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Lightweight Mortar Incorporating Various Percentages of Waste Materials

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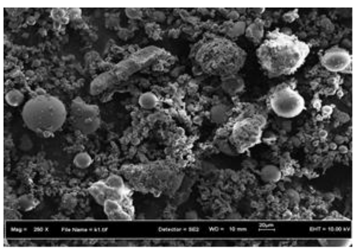
Graphical abstract



Abstract

The experimental study evaluated the performance of lightweight aerated concrete incorporating various percentages of palm oil fuel ash (POFA) and pulverized fuel ash (PFA) as partial cement replacement. Performance evaluation of the aerated concrete was investigated with respect to ultimate compressive strength, density and strength development. Twelve mixes are developed and tested at different periods, i.e. 3, 7and 28 days. In this work, two different curing regime namely air curing and water curing were used to monitor the effect of the curing regime. The results show that the mixtures produced by replacing cement with POFA and PFA were comparable to the mix without cement replacement. Furthermore, this investigation observed that the cement-POFA-PFA based lightweight aerated concrete can be produced as lightweight non-load bearing concrete units, because hazard of ashes (POFA & PFA) might be a serious issue for human health. Disposal of ashes contributes the shortage of landfill space in all the worlds, especially in Malaysia.

Keywords: Lightweight; waste materials; POFA; PFA

Abstrak

Kajian eksperimental ini adalah untuk menilai prestasi konkrit ringan berongga dengan menggabungkan beberapa peratusan abu kelapa sawit (POFA) dan abu bahan api terhancur (PFA) sebagai bahan ganti simen. Penilaian prestasi konkrit ringan berongga dikaji berdasarkan kekuatan mampatan, ketumpatan dan ujian peningkatan kekuatan. Dua belas campuran dihasilkan dan diuji untuk jangkamasa 3, 7 dan 28 hari. Dalam eksperimen ini, dua jenis pengawetan telah dijalankan iaitu pengawetan udara dan pengawetan air. Ini bertujuan untuk mengkaji kesan pengawetan keatas konkrit ringan berongga. Keputusan ujian menunjukkan bahawa campuran yang dihasilkan dengan menggantikan simen kepada POFA dan PFA setara dengan campuran tanpa penggantian simen. Tambahan pula, melalui kajian ini, didapati bahawa konkrit ringan berongga berasaskan simen-POFA-PFA boleh digunakan sebagai konkrit ringan tanpa beban, kerana abu yang berbahaya ini (POFA & PFA) mungkin salah satu isu serius yang boleh membahayakan kesihatan manusia. Penggunaan semula abu ini dapat menyelesaikan masalah kekurangan ruang tapak pelupusan di dunia, terutamanya di Malaysia.

Kata kunci: Konkrit ringan; bahan-bahan buangan; POFA; PFA

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1.0 INTRODUCTION

Lightweight concrete has been used in many civil engineering applications as a very useful alternative to conventional concrete.[1,2] Application of the lightweight concrete in structures reduces the overall self-weight and resulting in the reduction of the foundation size and by means of that reducing the cost and other specifications too.[3,4] Several economic and practical advantages can be derived by replacing normal high-density concrete 2000 kg/m^3 and above made of natural hard rock aggregates with lightweight concrete of lower density (300-1680 kg/m^3).[5] Lightweight concrete can be used for construction on soils with lower load-bearing capacity.[3] Reduced self-weight of the structures using lightweight concrete reduces the risk of earthquake damages to the structures. The earthquake forces influence the civil engineering structures and buildings are proportional to the mass of the structures. Thus reducing the mass of the structure or building is most importance to reduce their risk due to earthquake acceleration.[6]

The density of a given concrete can be lowered by partially replacing the solid content of the mix with air voids.[7] 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 autoclaved aerated concrete (AAC) meaning as aerated concrete is cured under steam curing regime. Aerated concrete refers to concrete having excessive amounts of air voids that provides a very good thermal insulation and good thermo acoustic properties thus it is applied in both hot and cold countries.[8] Noor Ahmed in (2007) report that aerated concrete was very good for tropical country such as Malaysia. 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.[9] AAC is produced by molding and hydrothermal processing of different raw materials containing fine sand, Portland cement and lime with small percentage of aluminum powder. In the mold process, equation (1) show the mix slurry generates hydrogen gas by the chemical reaction between fine aluminum powder and lime [10]:

$$2AL+3Ca(OH)_2+6H_2O \rightarrow 3CaO.AL_2O_3.6H_2O+3H_2\uparrow \quad (1)$$

Most often lightweight concretes contain supplementary materials like silica fume, blast furnace slag and POFA & PFA.[3,4,9] These materials can also improve the durability of concrete. Comprehensive research had been carried out in the past on the use of POFA, PFA, blast furnace slag, rice husk ash etc. as cement replacement material in concrete.[3,4,6,11,12] Replacement levels of Portland cements containing with POFA vary considerably with contents of well over 30% by weight common in some regions.[4,6,11,12] The POFA using to this study have same properties as standard ASTM C 618-05 because POFA don't have any standard specification until yet in Malaysia, but, exist for the use of Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolans, in concrete.[13] Anyway, the use 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. With regard to technology, 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.[10] 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. Some researcher report that a little information about to investigate the non-autoclaved aerated concrete.[3,4]

This experimental study is aimed to investigate the suitability of palm oil fuel ash (POFA) and pulverized fuel ash (PFA) as partial replacement of cement in lightweight non-autoclaved aerated concrete. The attempt is made to replace cement partially with POFA and 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 POFA and PFA on compressive strength and the density of the specimens at 28 days. The effect of curing regime by applying two curing regimes water curing and natural air are investigated. In addition, attempt is also made to examine the strength development of the specimens at 3, 7 and 28 days of curing.

2.0 MATERIALS AND METHODS

Cement: Ordinary Portland Cement (OPC) of Holcim Top Standard Cement brand from Holcim Cement Manufacturing (Malaysia) Sdn Bhd is used during the study. The OPC used complies with the Type I Portland Cement as in ASTM C150.[14]

POFA: Palm oil fuel ash (POFA) used is a by- product obtained from burning of palm oil shell and husk at temperature of 940ºC from a Kahang mill, Kluang Johor, Malaysia. Afterwards, they are ground using a modified Los Angeles abrasion test machine having 8 stainless bars, each of which is 12 mm diameter and 800 mm long in order to acquire finer particles.[15] The collected POFA were dried in the oven at the temperature of 110 °C ± 5 for 24 h to remove moisture in it before sieved and ground to obtain finer particles. The presence of higher silica content influences the pozzolanic reaction when it reacts with free lime thus creating extra C-S-H gels, which is beneficial to strength development of the POFA concrete. The sum of SiO_2 + Fe_2O_3 + Al_2O_3 of POFA is 75.37%, which is above 70%, this makes the pozzolanic material to be classified as Class N pozzolan ASTM C618-05. However, the high percentage of LOI and calcium oxide content of more than 5% , a maximum SO_3 content of 5% and a maximum alkali content (expressed as Na2O) of 1.5%, of this ash makes it to fall into class F but not class C, as enlisted in ASTM C618-05. Obviously, this finding also conforms to the observations made by Abdul Awal.[16]

PFA: Pulverise fuel Ash (PFA) used for this research was obtained from the silos of Kapar Power Station, located Selangor, Malaysia. The oxides analysis (silica, alumina and iron oxide) content is approximately 83.7% 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 618-05 (2005).

Fine sand: The sand used during this investigation passed from 600 micron sieved.

Water: In this experimental tap water is used for the manufacture of the lightweight concrete.

Superplasticizer: The superplasticizer use during this study was trade name SIKAMENT NN as chemical admixture. According to[17], that is type F high range water reducing admixture. It is from group Sulphonated Naphthalene Formaldehyde condensates (SNF) in dry powder form.

Aluminum powder: The aluminum powder use during this study type Y250 as the gaseous agent to insert the porosity within the mass of aerated concrete.

Tables 1 and Table 2 show the chemical and physical properties of OPC, POFA and PFA.

Table 1 Chemical composition of OPC, POFA and PFA

Chemical compositions %	OPC	POFA	PFA
SiO2	20.10	62.60	59
K2O	0.18	9.05	0.90
Fe2O3	2.40	8.12	3.70
CaO	65.00	5.7	6.90
Al2O3	4.9	4.65	21
P2O5	0.1248	3.86	- -
MgO	3.10	3.50	1.40
SO3	2.30	3.16	1
Cl	0.0005	0.45	- -
TiO2	- -	0.41	- -
Na2O	0.75	0.76	- -
LOI	2.00	6.25	4.62
SiO2 + Fe2O3 + Al2O3	- -	75.37	83.7

Table 2 Physical properties of OPC, POFA and PFA

Physical properties	OPC	POFA	PFA
Specific gravity	3.15	2.42	2.62
Particle retained on 45µm sieve	4.58	4.98	6.92
Median particle d10	--	1.69	--
Median particle d50	--	14.58	--
Blaine fineness (cm3/g)	3999	4935	3205
Soundness (mm)	1.0	2.0	--
Strength Activity Index (%)			
At 7days	--	80	84
At 28 days	--	84	92

In all twelve batches including one control batch, each containing 18 cubes (total 216 cubes) of standard size 100 x 100 x 100 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 POFA 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 3. Based on the previous research conducted at UTM, Malaysia[3,4] and with the subsequent modifications made through trial mix series, the value of water/dry mix ratio is fixed at 0.24 throughout the study while the dosage of aluminum powder is fixed at 0.13% by weight of dry mix and that of the superplasticizer is fixed at 0.60% by weight of the binder. All the weighed constituents were mixed in a mixer for about 4 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 35-50 min. The specimens became hard enough after 4 hours of casting (approximately) and ready to trim the expanded portion above the top of the specimens. After 24 hours the specimens were demoulded and were placed in water tank and in natural air to apply water and air curing regime accordingly.

The specimens were removed from the curing regime approximately three 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. Compression testing machines 1300 KN capacity to test cylinders up to dia. 160 x 320 mm and cubes up to 150 mm side. 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 EN679-2005 and ASTM C 39. For each test, a set of 3 specimens was tested and the average of three is calculated.

Table 3 Detail of the mixing ratio

Number of batch	Mixing ratio	Cement %	POFA %	PFA %
AC 1	1 : 1	100	0	0
AC 2	1 : 1	50	0	50
AC 3	1 : 1	50	5	45
AC 4	1 : 1	50	10	40
AC 5	1 : 1	50	15	35
AC 6	1 : 1	50	20	30
AC 7	1 : 1	50	25	25
AC 8	1 : 1	50	30	20
AC 9	1 : 1	50	35	15
AC 10	1 : 1	50	40	10
AC 11	1 : 1	50	45	5
AC 12	1 : 1	50	50	0

3.0 RESULTS AND DISCUSSION

The physical and chemical composition of POFA and PFA is shown in Table 1 and Table 2. From the table it can be seen that the materials contain high silica oxide which influences pozzolanic reaction when it reacts with free lime thus creating extra C-S-H gels, which is beneficial to strength development of the POFA and PFA concrete. The sum of silica, aluminium and iron oxide of POFA and PFA is greater than 75% of the total chemical composition, that make this pozzolanic material to be classified between class C and F pozzolan.[16] However, the material contained low CaO in the range of 4-8% and low SO_2 within the minimum allowable by the standard. The materials have relatively spherical, irregular particles in shape; a typical electron micrograph and XRD pattern of the ashes is shown in Figures 1-4.

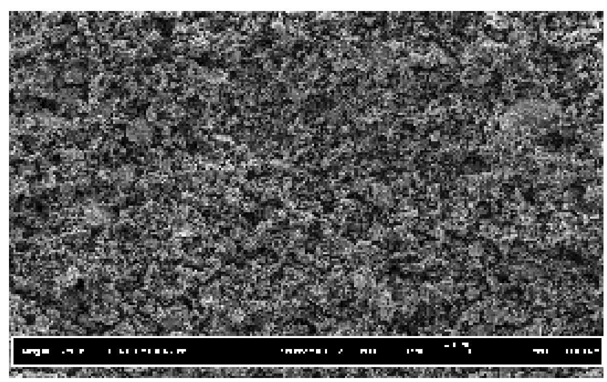

Figure 1 Scanning electron micrograph of POFA

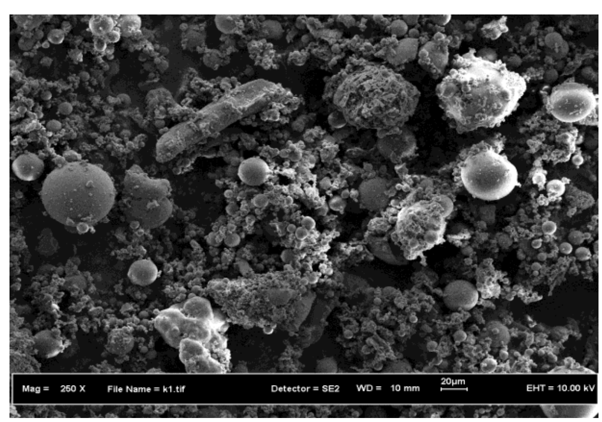

Figure 2 Scanning electron micrograph of PFA

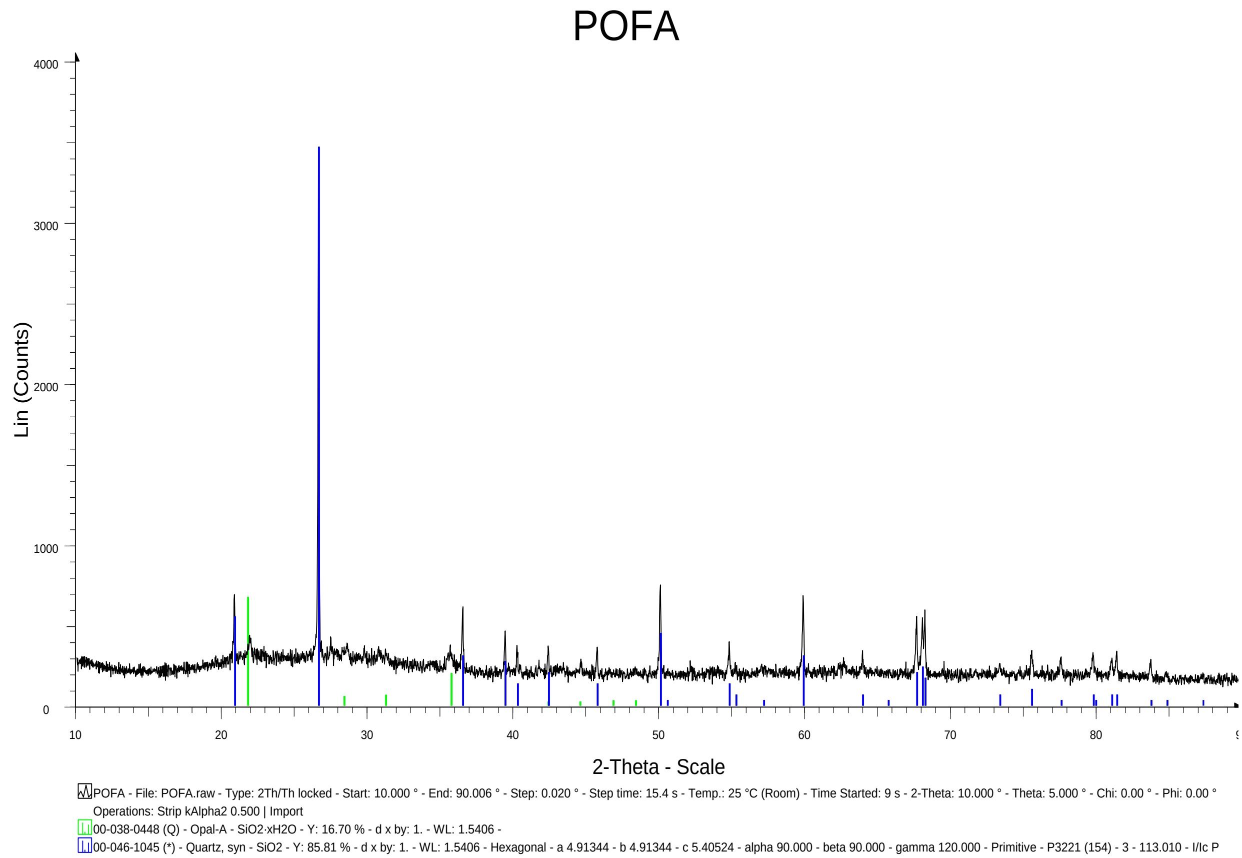

Figure 3 X-ray diffraction pattern POFA

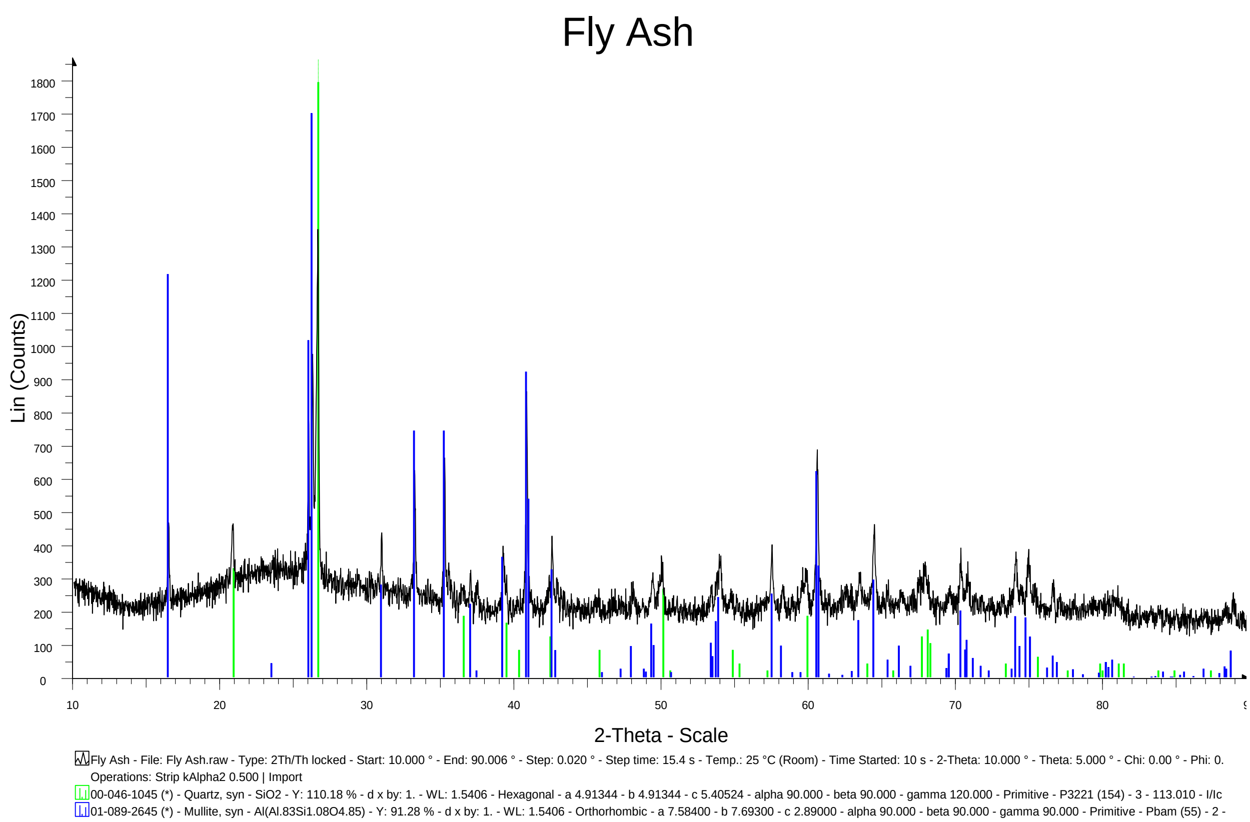

Figure 4 X-ray diffraction pattern PFA

Table 4 Compressive strength results (MPa)

Batch	Cement replacement	Initial water curing 3 Days	Initial water curing 7 Days	Initial water curing 28 Days	Air curing 3 Days	Air curing 7 Days	Air curing 28 Days
AC 1	0 %	10.4	17.18	19.49	13.61	17.1	18.32
AC 2	0 % POFA + 50 % PFA	3.092	4.86	7.07	4.85	8.46	12.2
AC 3	5 % POFA + 45 % PFA	4.42	5.24	10.93	4.85	9.69	9.98
AC 4	10 % POFA + 40 % PFA	4.32	5.23	10.34	4.68	8.53	9.56
AC 5	15 % POFA + 35 % PFA	4.24	4.75	8.26	4.55	8.04	9.39
AC 6	20 % POFA + 30 % PFA	4.27	5.8	9.62	5.24	8.39	11.11
AC 7	25 % POFA + 25 % PFA	3.49	5.47	7.57	4.803	7.32	10.63
AC 8	30 % POFA + 20 % PFA	4.52	5.92	11.34	6.28	8.53	14.56
AC 9	35 % POFA + 15 % PFA	3.49	4.076	9.09	5.85	7.023	8.84
AC 10	40 % POFA + 10 % PFA	4.76	7.13	8.78	6.4	7.77	10.74
AC 11	45 % POFA + 5 % PFA	5.09	6.64	7.43	6.55	8.74	11.2
AC 12	50 % POFA + 0 % PFA	6.27	8.21	9.55	6.92	9.038	10.6

Table 5 Density of samples in water curing and air curing regimes (kg/m^3)

Batch	Cement replacement	Initial water curing 3 Days	Initial water curing 7 Days	Initial water curing 28 Days	Air curing 3 Days	Air curing 7 Days	Air curing 28 Days
AC 1	0 %	1527	1566	1579	1522	1465	1453
AC 2	0 % POFA + 50 % PFA	1469	1503	1514	1452	1460	1462
AC 3	5 % POFA + 45 % PFA	1489	1508	1516	1451	1490	1502
AC 4	10 % POFA + 40 % PFA	1478	1481	1508	1442	1480	1495
AC 5	15 % POFA + 35 % PFA	1487	1503	1507	1460	1485	1504
AC 6	20 % POFA + 30 % PFA	1421	1448	1462	1455	1465	1477
AC 7	25 % POFA + 25 % PFA	1425	1455	1444	1491	1440	1452
AC 8	30 % POFA + 20 % PFA	1473	1436	1488	1459	1472	1486
AC 9	35 % POFA + 15 % PFA	1478	1487	1516	1471	1486	1404
AC 10	40 % POFA + 10 % PFA	1548	1552	1565	1447	1431	1421
AC 11	45 % POFA + 5 % PFA	1558	1564	1584	1455	1428	1413
AC 12	50 % POFA + 0 % PFA	1584	1594	1605	1507	1476	1461

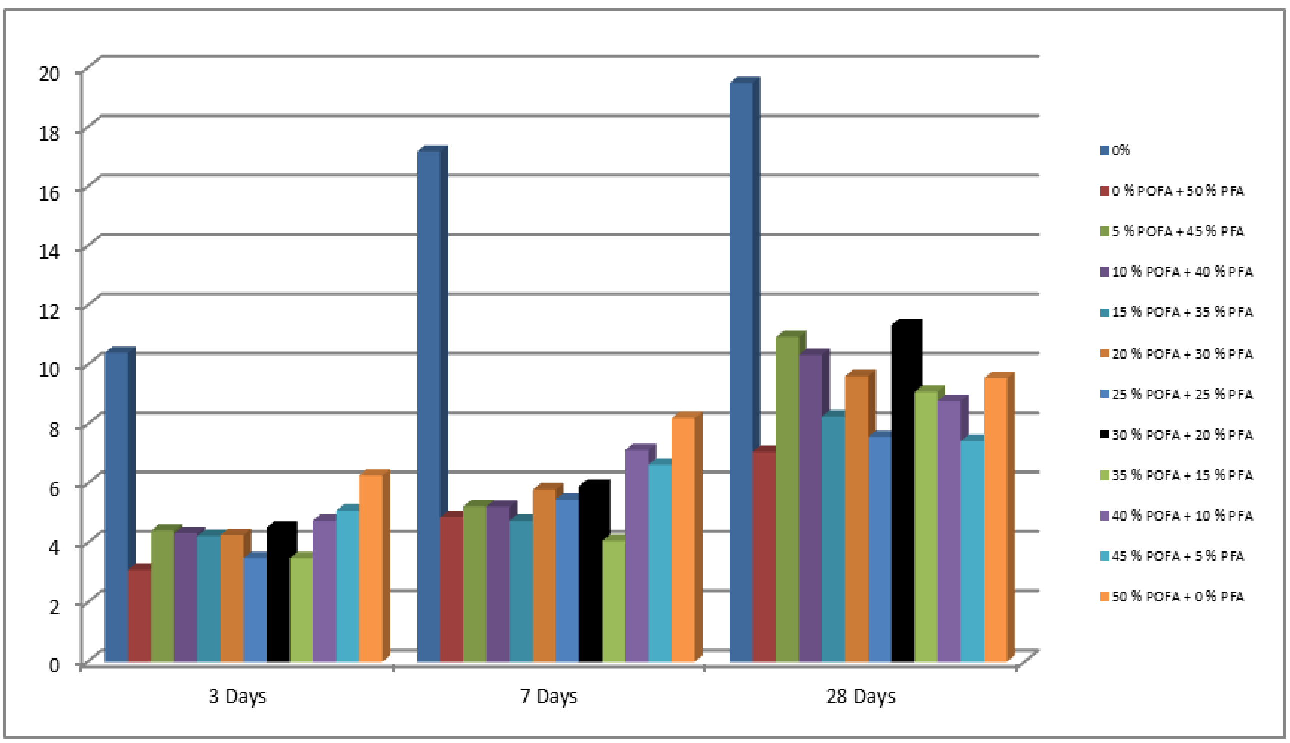

Figure 5 Compressive strength in Water curing regime

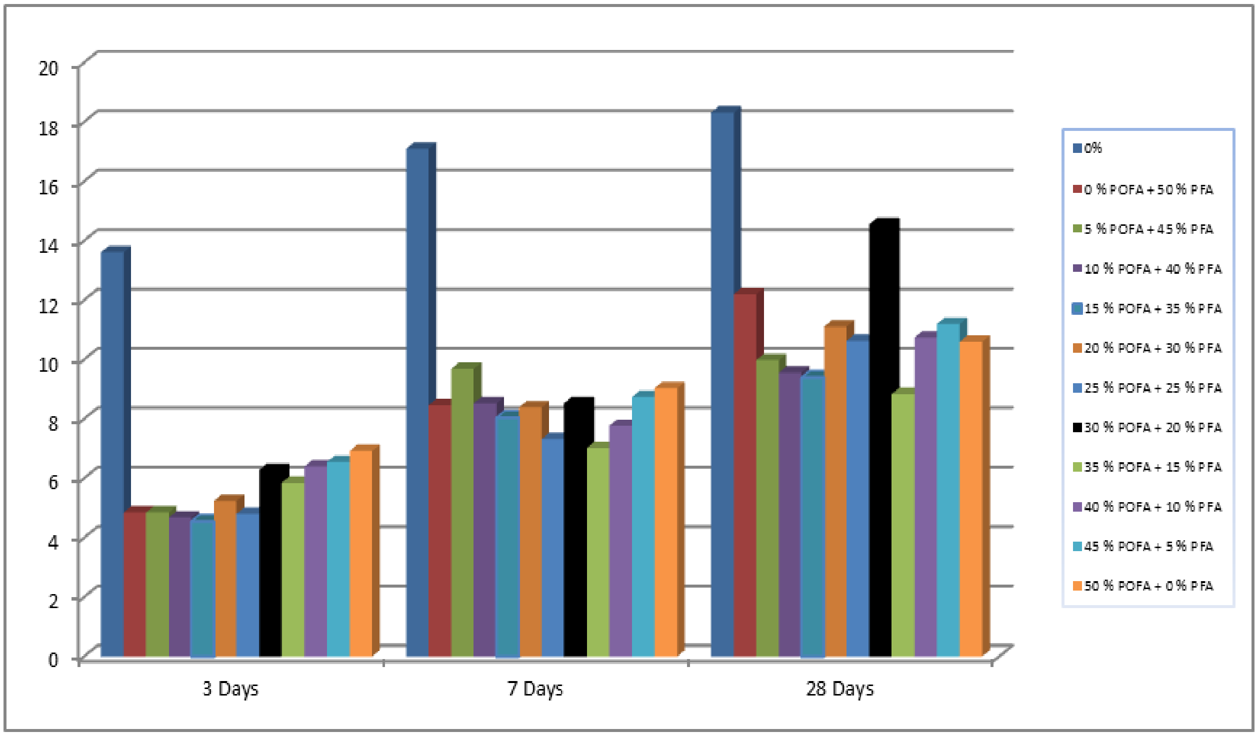

Figure 6 Compressive strength in air curing regime

Table 4 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 3 that the compressive strength increases with the partial replacement of cement with POFA and PFA, when cement is replaced by POFA and PFA respectively 30% and 20%. The maximum compressive strength is achieved when 50 percent weight of cement replaced with pozzolanic materials in case of AC8 and the compressive strength reached to 11.34 MPa in water curing and 14.56 in the air curing, which is the highest when cement is replaced partially with the combination of POFA and PFA (respectively 30% and 20%) in case of AC8. The further decrease or increase in combination of POFA and PFA content causes the decrease in the compressive strength. Hence from the compressive strength point of view the proper combination of POFA and PFA as cement replacement in aerated concrete might be deduced as 30% and 20% by weight of the total binder, respectively. However the cement replacement with pozzolanic waste material 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 7.07 and 11.34 MPa can be produced by incorporating different dosage of POFA 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.[5]

Comparing the compressive strength values of specimens tested at 28 days cured under two curing regimes as presented in Table 4, it is apparent that the compressive strength of the specimens cured in air for 28 days (Figure 6) exhibited better performance as compared to that of the specimens cured initial in water (Figure 5). Memon *et al*.[1] reported that After 28 days in water curing regime compressive strength increasing slightly, this is because, the water cured specimens have enough water to continue the hydration process and 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. Table 5 summarizes the density decreases with the increase in the pozzolanic content in this study.

■4.0 CONCLUSION

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

The optimal result of compressive strength is obtained in content of 20% POFA and 30% PFA.

Since the modern trend is towards the development of lightweight structural material which may replace the existing heavy weight or non-economical lightweight structural materials. Hence this study is step towards the development of lightweight aerated concrete economically by applying partial cement replacement with by-products, POFA and PFA and cured under normal curing methods instead of autoclave curing regime. The research presented in this study is first 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 shrinkage, water absorption, thermal conductivity, microstructure and chemical characteristics etc.

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