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Effect montmorillonite clay as aggregate in lightweight concrete cement-free

Mohammed H. Shamsa[1], Nadia M. Al-Abdaly[2*], Ali A. Jaber[3], Ali A. Al-Rammahi[2]
[1]Faculty of Engineering, University of Kufa, Najaf, Iraq
[2]Najaf Technical Institute, Al-Furat Al-Awsat Technical University, Najaf, Iraq
[3] Civil Engineering Department, University of Technology, Bagdad, Iraq

ABSTRACT

Light weight concrete has many advantages that can be used in the construction of buildings. Perhaps one of the most important of these features is its light weight, which contributes a lot to reducing stress on the soil, which provides the possibility of rising buildings and increasing the number of floors. In addition to its role in thermal insulation and its impact on reducing the consumption of energy sources in cooling and heating, light weight concrete is considered one of the sustainability factors in buildings. One of the second major factors in sustainability is to reduce or avoid the use of cement in the manufacture of this concrete, because of the harmful effects of cement on the environment and global warming. Cement-free concrete is considered a sustainable material in terms of its depletion of the waste materials and spin-off products from different industries apposite of consumption of natural resources in the cement industry (mud, limestone). In this research first aim is to produce lightweight cement-free concrete using pozolanic material and montmorillonite clay as coarse and fine aggregate. Studying some properties of producing light weight concrete (density, compression, tensile,) with different ages (7, 28, 56) days.

Keywords: *Clay, Fly ash, Cement-free, Lightweight concrete, Density.*

Corresponding Author: *Nadia M. Al-Abdaly2*

Najaf Technical Institute,
Al-Furat Al-Awsat Technical University,
Iraq, Najaf
E-mail: nadia.material@gmail.com

1. Introduction

As it is known that light weight concrete has more advantages than ordinary concrete in terms of reducing dead loads in structures, better insulation and less costly in transportation when it is pre-cast, and some other benefits[1, 2].

In addition to the advantages of lightweight concrete, its good specifications can be increased by using alternative bonding materials than using cement. Concrete cement-free reducing CO_2 emissions resulting from the cement industry and consumption of by-products materials resulting from industries and preserving natural resources[1, 3] so it is lightweight and sustainable concrete.

The use of lightweight aggregate is one of the best ways to output light weight concrete, research on the use of manufactured lightweight aggregate is still few in the production of lightweight cement-free concrete.

Abdulkareem et. al. [1] used fly ash class- C as pozzolanic material and natural sand and expanded clay as coarse aggregate in producing lightweight geopolymer concrete with a alkali- solution concentration of 12 M, and curing at 70C for 24 hours. They recorded that the presence of coarse aggregate led to a decrease in the density when comparing concrete with mortar or geopolymer paste by 26%, and they showed that the decrease in the compressive strength of the resulting concrete was caused by the decrease in density and the many pores in the lightweight aggregate led to the weakening of the aggregate first and the resulting concrete in the end in terms of compressive strength.

Posi et. al.[4] recycle light weight block and used as fine, medium, and coarse light weight aggregate in producing light weight geo-polymer concrete. Five groups of mixtures and studied the effect of alkali solution/ fly ash, the ratio of Na2SiO3 /NaOH, the concentration of NaOH, the effect of the treatment temperature, and finally the effect of the aggregate /fly ash. Where the proportions of the aggregates(fine: medium: coarse) 0:70:30, 30:40:30, and 70:0:30. In most of the results, mixtures containing a high percentage of fine aggregates had higher compressive strength and density than mixtures containing a percentage of medium aggregates. Mixtures that did not contain a percentage of fine aggregate had the highest percentage of water absorption.

Soner Top et.al.[5] considered the effect of alkali solution on the properties of lightweight geopolymer concrete using two types of aggregates expanded perlite (EP) and acidic pumice (AP).It was noted that the density of the concrete decreases with the increase in the size of the aggregate, and the compressive strength decreases with the increase in the proportion of the aggregate.

Wangsa et.al.[6] noted when replacing the natural (coarse and fine) aggregates with lightweight aggregates (bottom ash) in geopolymer concrete, the resulting concrete has a lower density of 1660-1688 kg/m3 and the compressive strength drops to 14-18 MPa. They attributed the reason for this decrease to the nature of aggregates (bottom ash) with high porosity and low density.

Thenmozhi et.al. [7] gradual decrease in compressive strength from 31.5 MPa to 27.4 MPa, as a result of replacing natural coarse aggregate with lightweight coarse aggregate (Pumice stone) in different proportions (0, 10, 20, 30, 40, 50)%. It was also accompanied by a decrease in the unit weight of the cube from 8.9 kg (0% replacement) to 5.3 kg (50% replacement).

Wongsa et.al. [8]used crushed clay bricks, pumice stone and high calcium fly ash as a source material to produce two types of lightweight geopolymer concrete and compared it with ordinary geopolymer concrete. Both types of lightweight concrete showed better resistance than normal geopolymer concrete at high temperatures of 400-800C. Geopolymer concrete containing crushed clay bricks had better structural strength (18 MPa) than that containing pumice stone as coarse aggregate, while the latter was the least dense (1000-1100) kg / m3 compared to the concrete of crushed clay bricks (1685-1750) kg / m3.

The aim of this research is to study the characteristics of lightweight cement-free concrete using pozolanic material and alkali solution as a binder and artificial aggregate from local materials made from montmorillonite clay as coarse and fine and to study the effect of aggregate ratios and sodium silicate / sodium hydroxide ratio on the density and absorption water of manufactured concrete and some of its mechanical properties (compressive strength, tensile strength).

2. Experimental work

The materials that were used in this study are the locally manufactured aggregates from the montmorillonite clays found in Najaf and its use as coarse and fine aggregate. Where the montmorillonite clay was burned at a temperature up to 750^{o}C, for two hours and then left to cool, it was crushed and sieved to the required coarse aggregate size and part of it was ground to obtain fine aggregates according to ASTM C330[9] requirements as shown in Figure 1. The surface shape of the resulting coarse aggregate was irregular as shown in Figure 2., Table 1 shows the physical properties of the resulting aggregate.

Pozolanic material that used in this research is flyash from Isken power station in Turkey, Table 2 shows the chemical properties of montmorillonite clay and fly ash.

The pozzolanic material reacts with a base solution consisting of sodium hydroxide at a concentration of 12 M with a solution of sodium silicate to form the binder in concrete To prepare 1 kg of sodium hydroxide solution at a concentration of 12 M, 360 g of pure sodium hydroxide flakes are dissolved in 640 g of water, then left to cool due to the heat generated by the reaction[10]. Sodium silicate solution, it consists of 12.5% of sodium oxide, 30.2% of silicon oxide, and 57.3% of water. The solutions are mixed together according to the required proportions.

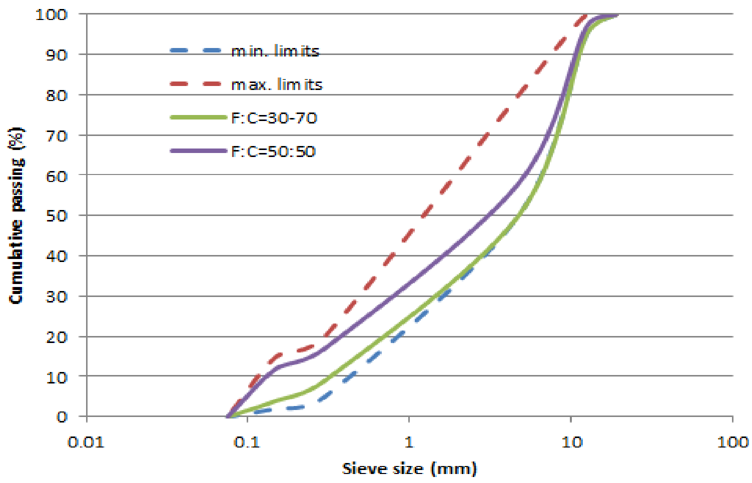

Figure 1. Grain size distribution of combined aggregate according to ASTM C330 [9]

(a) **(b)**

Figure 2. Montmorillonite clays, (a) before burning, (b) after burning

Table 1. Properties of Montmorillonite clay

Properties	Test results of aggregate
Water absorption (%) [11]	10.9
Specific gravity [11]	1.61
Dry loos unit weight (kg/m3) [12]	1015 – 975*

* Change in unit weight depending on the ratio of fine aggregate to coarse aggregate

Table 2. Chemical Composition of Materials

Oxides %	SiO_2	Al_2O_3	CaO	Na_2O	Fe_2O_3	SO_3	L.O.I
Fly ash	59.14	29.45	2.16	0.22	3.37	0.59	2.75
Montmorillonite clay	55.71	14.55	3.23	1.01	2.68	0.81	9.36

2.1 Material properties

The aggregate resulting from the burnt Montmorillonite clay was used as coarse and fine aggregate as previously mentioned in the form of combined aggregate. Four mixtures were made as shown in Table 3. The effect of the ratio of fine aggregate to coarse aggregate (50%:50%), (30%:70%), as well as the ratio of sodium silicate to sodium hydroxide (1:2), (2:1) on the properties of the resulting lightweight cement-free concrete was studied. In all mixtures, the concentration of sodium hydroxide was 12 molar.

Table 3. Details of the mixtures for the preparation of light weight cement-free concrete

Mix	Fly ash (FA)	Combined aggregate (CA)	Sodium silicate (S)	Sodium hydroxide solution (H)
0.5CAS:H0.5 (mix 1)	400	1240 (50% fine+50% coarse)	73	147
0.5CAS:H2 (mix 2)	400	1240 (50% fine+50% coarse)	147	73
0.7CAS:H0.5 (mix 3)	400	1240 (30% fine+70% coarse)	73	147
0.7CAS:H2 (mix 4)	400	1240 (30% fine+70% coarse)	147	73

* Alkali liquid/ fly ash = 0.55

2.2 Mixing, casting, and curing

To reduce the impact of the aggregate in absorbing the mixing water, the aggregate is used in a state saturated with moisture and the surface is dry (SSD), so the aggregate is immersed in water before using it for 24 hours and then left in the air for a while until the surface is completely dry. The pozzolanic material is mixed with the aggregate in the mixer bowl in a dry condition to ensure the homogeneity of the mixture for 3 minutes. The alkali solution that was previously mixed (sodium silicate and sodium hydroxide) according to the required proportions was added to the dry mixture (aggregates and fly ash) in the mixer and mixed for 3 minutes. The fresh cement-free concrete was placed in the molds and compacted on the vibrating table for 40-60 seconds depending on the type of mold [13]. Two types of molds were used, 10 x 10 x 10 cm cubes to test dry density [14] and compressive strength [15], cylinders 10 cm in diameter and 20 cm in height for tensile testing [16]. The specimens were placed in the oven at 70 °C for 48 hours, then they were taken out and covered with plastic sheet until the time of the tests.

3. Results and discussions

3.1 Compressive strength, splitting tensile strength

Three samples, aged 7, 28 and 56 days, were tested for each of the four mixtures. The results were as shown in Figures (3,4), which show the compressive strength and splitting tensile strength respectively. In general, compressive strength of cement-free concrete increases with age and is affected by curing temperature, curing period and alkali solution concentration[17]. It is noted that the strength gained from the age of 7 days to the age of 28 and 56 days 14% - 20%, respectively, and obtained high results of compressive strength due to the high percentage of active silica and alumina present in the source material (fly ash) and the manufactured aggregate used[18], so increasing the percentage of alkali solution in the mixes to increase the results because it has an important role in the polymerization process.

The reason for the low compressive strength in mixtures 2 and 4 compared to mixtures 1 and 3 respectively is the difficulty of mixing and compacting them due to the low content of liquid in the alkaline solution [4,6], considering that the lightweight aggregate has high porosity, so it needs a higher water percentage than the natural aggregate.

It is also noted that the mixture in which the fine aggregate has a higher percentage in the combined aggregate (mix 1) has a higher strength than (mix 3) due to the decrease in the proportion of coarse aggregates, where coarse aggregate causes an increase in voids and pores due to the shape that is heterogeneous granules, as well as coarse aggregate has weak resistance.

It is noted from Figure (4) that the splitting tensile strength of mixtures ranged in (2-2.5) at 56 days, the ratios of splitting tensile strength to compressive strength at the age of 28 days were (7-13%) [19], It is noted that the mixtures 1,3 have a tensile strength more than 2,4 due to the decrease of water in the alkaline solution caused the mixtures to be semi-dry and thus not being able to compact them well, and the lack of polymerization bonds due to the decrease in the proportion of sodium hydroxide in alkali solution.

3.2 Dry density

Density results are shown in Table 4., the use of aggregates made of Montmorillonite clay in the manufacture of lightweight cement-free concrete had a major role in reducing the density. Density values ranged between 1750-1660 kg/m3 and are within the limits of lightweight concrete installed in ACI 213 (1440-1850 kg) [20][as well as the compressive strength, which was within the requirements of ACI 213 (17.24-41.36).

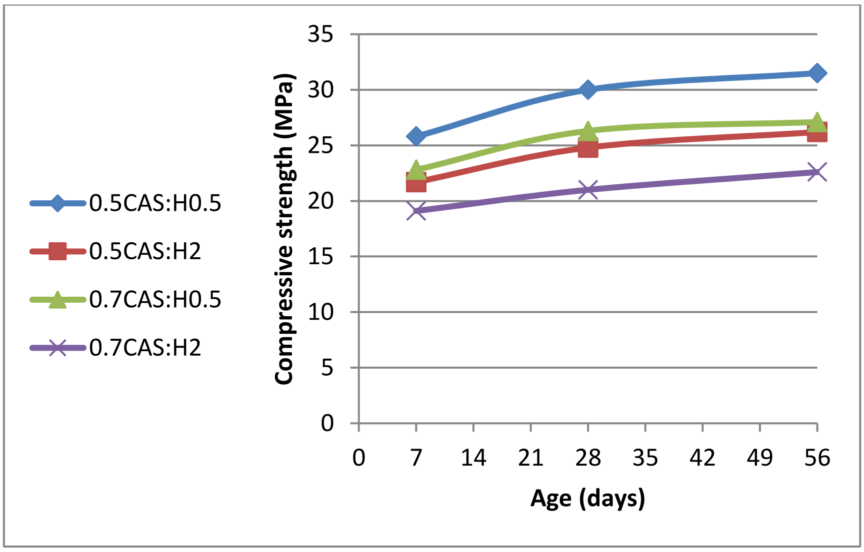

Figure 3. Compressive strength with age

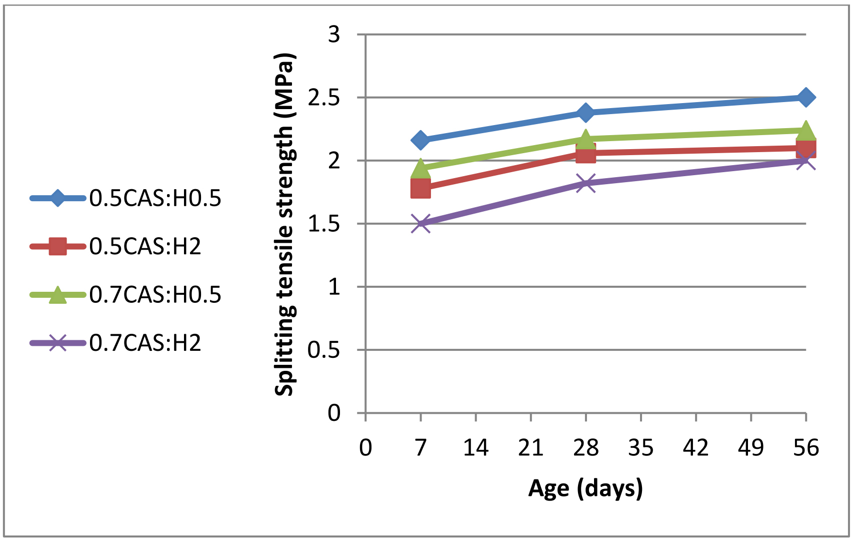

Figure 4. Splitting tensile strength with age

It is noted from the results that mixtures 1, 2 had a density higher than 3,4 due to the increase in the proportion of fine aggregates in the combined aggregates (50:50%), the density of fine aggregates was higher than coarse aggregates, which led to an increase in density [4].

It is also noted that mixture 2 is less than mixture 1 and mixture 4 is less than mixture 3, for the same reasons mentioned earlier, is that mixtures 1, 3 and because of their better workability than 2 and 4, therefore, the mixture became more homogeneous, fewer voids and better distribution of the polymerization products resulting from the reaction of the alkali solution with active silica and alumina in fly ash and artificial aggregates.

Table 4. Effect of fine LWA percentage and sodium silicate/ sodium hydroxide ratio on dry density

Mix symbol	Oven dry density (kg/m^3) [22]
0.5CAS:H0.5	1750
0.5CAS:H2	1690
0.7CAS:H0.5	1700
0.7CAS:H2	1660

3.3 Water absorption

Water absorption tested at 7,28, and 56 days as shown in Figure 5. It is noted that the water absorption decreases with the age of the lightweight cement-free concrete due to the progress of the polymerization process, whose products fill the pores in the concrete structure with time [21].

The absorption ratio of the mixtures (1-4) was less than 10% at age 56 days, so the manufactured cement-free concrete is considered good [22]. It is noticed from the figure that the absorption ratio of the mixtures 1,3 is less than 2,4 due to reasons including the good fine aggregate ratio in the mixture 1, which in turn reduced the percentage of voids between the components of the cement-free concrete mixture, and the ratio of sodium silicate to sodium hydroxide, which played a role in the process of forming polymers bonds, which would reduce the proportion of pores in concrete with time. As the 2,4-mixtures, cement-free concrete does not form well due to the saturation of the alkali solution with a high percentage of sodium silicate [5], as well as due to the decrease in the percentage of water in the alkali solution, which led to the difficulty of mixing and compaction, which resulted in an increase in the proportion of pores and voids in the resulting concrete [4].

3.4 Effect of sodium silicate to sodium hydroxide ratio

An alkaline solution is a solution resulting from the reaction of sodium silicate with sodium hydroxide flakes dissolved in water according to a certain concentration. This solution is mixed with a pozolanic material (fly ash, metakaolin, GGBS…etc.) that contains active silica and alumina to form bond matrix. Each of these two compounds has a role in cement-free concrete, sodium hydroxide helps the reaction process between silica and alumina to form strong polymerization bonds, while sodium silicate accelerates the polymer reaction process [23]. Opinions differed about the ratio of Na2SiO3/NaOH in the alkaline solution and its effect on the properties of cement-free concrete [6,8], but it was noted in this study that reducing this ratio (as in mixtures 1 and 3) helps to increase the workability of cement-free concrete and thus affects the process of compaction in the molds, which leads to reducing the pores and voids between the components of the mixture.

In addition to the presence of a high percentage of active silica and alumina (the pozolanic material and the aggregate used), the increase in the percentage of sodium hydroxide in the alkaline solution gave good results in compressive strength and splitting tensile strength.

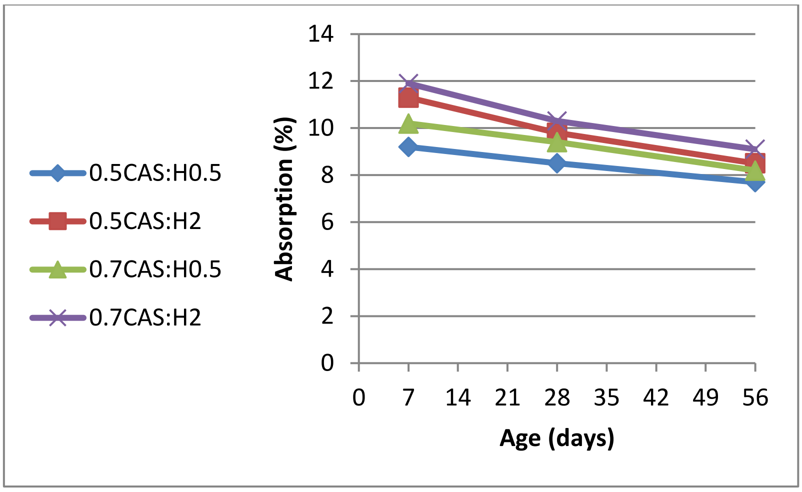

Figure 5. Absorption ratio with age

4. Conclusion

- Production of lightweight cement-free concrete using aggregates made from Montmorillonite clay and fly ash in the presence of the base solution and with a base solution to fly ash ratio of 0.55 fixed for all mixtures.
- The highest compressive strength and tensile strength were obtained at the age of 56 days (31.5, 2.5) respectively for concrete with combined aggregate 50:50 (fine aggregate: coarse aggregate) and with a ratio of sodium silicate to sodium hydroxide 0.5.
- Obtaining the dry density of lightweight cement-free concrete with a range of (1660-1700) kg/m3 when the proportion of coarse aggregate was increased to 70% in the compact aggregate.
- Doubling the ratio of sodium hydroxide in the base solution to sodium silicate improved workability, increased compressive strength and increased dry density.
- The water absorption of produced concrete decreases with time and its rate was less than 10% at the age of 56 days.

Compliance with ethical standards

Conflict of interest: The authors have no conflict of interest to declare.

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