# Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 6 (7): 1560-1565, 2006
ISSN 1812-5654


# Lightweight Aerated Concrete Incorporating Various Percentages of Slag and PFA

[1]Noor Ahmed Memon, [1]Salihuddin Radin Sumadi and [2]Mahyuddin Ramli
[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia
[2]School of Housing and Planning, Universiti Sains Malaysia

**Abstract:** The present experimental study evaluates the performance of lightweight aerated concrete incorporating various dosages of Ground Granulated Blast Furnace Slag (GGBFS) and Pulverized Fuel Ash (PFA) as partial cement replacement. Performance of the aerated concrete is investigated in terms of ultimate compressive strength, density and strength development. Eight mixes are developed and tested at the age of 7, 14 and 28 days. Specimen were cured in water (initially for 14 days) and open air (at room temperature) to examine the effect of the curing regime. The results of the study show that the mixes produced by replacing cement with slag (GGBFS) and PFA are comparable with the mix without cement replacement. It is also observed from the study that the cement-slag-PFA based lightweight aerated concrete can be produced of adequate compressive strength and capable to apply as lightweight non-load bearing concrete units.

**Key words:** Aerated concrete, lightweight, compressive strength, slag, PFA

## INTRODUCTION

Structural lightweight concrete has been used in many civil engineering applications as a very convenient alternative to conventional concrete (Cavaleri *et al*., 2003). Lightweight concrete reduces the over all self weight of the structures resulting in the reduction of the foundation size and thereby reducing the cost and other specifications too (Noor *et al*., 2006a). A number of economic and practical advantages can be derived by replacing normal high-density concrete (2200-2600 kg m$^{-3}$) made of natural hard rock aggregates with lightweight concrete of lower density (300-1900 kg m$^{-3}$) (ACI 213R-1987). Lightweight concrete can be used for construction on soils with lower load-bearing capacity (Carmichael, 1986). Reduced self weight of the structures using lightweight concrete reduces the risk of earthquake damages to the structures because the earth quake forces that will influence the civil engineering structures and buildings are proportional to the mass of the structures and building. Thus reducing the mass of the structure or building is of utmost importance to reduce their risk due to earthquake acceleration (Ergul *et al*., 2003).

The density of a given concrete can be lowered by partially replacing the solid content of the mix with air voids (Arvind *et al*., 2002). Thus the concrete without coarse aggregates and a large number of air voids induced with the help of some aeration agent, within the concrete mass is known as aerated concrete. Generally aerated concrete is cured under steam curing regime thus called as autoclaved aerated concrete (AAC). Aerated concrete refers to concrete having excessive amounts of air voids that provides a very good thermo acoustic properties thus it is applied in both hot and cold countries (Noor *et al*., 2006b; Al-Mudhaf *et al*., 1996; Ian, 1997). Modern AAC have porosities between 60 and 90% of the total volume of concrete which correspond to bulk densities between 1 and 0.3 g cm$^{-3}$ (Narayanan and Ramamurthy, 2000). AAC is produced by molding and hydrothermal processing of various raw materials containing fine sand, Portland cement and lime with traces of aluminum powder. In the mold process, the mix slurry generates hydrogen gas by the chemical reaction between fine aluminum powder and lime (Mostafa, 2005):

$$2Al + 3Ca(OH)_2 + 6H_2O \rightarrow 3CaOAl_2O_3.6H_2O + 3H_2$$

Most often lightweight concretes contain supplementary materials like silica fume, blast furnace slag and fly ash (Kayali and Zhu, 2005). These materials can also improve the durability of concrete. Comprehensive research had been carried out in the past on the use of FA, PFA, blast furnace slag, rice husk ash etc as cement replacement material in concrete. (Al-Ani and Hughes, 1989; Mehta, 1979; Bilodeau and Malhotra, 1998; Hooton, 2000). Replacement levels of Portland cements containing blast furnace slag vary considerably with contents of well over 50% by weight common in some regions (Khandakar and Anwar, 2004). FA typically replaces 10-30% of the Portland cement although levels of 50-60% have been

**Corresponding Author:** Noor Ahmed Memon, Faculty of Civil Engineering, Universiti Teknologi Malaysia H/P: 006017-7187483

advocated (Bilodeau and Malhotra, 1998). ASTM standards (ASTM C 612-97, ASTM C 989-95 and ASTM C 1240-97) exist for the use of natural pozzolans, FA, silica fume and blast furnace slag in concrete. However, the utilization of by-products in autoclaved building materials is not only controlled by suitability of these materials for this purpose but also by the local economy and the competitive position of other building materials within the area. Technically it may be possible to partly replace sand or binding material with by-products if this is accompanied with improving the end products or reducing the production cost through reduction of the autoclaving time and temperature (Mostafa, 2005). Autoclave treatment performed under high temperature and high pressure is economically and environmentally costly approach to produce aerated concrete however non-autoclaved aerated concrete would not have modified the influence of the induced porosity and mechanical anisotropy. A very little research is reported in the literature to investigate the non-autoclaved aerated concrete (Richard *et al.*, 2005; Arresh, 2002; Arresh and Fadhadli, 2002; Arresh *et al.*, 2005).

This experimental study is aimed at to investigate the suitability of GGBFS and PFA as partial replacement of cement in lightweight non-autoclaved aerated concrete. The attempt is made to replace cement partially with Ground Granulated Blast Furnace Slag (GGBFS) and Pulverized Fuel Ash (PFA) to produce non-autoclaved aerated concrete. The main objective of the study is to determine the effect of the incorporation of different percentages of GGBFS and PFA on compressive strength and the density of the specimens at 28 days. The effect of curing regime by applying two curing regimes; initial water curing (14 days) and air (at room temperature) is investigated. In addition, attempt is also made to examine the strength development of the specimens by testing those at 3, 7 and 28 days of curing.

## MATERIALS AND METHODS

**Cement:** Ordinary Portland Cement (OPC) of 'SELADANG' brand from Tenggara Cement Manufacturing Sdn. Bhd. is used during the study. The OPC used complies with the Type I Portland Cement as in ASTM C150 (1992) and BS 12 (1991) which is same as Malaysian Standard MS 522: part I (2003).

**Ground Granulated Blast Furnace Slag (GGBFS):** GGBFS is obtained from YTL Cement sdn. Bhd. at Pasir Gudang, Johor. The GGBFS used complies with the requirements in ASTM C989-89 (1992), which is same as in BS 6699 (1992).

Table 1: Detail of the mix proportion of the batches cast and tested

| Batch code | Mix proportion (binder: sand) | Cement (%) | Slag (%) | PFA (%) |
|---|---|---|---|---|
| ACC | 1:1 | 50 | 0 | 0 |
| ACSA1 | 1:1 | 50 | 10 | 40 |
| ACSA2 | 1:1 | 50 | 15 | 35 |
| ACSA3 | 1:1 | 50 | 20 | 30 |
| ACSA4 | 1:1 | 50 | 25 | 25 |
| ACSA5 | 1:1 | 50 | 30 | 20 |
| ACSA6 | 1:1 | 50 | 40 | 10 |
| ACSA7 | 1:1 | 50 | 50 | 0 |

* % = Percentage of total binder by weight, ** ACC = Aerated Concrete Control, *** ACSA = Aerated concrete with Slag (GGBFS) and Ash (PFA)

**Pulverized Fuel Ash (PFA):** PFA used for this research was provided by coal-power station located in Sepang, Selangor Malaysia. The oxides analysis (silica, alumina and iron oxide) content is approximately 83.9% of total composition. The content of CaO is less than 10% thus the PFA used during this study is of class F. The fineness of PFA complies with the specifications of ASTM C 618-84 (1992).

**Fine sand:** The sand passed from 600 μm is used during entire casting of the specimens during this study.

**Water:** Through out this experimental study tap water is used for the manufacture of the concrete.

**Superplasticizer:** The superplasticizer of trade name SIKAMENT NN is used as the chemical admixture during this study. It is type F high range water reducing admixture according to ASTM C 494-92 (1992). It is from group Sulphonated Naphthalene Formaldehyde condensates (SNF) in dry powder form.

**Aluminum powder:** The aluminum powder type Y250 is used as the gaseous agent to introduce the porosity within the mass of aerated concrete.

**Specimen preparation and testing:** In all eight batches including one control batch, each containing 18 cubes (total 144 cubes) of standard size 70.6×70.6×70.6 mm are cast and tested. Mix ratio 1:1 (binder: sand) is considered as basic mix proportion. Over all 50% cement replacement is adopted for all the mixes. The 50% cement replacement is adjusted between GGBFS and PFA by varying their proportions accordingly. One batch of control specimen without cement replacement is also cast to compare the values. The detail of batches and mix proportion is presented in Table 1. Based on the previous research conducted at UTM, Malaysia (Arresh, 2002) and with the subsequent modifications made through trial mix series, the value of water/dry mix ratio is fixed at 0.24 through out the study while the dosage of aluminum powder is fixed at

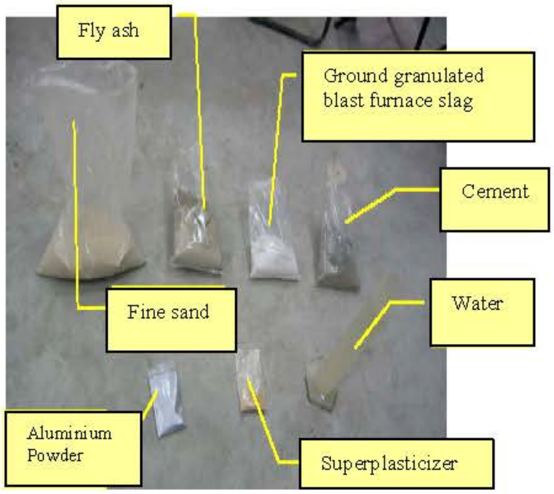


Fig. 1: Constituents of AC mix

Fig. 3: Expansion of the AC mix

Fig. 2: Mould filled with AC mix upto 80% of depth (ppox.)

Fig. 4: Specimen in TONPAK machine

0.13% by weight of dry mix and that of the superplasticizer is fixed at 0.7% by weight of the binder. All the weighed constituents were mixed in a mixer for about 3 min to achieve the uniform mix and then poured in the specimen to fill the specimen approximately up to 80% of its depth. Immediately after pouring the mix in mould, expansion started and continued for next 30-45 min. The specimens were become hard enough after 3 hours of casting (appox.) and ready to trim the expanded portion above the top of the specimens. Figures 1-3 show the casting procedure of the specimens. After 24 hours the specimens were demoulded and were placed in water tank and in open air inside room (room temperature) to apply water and air curing regime accordingly.

The specimens were removed from the curing regime approximately one hour before testing. Before applying the test of compressive strength all the specimens were weighed to determine the density of the product at the time of the testing. TONIPAK 300 testing machine available in the materials and structures laboratory UTM, Malaysia was used to conduct the test of compressive strength as per the specifications of EN679-1993 and AAC 2.1 RILEM-1992. Figure 4 depicts the specimen in TONPAK 300 machine during compressive strength test. For each test a set of 3 specimens was tested and the average of three is calculated nearest to the one digit after decimal.

## RESULTS AND DISCUSSION

Table 2 summarizes the compressive strength results of the specimen tested at different ages and cured under the two curing regimes. Regarding the compressive strength it can be observed from the table that the

Table 2: Compressive strength values of all the specimens cast and tested

| Batch | Mix (Cement replacement) | Compressive Strength (Mpa) Initial water curing 7 (days) | 14 (days) | 28 (days) | Air curing 7 (days) | 14 (days) | 28 (days) |
|---|---|---|---|---|---|---|---|
| ACC | (0%) | 3.3 | 4.2 | 6.2 | 3.5 | 3.6 | 4.4 |
| ACSA1 | 10% slag + 40% PFA | 2.9 | 3.4 | 4.7 | 3.6 | 3.2 | 4.0 |
| ACSA2 | 15% slag + 35% PFA | 4.9 | 6.8 | 9.6 | 5.6 | 6.7 | 8.2 |
| ACSA3 | 20% slag + 30% PFA | 4.4 | 5.7 | 9.1 | 4.5 | 6.5 | 7.6 |
| ACSA4 | 25% slag + 25% PFA | 4 | 5.6 | 8.6 | 4.7 | 6.1 | 7.0 |
| ACSA5 | 30% slag + 20% PFA | 3.7 | 6.0 | 8.6 | 4.0 | 5.0 | 6.6 |
| ACSA6 | 40% slag + 10% PFA | 3.3 | 7.5 | 9.3 | 3.5 | 6.2 | 7.6 |
| ACSA7 | 50% slag + 0% PFA | 2.9 | 9.0 | 11.5 | 3.2 | 7.2 | 8.9 |

Table 3: Density values of all the specimens cast and tested

| Batch | Mix (Cement replacement) | Density ( kg $m^{-3}$) Initial water curing 7 (days) | 14 (days) | 28 (days) | Air curing 7 (days) | 14 (days) | 28 (days) |
|---|---|---|---|---|---|---|---|
| ACC | 0% | 1213 | 1117 | 1046 | 971 | 965 | 960 |
| ACSA1 | 10% slag + 40% PFA | 1149 | 1082 | 989 | 936 | 918 | 912 |
| ACSA2 | 15% slag + 35% PFA | 1256 | 1190 | 1072 | 994 | 989 | 982 |
| ACSA3 | 20% slag + 30% PFA | 1308 | 1248 | 1112 | 1073 | 1065 | 1059 |
| ACSA4 | 25% slag + 25% PFA | 1373 | 1250 | 1191 | 1159 | 1153 | 1147 |
| ACSA5 | 30% slag + 20% PFA | 1380 | 1258 | 1197 | 1189 | 1181 | 1176 |
| ACSA6 | 40% slag + 10% PFA | 1388 | 1271 | 1211 | 1203 | 1190 | 1184 |
| ACSA7 | 50% slag + 0% PFA | 1393 | 1283 | 1219 | 1213 | 1194 | 1188 |

compressive strength increases with the partial replacement of cement with slag and PFA except in case of ACSA1 when cement is replaced by 10 and 40% with slag and PFA, respectively. The maximum compressive strength is achieved when slag is adopted solely as cement replacement in case of ACSA7 and the compressive strength achieved is 11.5 MPa where as the compressive strength of the order of 9.6 MPa is obtained which is the highest when cement is replaced partially with the combination of slag and PFA (15 and 35%) in case of ACSA3. The further decrease or increase in PFA content causes the decrease in the compressive strength. Hence from the compressive strength point of view the proper combination of slag and PFA as cement replacement in aerated concrete might be deduced as 15 and 35% by weight of the total binder, respectively. However the cement replacement with slag up to 50% could be considered as the most appropriate in terms of compressive strength. Therefore, regarding compressive strength it can be concluded that the aerated concrete of compressive strength ranging between 4.5 and 11.5 MPa can be produced by incorporating different dosage of slag and PFA and different curing regimes this range of compressive strength is much more as compared to the minimum compressive strength specified for the non-load bearing concrete units (ASTM C 129-85).

It is obvious from the values given in Table 2 that the initial strength gain is lower at early age of the specimens containing higher content of slag as cement replacement. However it is lower in some cases otherwise equal or more to some extent to the control in almost all other cases at 7 days. The strength gain is faster beyond 7 days and the value of compressive strength becomes rather higher than the control after at 28 days in all the cases except ACSA1 when the PFA content is highest being 40%. This trend is similar to that obtained in normal concrete and mortar mix (Noor and Salihuddin, 2005).

Comparing the compressive strength values of specimens tested at 28 days cured under two curing regimes presented in Table 2, it is apparent that the compressive strength of the specimens cured initially in water for 14 days exhibited better performance as compared to that of the specimens cured in air. This is because, the water cured specimens have enough water to continue the hydration process even after they are placed in open air after 14 days of initial curing of water thus producing more C-S-H gel which leads to the higher strength. Hence it can be deduced that the water curing of aerated concrete causes the increase in compressive strength.

The most obvious characteristic of lightweight concrete is its lower density (300-1800 kg $m^{-3}$) compared with the density of ordinary concrete (up to 2600 kg $m^{-3}$). From the Table 3 it is obvious that almost all the mixes are within the range of lightweight concrete. The lowest density is achieved in case of control mix without cement replacement. The density increases with the increase in the GGBFS content and it is highest in case of ACSA 7 when 50% cement replacement is adopted solely with slag. It is also apparent from the table that the specimens cured initially in water showed more density than the specimen cured in the air. This is due to the fact that water cured specimens become saturated and causing the production of more C-S-H gel which also contributes to the increase in the density. However after 14 days of initial water curing, the density of water cured specimens at 28 days is closer to that of the specimen cured in air.

## CONCLUSIONS

Within the scope of this experimental investigation, the following conclusions can be drawn:

- A marked improvement in compressive strength of non-autoclaved aerated concrete is achieved with the incorporation of slag and PFA as cement replacement. This trend is similar to the ordinary concrete and mortar as reported in literature.
- The combination of slag and PFA being 15 and 35% by weight of total binder might be considered as appropriate in terms of compressive strength to adopt as cement replacement.
- Maximum strength is achieved when 50% slag is added solely as cement replacement. This confirms the findings of the previous research reported in literature already conducted to develop slag-based aerated concrete.
- The density of all the mix proportions remained well below the upper limit of the lightweight concrete.
- Though the addition of slag and PFA in non-autoclaved aerated concrete also tends to the slow strength gain in early age, like in normal concrete and mortar, however it becomes faster after 7 days and the ultimate compressive strength at 28 days and later is more than that of the control mix without slag and PFA.
- Specimen cured initially in water exhibited better performance in terms of compressive strength however showed higher density.
- Since the modern trend is towards the development of lightweight structural material which may replace the existing heavyweight or non-economical lightweight structural materials. Hence this study is step towards the development of economical lightweight aerated concrete by applying partial cement replacement with by-products, slag and PFA and cured under normal curing methods instead of autoclave curing regime.
- The research presented in this study is preliminary in nature. It is therefore, suggested that the experimental study be continued to identify other major parameters of non-autoclaved aerated concrete like porosity, drying shirinkage, water absorption, thermal conductivity, microstructure and chemical characteristics etc.

## REFERENCES


ACI213R-87, Guide for structural lightweight aggregate concrete, ACI, Manual of concrete practice: Part I. Materials and general properties of concrete. Detroit, MI, USA., pp: 27.

Al-Ani, M. and B. Hughes, 1989. Pulverized-fuel ash and its uses in concrete. Mag. Concr. Res., 41: 55-63.

Al-Mudhaf, H.A. and E.K. Attiogbe, 1996. Performance of autoclaved aeratedconcrete masonry walls in Kuwait, Mater. Struct./Mater. Constr, 29: 448-452.

Arresh, V., 2002. Application of slag cement based aerated lightweight concrete in non-load bearing wall panels. M.Sc. Thesis, UTM, Malaysia.

Arresh, V. and F. Zakaria, 2002. Drying shrinkage and water absorption of slag cement based aerated lightweight concrete wall panels. Proceedings of the Research Seminar on Materials and Construction, Johor Bahru, pp: 118-134.

Arresh, V., F. Zakaria, M.H. Warid, S. Gerald and Roswadi, 2005. Microstructural investigations on slag cement based aerated lightweight concrete, Proceedings of Seminar Kebangsaan Penyelidikan Kejuruteraan Awam, SEPKA 2005, FKA, UTM, Malaysia, pp: 383-388.

Arvind, K., Suryavanshi and S.R. Narayan, 2002, Development of lightweight mixes using ceramic microspheres as fillers. Cement and Concrete Research, 32: 1783-1789.

ASTM C 989-95, Standard Specification for Blast Furnace Slag for use in Concrete and Mortars, 1995.

ASTM C 612-97, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Concrete, 1997.

ASTM C 1240-97, Standard specification for silica fume for use as a mineral admixture in hydraulic-cement concrete. Mortar and Grout, 1997.

Bilodeau, A. and V.M. Malhotra, 1998, High volume fly ash system: The concrete solution for sustainable development. Compilation of papers, Three day CANMET/ACI Symposium on Sustainable Development of the Cement and Concrete Industry, Attawa, pp: 193-214.

Carmichael, J., 1986. Pumice concrete panels. Concr. Intl. 8: 31-32.
Cavaleri, L., N. Miraglia and M. Papia, 2003. Pumice concrete for structural wall panel. Eng. Struc., 25: 115-125.
Ergul, Y., D.A. Cengiz, K. Aleaettin and G. Hassan, 2003. Strength and properties of lightweight concrete made with basaltic pumice and fly ash. Materials Lett., 57: 2267-2270.
Hooton, R.D., 2000. Canadian use of ground granulated blast-furnace slag as a supplementary cementing material for enhanced performance of concrete. Can. J. Civ. Eng., 27: 754-760.
Ian, E., 1997. Aircrete blockwork, Concrete (Lond.) 31: 10-11.
Kayali, O. and B. Zhu, 2005. Chloride induced reinforcement corrosion in lightweight aggregate high-strength fly ash concrete. Construction and Building Materials, 19: 327-336.
Khandakar, M. and A. Hossain, 2004. Properties of volcanic pumice based cement and lightweight concrete. Cement and Concrete Res., 34: 283-291.
Mehta, P.K., 1979. Properties of blended cements made from rice husk ash. J. Am. Concr. Inst., 74: 440-442.
Mostafa, N.Y., 2005. Influence of air cooled slag on physiochemical properties of autoclaved aerated concrete. Cement and Concrete Res., 35: 1349-1357.
Narayanan, N. and K. Ramamurthy, 2000. Structure and properties of aerated concrete: A Rev. Cement and Concrete Composites, 22: 321-329.
Noor, A.M. and R.S. Salihuddin, 2005. Study of ground granulated blast furnace slag as cementitious material in mortar mix. Accepted for Publication in Mehran Univ. J. Eng. Technol., Pakistan.
Noor, A.M., R.S. Salhuddin and R. Mahyuddin, 2006a. Strength and behaviour of aerated concrete encased with ferrocement box. Proceedings of Ferro-8, 8th International Symposium and Workshop on Ferrocement and Thin Reinforced Cement Composites, Bangkok, Thailand, pp: 153-164.
Noor, A.M. R.S. Salhuddin and R. Mahyuddin, 2006b. Ferrocement encased lightweight aerated concrete sandwich with variable core size and wire mesh layers. Proceedings of Ferro-8, 8th International Symposium and Workshop on Ferrocement and Thin Reinforced Cement Composites, Bangkok, Thailand, pp: 165-175.
Richard, C., B. Fiorio, A.L. Beaucour, H. Dumontet and S. Ortola, 2005. Experimental study of the mechanical anisotropy of aerated concretes and of the adjustment parameters of the introduced porosity. (In Press), Construction and Building Materials.