Enhance Properties of Autoclaved Aerated Concrete by Adding Silica Fume

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***Abstract*: Autoclaved aerated concrete (AAC) is important, building materials which has unique physical and mechanical properties compare with normal concrete. In this research silica fume used as the chemical additive to increase compressive strength, the percentage of silica fume added in this study is (4, 8, 12 % and 16% by weight of cement that used in recipe) the result shows the compressive strength increased with increasing silica fume to a specific limit than the compressive decreased with an additional amount of silica fume. It has been found that the density are not affected with silica fume due to less amount of silica compare with the total amount of the mix, and for thermal conductivity the same behavior was shown for the same reason as the lack of density.**

Index Terms: AAC, Autoclaved aerated concrete, cellular concrete, Silica fume.

I. INTRODUCTION

Autoclaved aerated concrete (AAC) which called in Iraq (thermo stone) is a structural material which is commonly used Iraq in the last few years, it has unique properties such as lightweight, easy insulations and good thermal insulation [1].

AAC is manufactured by using special technology depending on steam curing autoclave, the raw materials used in manufacturing AAC are sand, cement, lime and gypsum, aluminum powder as porous generating agent and water [2]. These components are mixed together with the high ratio of water and pouring into special molds to produce a cellular green cake by H2 gas generation at atmospheric pressure, and then autoclaved at 170-190 C under saturated steam pressure for (8 to 12 hr.) [3], [4]. The reaction between calcium hydroxide, aluminum powder, and water, to form hydrogen gas in the making of aerated concrete, as follows [5], [6].

$$2Al + 3Ca(OH)_2 + 6H_2O \rightarrow 3CaO{\bullet}Al_2O_3{\bullet}6H_2O + 3H_2$$

AAC producing technique consists of four major steps, the first step is milling sand to make slurry then mix slurry with the other components according to specific mix design, the second step is pouring the mixture into a mold for curing the mixture at (45-70 C) for approximately (3 hr.) to make AAC cake, the third step is cutting the cake in desired dimensions, the final step is autoclaved produced the give it desired properties [7].

It is a highly pozzolanic material which it's a very fine grain structure and high amounts of silicon dioxide (SiO2) contains [8]. In this research used silica fume as an additive to enhance AAC properties especially mechanical properties. Silica fume (SF) is a byproduct of the smelting process in the silicon and ferrosilicon industry. The reduction of high-purity quartz to silicon at temperatures up to 2,000 C produces SiO2 vapors, which oxidizes and condense in the low-temperature zone to tiny particles consisting of non-crystalline silica [4,9]. Silica fume added to cement in specific proportions (4%, 8%, and 12%) and made samples. The samples treated similar commercial AAC.

II. EXPERIMENTAL WORK

A. Used Materials

In this research the raw materials (Sand, Cement, Lime, Gypsum, Al powder, water and chemical additives) preparation in ASAD-BABYLON Company's Laboratory for producing construction materials, the table (I) shown the chemical analysis of major raw materials (Cement, Lime, Sand). , the table (II) shown the physical properties of major raw materials (Cement, Lime).

Cement

Cement use in production of AAC is ordinary Portland cement (OPC) with 53 grades (according to ASTM C150) supplied from Lafarge Co. Karbala plant.

Sand

Sand with high amounts of silicon dioxide ($SiO_2 \geq 80\%$, according to ASTM C 1555).

Lime

Lime used in this research is fine, soft, burned lime (according to C110).

Gypsum

Gypsum used for producing AAC is anhydrite as powder form.

Water

Water use, in this case RO water with TDS 25.

Silica Fume

Silica fume with an average particle diameter of 0.15 μm, and high amount of an amorphous (non-crystalline) polymorph of silicon dioxide ($SiO_2 \geq 90\%$). Table III, gives the properties of sillica fume.

Aluminum powder

Al powder with a specific surface area (15000 cm^3/gr) used in this research.

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Table I. Chemical analysis of major raw materials.

Chemical analysis % by weight	Sand	Lime
L.O.I	2.76	2.43
SiO_2	87.96	1.31
Al_2O_3	-	0.95
MgO	-	0.11
SO_3	0.78	0.37
Fe_2O_3	-	0.22
CaO	-	93.94
Silt	1.2	-
TSS	1.9	-
CL	0.08	-

Table II. Physical properties of major raw materials.

Property	Lime	Limitations	Property	OPC	Limitations
T6o	11 min	5-15 min	Finesse (blain)	2767	≥ 2500 m^2/kg
CO_2	2.13 %	≤ 3%	Initial Setting time	109	≥ 45 min
Activity	90.46	≥ 85%	Final setting time	2.6	≤ 10 hr

Table III. Properties of Sillica Fume.

Property	
Color	Light-Gray
Specific gravity	2.6
Bulk density	550-650 kg/m^3
SiO2 content	≥ 90%

B. Methods

Raw materials are mixed in the desired proportion to give the best possible mix design. A sample of 150x150x150 mm is produced by mixing sand, cement, water, lime, gypsum and the AL powder as foaming agent is added to it in the proportions percentage and poured into the mold is filled up to 65% percent of its height. The mold poured as shown in the fig (1).

Fig. 1. Shown the mold poured.

Mix design

The percentage of silica fume with cement for producing AAC in this study shown in the table (4).

Table. IV. Silica fume proportion with cement.

Additives	Mix 0	Mix 1	Mix 2	Mix3	Mix 4
Silica fume (%)	0	4	8	12	16

Steps of preparation of AAC

The procedure, time of mixing and all preparation steps as shown in fig (2). The fig (3a) shown the uniform porosity and fig (3b) shows the product in this research.

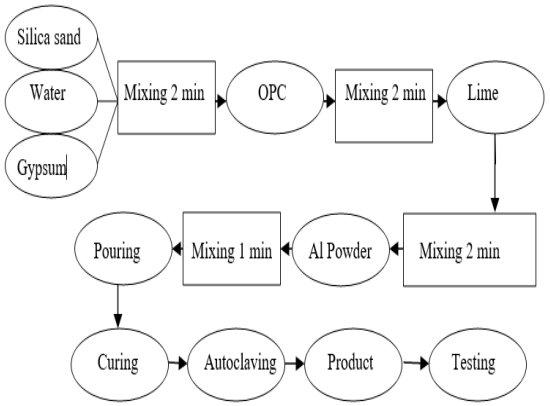

Fig. 2. The procedure.

Fig 3a. Shows the uniform porosity.

Fig 3b. AAC product in this research.

C. Tests

XRD

X-Ray diffraction test is used to determine the crystal structure of solids through the X-ray diffraction after reaction with atoms of crystalline materials, which are distributed regularly and repeatedly in the habit. X-ray diffraction test (Type XRD-6000, Shimadzu) was conducted in Babylon University / College of Materials Engineering / Department of Ceramics Engineering and Building Materials Laboratories. Fig. (4a) and Fig (4b) show the XRD device.

Fig. 4a. XRD device.

Fig. 4b. XRD device.

Bulk density

Bulk density (B), in grams per cubic centimeter of a specimen is the quotient of its dry weight divided by the exterior volume; including pores. It can be calculated according to the (ASTM C373-88) [10] :

$$B=D/V \quad (1)$$

Where B is Bulk density, D is dry weight of the samples and V is the exterior volume of the samples.

Thermal conductivity

The thermal conductivity property (K) may vary locally with temperature, humidity, material composition, direction, etc. Knowledge of local thermal conductivity is important in the evaluation of heat transfer rates. A cylindrical mold is prepared to produce the required specimen with dimensions of (2cm) diameter and (1cm) thickness for all samples.

The hot disk method is used for determining the thermal conductivity (K) as shown in Fig (6a) and Fig (6b), quickly and accurately measures the thermal conductivity of a wide range of samples. The thermal conductivity test is conducted by the Department of Materials Engineering, Laboratories / University of Technology/Baghdad.

Fig 6a. Hot disk device.

Fig 6b. View of hot disk device.

III. RESULTS & DISCUSSION

The results are summarized, X-Ray, the compressive strength, dry density and thermal conductivity of the autoclaved aerated concrete.

X – Ray

In XRD observations (Figure 7.) Xonotlit and tobemorite phases are detected, some unclear peaks were found. It is thought that those unclear peaks are semi-crystal C-S-H system. t , tobemorite
x, xonolite
C_3 , C_3S
C_2 , C_2S
Q , quartiz
E , etiringite

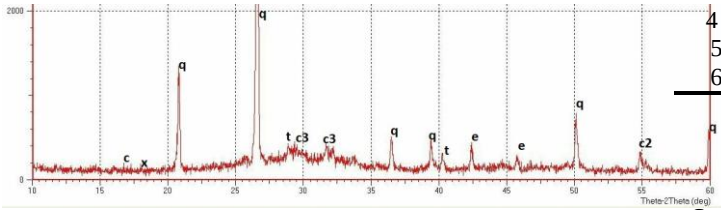

Fig. 7: XRD test.

Compressive strength

The compressive strength values increase with increasing of micro silica ratio. Additional C-S-H gels occurred because of the reaction formatted between silica fume and free cement created from hydration of cement, which resulted in high compressive strength.

Due to the high amount of cement ratio, it is observed that in the early phases of hydration there is a significant amount of ettringite phase, but the amount of this phase descents under autoclave curing conditions. However, the microstructure investigations done after autoclave curing shows the ettringite crystals in the structure is shown in table 5.

Table V. Compressive strength of AAC.

NO.	Mix No.	Compressive Strength Mpa	Limits ASTM C1555
1	Mix0	2.90	≥ 2 Mpa
2	Mix1	3.31	
3	Mix2	3.35	
4	Mix3	3.83	
5	Mix 4	3.21	

Bulk density

The values of density are not affected with silica fume because of the percentage of silica fume is a too little amount compare with the total amount of the mix is shown in table 6. So it has been shown that there is no more difference in the result of density.

Table VI. Bulk density of AAC.

NO.	Mix No.	Bulk density Kg/m^3	Limits ASTM C1555
1	Mix0	496.5	450-550
2	Mix1	485	
3	Mix2	490	
4	Mix3	494	
5	Mix4	493	

Thermal conductivity

The values of thermal conductivity for all recipes are the same amount with all percentages of silica fume. The similarity of result shown in table 7 appears due to few of dray density differences.

Table 7. Thermal conductivity of AAC

NO.	Mix No.	Thermal conductivity
1	Mix0	0.13
2	Mix1	0.13
3	Mix2	0.13
4	Mix3	0.13
5	Mix4	0.13
6	Mix5	0.13

IV. CONCLUSION

Sand-lime-OPC cement system samples were produced in this research have high mechanical value results compared with the AAC that produced in commercial scale in Iraq by using the same raw materials.

In the microstructure exploration of silica fume added aerated concrete, 6structures closer to cement paste were observed. In addition, there were structures who look like weak tobemorite plates and which were seen in specific areas.

When XRD results obtained at the end of autoclave curing are compared to the mineralogical analysis of the commercial aerated concrete samples; it is seen that the tobermorite phase which is important for compressive strength does not evolve well. This result indicated the need for refinement of hydration conditions. This refinement would occur with high pressure autoclave usage. Whereby this may enable the reduction of cement usage and improve the durability of the product. Additionally, re-usage of raw materials in production would provide value to the economy of the country.

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