the 28th day, filler-cement ratio and the fresh density, normal mix design was done according to Ramamurthy [14], which determinates the constituents of the mixture as a percentage of the volume of foam, water, cement and fly ash replacement percentage.

Most of the proposed method, helps in calculating the batch quantities if mixing ratio is known. Although the strength of foam concrete depends on the density, with the given density, the strength can be increased by changing the constituent materials. For a given density as well, the needs of the volume of foam concrete depend on constituent materials [14]. Hence the need for strength and density are given, the mix design strategy will be able to determine the quantity of the batch. Other similar studies have been taken into consideration on various paramters [15-19]

Experimental part

Foaming Agent

Lightweight geopolymer concrete (also known as foam concrete) is produced by mixing a paste of geopolymer

* *email: mustafa_albakri@unimap.edu.my, or sav@tuiasi.ro*

Sample	Fly Ash: Alkaline Activator	Na_2SiO_3/NaOH	Foam: Geopolymer Paste	Curing Temperature
LC1	2:1	2.5:1	1:1	Room temperature
LC2	2:1	2.5:1	1:1	60 °C
LC3	2:1	2.5:1	2:1	Room temperature
LC4	2:1	2.5:1	2:1	60 °C
LC5	2:1	2.5:1	2.5:1	Room temperature
LC6	2:1	2.5:1	2.5:1	60 °C

Table 1
GEOPOLYMER LIGHTWEIGHT CONCRETE MIX DESIGN

Sample	Fly Ash: Alkaline Activator	Na_2SiO_3: NaOH	Foam: Geopolymer Paste	Density (kg/m^3)	Strength (MPa)
LC1	2:1	2.5:1	1:1	2293	17.32
LC2	2:1	2.5:1	1:1	2216	22.19
LC3	2:1	2.5:1	2:1	1722	13.45
LC4	2:1	2.5:1	2:1	1667	17.60
LC5	2:1	2.5:1	2.5:1	1357	3.89
LC6	2:1	2.5:1	2.5:1	1215	6.75

Table 2
DENSITY AND COMPRESSIVE STRENGTH OF THE 7TH DAY LIGHTWEIGHT GEOPOLYMER CONCRETE CURED AT 60 °C

with foam produced by using *NCT Foam Generator*, Malaysia which uses plasticizer additives as a compressed foam agent in NCT machines to reduce production costs.

Mix Proportion

The ratio of geopolymer paste to the foam is between 1:1, 1:2 and 1:3 by volume ratio method without the use of lightweight aggregate. Design capacity is used in any mixing condition with production 4 liters of foam per second. The ratio of fly ash / alkaline activator solution and Na2SiO3/NaOH ratio derived from the ratio of geopolymer paste as possible. Table 1 shows the mix design of lightweight geopolymer concrete. Two curing conditions are used, curing at room temperature and curing in an oven with a constant temperature optimum obtained from the optimum design based on the previous experimental curing temperature.

Result and discussions

Lightweight Concrete Strength and Density

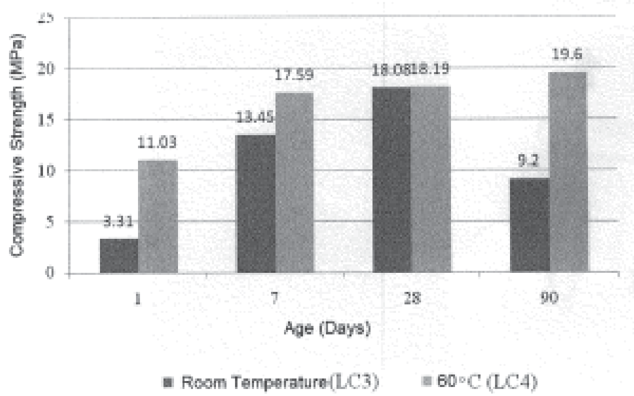
Table 2.0 shows the density and compressive strength of lightweight geopolymer concrete. The mix design of this study is taken from the best mix design for geopolymer past the ratio of fly ash/alkaline activator solution which is 2.0 and ratio, sodium silicate/NaOH which is 2.5 with a curing temperature of 60°C and also cured at room temperature. This table shows the sample L1 and L2 do not achieve the objective of creating lightweight concrete, which have more than 1800 kg/m^3 density when compared to other samples although achieved the highest strength.

From the table 2.0, shows that the compressive strength of the samples LC2 gives highest compressive strength at day 7 with 22.19 MPa compared to LC4 and LC6. LC2 achieved high strength because of the ratio of foam to geopolymer paste 1:1. However, this strength is not in line with the desired density, which should be less than 1800 kg/m^3 similar with the study by Narayanan [1]. Lightweight concrete density is between 300 - 1800 kg/m^3. LC2 achieve density 2216 kg/m^3 which exceed the target density compared with other samples of 1722 kg/m^3 for sample LC3, LC4 with 1667 kg/m^3, LC5 and LC6 with density 1357 kg/m^3 and 1215 kg/m^3 respectively. Samples LC4 and LC6 both have a density of less than 1800 kg/m3. LC4 show higher strength of 17.60 MPa compared with 6.75 Mpa for sample LC6 for the strength tested at day 7 in the curing oven. Curing at room temperature shows low densities due to the sufficient heat to stimulate geopolymerization process.

Compressive Strength, Porosity and Water Absorption with Various Curing Conditions

Figure 1 shows the compressive strength at day 1, 7, 28 and 90 for lightweight geopolymer concrete with the curing temperature at room temperature (25 to 27 ° C) and cured at 60 °C. For each day of the test (1, 7, 28 and 90 days), the maximum compressive strength were observed the samples cured at room temperature (LC3) and cured at 60 °C in an oven (LC4). LC4 samples show values of higher compressive strength for days 1, 7, 28 and 90 were compared with the samples cured at room temperature, which is 11.0 MPa, 17.6 MPa, 18.2 MPa and 19.6 MPa respectively.

Interesting trends obtained in figure 1 which shows strength on days 28 and 90 for both samples LC3 and LC4 are almost the same. Therefore, it can be concluded that the curing temperature affects the early compressive strength of geopolymer as reported by Hardjito [20]. The increase in the strength of the sample LC4 almost complete after day seven. It has been proved by the fact that the rate of strength increment only increased slightly until day 28 and thereafter. However, for LC3, the results show a significant difference in strength from day 1, 7, 28 and 90. This proves that the heat treatment is needed to accelerate the process of geopolymerization.



Both samples show that the compressive strength on day 28 and 90 did not give a lot of difference. Less than 8% increment between the 28 days to the 90 days. This shows lightweight geopolymer concrete achieved maturity on the 28 days and maybe early because the strength increments from the 7 days to the 28 days is around 3%. The decrease in the strength of the 90 day of samples cured at room temperature is caused by the initial geopolymerization does not occur properly and this creates an unstable solid

Table 3
AVERAGE POROSITY AND WATER ABSORPTION OF LIGHTWEIGHT GEOPOLYMER CONCRETE

Sample	Curing Temperature	Porosity (%)	Water Absorption (%)
LC3	Room temperature	15.29	2.35
LC4	60 °C	6.78	1.22

structure despite high initial strength. This is because, geopoly-merization process still occurs after the 90th day.

Lightweight geopolymer concrete porosity is defined as the amount of entrained air voids and voids in geopolymer paste. Porosity and water absorption of LC4 samples is the lowest that contribute to a higher compressive strength. This is because, the sample is more compact and less pores existence contributes to high compressive strength results. Samples LC3 gives porosity and water absorption results 15.29 and 2.35% respectively while LC4 samples showed lower values of porosity and water absorption which is 6.78% and 1.22% respectively as shown in table 3. Water absorption for the two samples are categorized as low as the percentages is less than 3% based on BS 1881:122 [21].

Conclusions

Based on the selected trial and error method, this study successfully produced a lightweight geopolymer concrete by using foam produced by the foaming machine with a solution of plasticizer. Bulk density showed that fly ash-based geopolymer lightweight concrete is light with the density of 1225 kg/m^3 - 1667 kg/m^3 with an acceptable compressive strength of 17.60 MPa for the density of 1667 kg/m^3. It will be a reference for other researchers as there are no other researchers focus on the study of lightweight geopolymer concrete.

References

1.NARAYANAN, N., RAMAMURTHY, K., ACI Materials Journal, **97**, 2000, p. 367.
2.***, Cement and Concrete Institute, Foamed Concrete, Cement and Concrete Institute: Midrand, South Africa, 2010.
3.KEARSLEY, E.P., WAINWRIGHT, P.J., Cement Concrete Research, **31**, 2001, p. 105
4.DE ROSE, L., MORRIS, J., Specialist Techniques and Materials for Construction (Editors Dhir, R.K., Handerson, N.A.), Thomas Telford, London, 1999, p. 185.
5.TURNER, M., Proceedings of One Day Seminar on Foamed Concrete: Properties, Applications and Latest Technological Developments; Loughborough University: Leicestershire, 2001, p. 12
6.JONES, M.R., MCCARTHY, A., Fuel, **84**, 2005, p. 1398.
7.PICKFORD, C., CROMPTON, S., Concrete, **1996**, p. 14.
8.KEARSLEY, E.P., Appropriate Concrete Technology (Editors Dhir, R.K., McCarthy, M.J.), E & FN Spon, London, 1996, p. 233.
9.NEHDI M., DJEBBAR Y., KHAN A., ACI Materials Journal, **98**, 2001, p. 402.
10.MCCORMICK F.C., ACI Material Journal, **64**, 1967, p. 104.
11.***, ACI Committee 523, Guide for cellular concretes above 50 pcf, and for aggregate concretes above 50 pcf with compressive strengths less than 2500 psi, ACI Journal **72**, 1975, p. 50
12.ASTM C 796-97. Standard test method for foaming agents for use in producing cellular concrete using preformed foam, Philadelphia, 1997.
13.KEARSLEY, E.P., MOSTERT, H.F., Use of foamed concrete in construction (Editors Dhir, R.K.) London, Thomas Telford, 2005, p. 29
14.RAMAMURTHY, K., KUNHANANDAN NAMBIAR, E.K., INDU SIVA RANJANI, G., Cem. Concr. Compos., **31**, 2009, p. 388
15.YAHYA, Z., ABDULLAH, M.M.A., HUSSIN, K., ISMAIL, K.N., SANDU, A.V., VIZUREANU, P., ABD RAZAK, R., Rev. Chim. (Bucharest), **64**, no. 12, 2013, p. 1408.
16.IBRAHIM, W.M.W., ABDULLAH, M.M.A., SANDU, A.V., HUSSIN, K., SANDU, I.G., ISMAIL, K.N., RADIR, A.A., BINHUSSAIN, M., Rev. Chim. (Bucharest), **65**, no. 11, 2014, p. 1340.
17.SHAHEDAN, N.F., ABDULLAH, M.M.A., HUSSIN, K., SANDU, I., GHAZALI, C.M.R., BINHUSSAIN, M., YAHYA, Z., SANDU, A.V., Ma. Plast., **51**, no. 3, 2014, p. 258.
18.IZZAT, A.M., AL BAKRI, A.M.M., KAMARUDIN, H., MOGA, L.M., RUZAIDI, G.C.M., FAHEEM, M.T.M., SANDU, A.V., Mat, Plast., **50**, no. 3, 2013, p. 171.
19.DIMA, S.O., SARBU, A., DOBRE, T., RADU, A.L., NICOLESCU, T.V., LUNGU, A., Mat. Plast. **46**, no. 3, 2009, p. 224.
20.HARDJITO, D., RANGAN, B.V., Research report GC1. Faculty of Engineering Curtin University of Technology, Perth, Australia, 2005.
21.***, BS 1881-122, Testing concrete - Method for determination of water absorption, British Standards Institute, 1983

Manuscript received: 21.12.2014