Effect of using Fly Ash and Attapulgite Lightweight Aggregates on Some Properties of Concrete

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ABSTRACT

Attapulgite is a natural clay mineral, that has been investigated as a potential lightweight aggregate due to its low density and unique structural properties. Recently, the interest in using attapulgite has increased. In this study, the combined attapulgite (fine and coarse) is used in a concrete mixture. Tests were conducted to select the best content of attapulgite in mixtures by investigating its properties, including slump, compressive strength, and density characteristics to evaluate Lightweight Concrete (LWC) performance. The outcomes exhibited that different attapulgite aggregate contents influence compressive strength, with the highest value being 21 MPa for 984 kg/m^3 attapulgite content at 28 days of curing. Furthermore, the dry density is positively correlated with the increment of the attapulgite aggregate percentage. Then, different percentages of Superplasticizer (SP) of 0.9%, 1.1%, 1.3%, 1.5%, and 1.7% were utilized, which led to the enhancement of the slump flow. The ideal ratio adopted for the subsequent mixtures was 1.3% by weight of cementitious material, which gave the highest compressive strength (26.2 MPa at 28 days). Also, mixtures in which cement was replaced by fly ash of 10%, 20%, 30%, 60%, and 100% ratio by weight of cement were prepared. The results demonstrated that the highest compressive strength was 32.7 MPa with a 30% ratio of fly ash by weight of cementitious materials after 90 days of curing.

Keywords-attapulgite aggregate; compressive strength ;superplasticizer; fly ash ;density

I. INTRODUCTION

LWC is preferred from normal concrete due to its lower weight, and therefore lower delivery cost, as well as energy and maintenance expenditure savings [1]. Given its unique chemical composition and crystal structure, the clay mineral attapulgite equivalently possesses unique mechanical and chemical properties, namely cohesiveness and pozzolanic properties. Consequently, attapulgite is widely used in different industry applications especially in the construction field, since it is considered an eco-friendly replacement of the traditional material [2]. The attapulgite is commonly extracted from a clayey top-cover soil at places where the temperature is relatively low [3]. This material is discovered in Iraq specifically in the middle-west of this country and its color is usually around the gray scale. Its manufacturing process is as simple as collecting and grinding it to fine particles through hammering, making it ready to be used in a different manner [4]. However, in terms of construction, the attapulgite might be heated up to a temperature from 550 °C–800 °C for a certain duration to increase its reactivity to the required size after the grinding. This process enhances the properties of attapulgite by changing its chemical properties and developing its reactivity when used in a concrete mix [5, 6].

Attapulgite concrete is an LWC with a lower density ranging between 300 Kg/m^3 and 1850 Kg/m^3. There are several ways to produce LWC, such as by substituting traditional aggregate with lightweight aggregate or cellular porous aggregate and by using air-entrained mortar [7]. The lower density of LWC has a positive impact on the construction industry, represented by reduced dead loads. Hence, a subsequent reduction in the cost of foundations and construction is observed, providing better thermal insulation and sound absorption compared to normal concrete, while it also increases fire resistance, and reduces the damage caused by earthquakes, storms, or other dynamic effects [8]. There are many types of LWC. One of them is the structural LWC, which has a compressive strength not less than 17 MPa and an equilibrium density ranging from 1120 kg/m^3-1920 kg/m^3 at 28 days of curing. Moreover, it entirely consists of lightweight aggregate or a combination of lightweight aggregate with normal aggregate [9]. The utilization of waste recyclable materials, like fly ash, to create lightweight aggregates has been a significant breakthrough development in construction materials. Besides, the benefits of the advanced LWC characteristics in the construction industry, LWC also contributes to sustainability enhancement by repurposing waste materials. The volume and quality of these aggregates are crucial for identifying the overall attributes of LWC, impacting its strength, density, and durability [10]. Also, the replacement of cement by pozzolanic material positively affects the environment, as it has decreased the CO_2 emissions produced from the cement manufacturing process [11]. Former studies aimed to characterize the behavior and properties of attapulgite LWC. Authors in [12] studied the use of three types of coarse aggregate (normal, attapulgite, and crushed brick) to structurally produce LWC. The research revealed that the utilization of attapulgite aggregate produced 25 MPa compressive strength as well as 1805 kg/m^3 dry density. However, the compressive strength and dry density obtained from the aggregates of crushed bricks were 43.7 MPa and 1977 kg/m^3, respectively. Also, normal aggregate concrete exhibited the highest compressive strength and dry density from all mixtures.

Authors in [4] explored the impact of coarse lightweight aggregates and fibers on their engineering properties. Mixtures with different coarse aggregates (normal, crushed brick, and attapulgite) were prepared and the outcomes highlighted that the Unconfined Compressive Strength (UCS) declined by approximately 7.4% for the clay brick (crushed) and by 22.2% for the attapulgite concrete compared to the normal concrete. Then, they were mixed with two steel fibers of 0.5% and 1% ratio. Additionally, a 1% steel fiber ratio caused an increase in the compressive strength by 38% and 26% for the crushed brick and attapulgite, respectively compared to a mixture with no steel fibers. These results underscore the contrast in optimizing the concrete properties of lightweight aggregates and steel fibers. Authors in [13] examined using attapulgite as a replacement material for fine aggregate. Three mixtures were studied, the first mixture was the reference one, which was composed of sand, cement, silica fume, gravel, and SP, with a content of (700 kg/m^3, 450 kg/m^3, 50 kg/m^3, 950 kg/m^3, and 1 L/100 kg of cementitious material), and with a ratio of 0.3 per w/c. The second and third mixtures were prepared with the replacement of fine aggregate by attapulgite, with a ratio of 10% and 20% by volume of sand, respectively. The compressive strength results at 60 days of curing were 56 MPa, 50 MPa, and 41 MPa, and those of the dry density were 2476 kg/m^3, 2475.6 kg/m^3, and 2475 kg/m^3, respectively, for all mixtures. Authors in [14] studied the impact of attapulgite on structural LWC. The experiment included 22 mixes having various attapulgite replacement rates, ranging from 100% to 50%, with a decrement of 10% for each mix. Their findings indicated that the increase of cement portion in the concrete mix enhanced density by 36.61%. Additionally, the UCS value incremented was enhanced by up to 100.94%. Authors in [15] investigated the ideal ratio of the attapulgite to cement percentage in the concrete mix. Five mixtures were prepared with a ratio of cement to sand of 1:2.57, a w/c of 0.48, and with an optimum ratio of replacement cement/cement replaced by silica fume of 10%. Various percentages of attapulgite (ranging from 0% to 16%) were tested to assess their compressive strength. The findings indicated that the mix containing 4% attapulgite exhibited a 9% growth in compressive strength compared with the normal concrete mix. In contrast, the mix with the highest percentage of attapulgite (16%) showed a lower compressive strength than that of the slightly normal mix.

II. MATERIALS

A. Cement

All specimens utilized in the experimental study were cast using standard Portland cement from Iraq. To prevent variations in its chemical or physical characteristics, the necessary amount of cement was supplied in a single lot. The physical and chemical characteristics of cement, as depicted in Tables I and II, corresponded to the Iraqi Specifications No.5/2019 [16].

TABLE I. PHYSICAL PROPERTIES OF CEMENT

Properties	Test results	Limit of [16]
Specific surface area (m^2/kg)	305	Min 280
Initial setting time(min)	130	Min 45
Final setting time (hr)	6.5	10
Soundness by autoclave approach(%)	0.27	≤0.8
Compressive strength at 2 days (MPa)	25	Min 20
Compressive strength at 28 days(MPa)	43	Min 42.5

TABLE II. CHEMICAL PROPERTIES OF CEMENT

Oxide composition	Weight %	Limit of [16]
Lime (Cao)	60.63	-
Iron oxide (Fe_2O_3)	4.31	-
Alumina (AL_2O_3)	5.36	-
Silica (SiO_2)	20.68	-
Insoluble Residue(IR)	1.25	Max (1.5)
Magnesia (Mgo)	1.95	Max (5)
Loss On Ignition(L.O.I)	3.3	Max (4)
Sulfate (SO_3)	1.54	$SO_3 \leq 2.5$ if $C_3A>3.5$ $SO_3 \leq 2.8$ if $C_3A \leq 3.5$

B. Superplasticizer (SP)

An SP, KUTPLAST SP 400,based on ASTM C494 [17], was utilized as a plasticizer in all the specimens' preparation.

C. Attapulgite Aggregate

Attapulgite was brought from the Tar Al-Najef region. Table III presents the sieve analysis of combined fine and coarse attapulgite in line with the ASTM C330 specifications [18] and Tables IV and V list the attapulgite characteristics. To increase the reactivity of the attapulgite aggregate, the attapulgite was burned at 1000 °C and soaked for 30 min.

TABLE III. SIEVE ANALYSIS OF COMBINED ATTAPULGITE

Sieve size (mm)	Cumulative passing %	Limits of ASTM C330(12.5-0) mm
19	100	100
12.5	97	95-100
4.75	67	50-80
0.300	15	5-20
0.150	8	2-15
0.075	4	0-10

TABLE IV. PHYSICAL AND CHEMICAL CHARACTERISTICS OF ATTAPULGITE

Property	Result
Bulk density (kg/m^3)	784.12
Specific gravity	0.92
Absorption (%)	16.03
Sulfate content (SO_3) (%)	0.031

TABLE V. CHEMICAL ANALYSIS OF ATTAPULGITE

Oxide composition	Test result
SiO_2	50.74
AL_2O_3	16.42
FeO_3	2.45
Cao	15.68
Mgo	5.21
SO_3	1.47
L.O.I	8.02

D. Fly Ash

The present study employed fly ash type F, complying with the ASTM 618-2019 specifications [19]. Its physical and chemical properties are shown in Tables VI and VII.

E. Water

Tap water was utilized in the mixing and treatment, on the basis of the IQS No. 1073 specifications [20].

TABLE VI. CHEMICAL REQUIREMENTS OF FLY ASH

Oxide	Content%	ASTM 618-19 Requirement (Type F) %
Fe_2O_3	5.3	Sum.>50
Al_2O_3	18.1	
SiO_3	64.7	
SO_3	0.28	Max. 5
MgO	0.88	__
CaO	2.34	Max.18
K_2O	3.5	__
Na_2O	2.2	__
L.O.I	2.9	Max. 6%

TABLE VII. PHSICAL REQUIREMENTS OF FLY ASH

Property	Content %	ASTM 618-2019(Type F) %
Specific gravity	2.2	__
Physical form	Powder	__
Surface area, m^2/g	7.76	__
Color	Grey	__
Amount retained when wet sieved on 45 m (No.325)%	29	Max.34%

III. EXPERIMENTAL WORK

A. Concrete Mixes

Five mixtures were made, as evidenced in Table V. The first mixture (M1) is considered the reference mixture, which is compared with the other mixtures by starting with an aggregate content approximately twice the amount of cement. Several attempts were made to choose the best mixture. The proportion of the best mixture was cement combined with attapulgite (1:2.1), utilizing various proportions of SP, as presented in Table VIII. Also, cement was replaced by fly ash in various ratios of cement weight, as displayed in Table VII.

TABLE VIII. PROPORTIONS OF REPLACED ATTAPULGITE WITH RESPECT TO THE MIX TYPE

Mix*	Attapulgite (kg/m^3)	Slump** (mm)	Density (kg/m^3)	Compr. Str. with days (MPa)		
				7	28	90
M1	900	95	1882	16	19.8	21.9
M2	960	88	1840	17.7	20.2	22.12
M3	984	80	1748	18.1	21	23.1
M4	1050	68	1702	14.8	17.7	19.27
M5	1080	58	1685	14.2	16.4	18.02

*w/c ratio =0.46 and cement content 480 kg/m^3

**Slump test was carried according to ASTM C142 [21] specification

B. Preparation of Specimens

The concrete samples underwent a specific processing, which started immediately after pouring. The samples were warped by a plastic sheet for 24 hours to maintain the concrete moisture content after mold removal. Subsequently, all samples were soaked in water for 7, 28, and 90 days of curing before the tests were conducted.

TABLE IX. CONCRETE MIXES WITH DIFFERENT DOSAGES OF SP

Mix*	Slump	Density (kg/m^3)	Compr. Str. with days (MPa)			S.P (%) of cementations material
			7	28	90	
M3S1	68	1882	19.1	22.4	24.61	0.9
M3S2	73	1802	19.3	24.1	26.48	1.1
M3S3	81	1748	20.8	26.2	27.3	1.3
M3S4	97	1706	17.8	25.1	26.57	1.5
M3S5	110	1665	17.2	23.4	25.74	1.7

*w/c=0.3, cement content 480 kg/m^{3}and attapulgite content 984 kg/m^3

TABLE X. CONCRETE MIXES WITH DIFFERENT DOSAGES OF FLY ASH

Mix*	Fly ash%	Cement (kg/m^3)	Slump (mm)	Density (kg/m^3)	Compr. Str. with days (MPa)		
					7	28	90
F1M3S3	10	432	84	1762	22.8	27.4	30.9
F2M3S3	20	384	88	1771	23.3	27.7	31.8
F3M3S3	30	288	90	1778	23.7	28.1	32.7
F4M3S3	60	192	105	1530	19.9	24.3	26.9
F5M3S3	100	0	115	1432	16.8	20.8	22.25

*w/c= 0.3, SP=1.3% of cementitious materials and attapulgite content 984 kg/m^3

C. Experimental Tests

1) Dry Density

Dry density measurements following the specifications of ASTM C567-10 [22] involve the use of cylinder specimens, with a size of 150 mm × 300 mm.

2) Compressive Strength Test

Concrete specimens, with dimensions of 100 mm × 100 mm ×100 mm, were subjected to compressive force, as illustrated in Figure 1, following the BS EN 12390 [22] specifications. The mean value of the three samples was determined from all concrete mixtures at the curing age of 7, 28 and 90 days. The equation provided below is used to calculate the compressive strength value:

$$fcu = P / A \quad (1)$$

where fcu is the value of compressive strength (MPa) and P is the compressive failure load (N). A is the cross-sectional area of the cubic concrete specimens (mm²).

IV. RESULTS AND DISCUSSION

A. Dry Density

The density results, presented in Table VIII and Figure 2, disclosed that the density decreased with an increased attapulgite content, due to the porous structure of the attapulgite, which is the effect of the overall density. The impact of the SP ratio on the density of the mixes is shown in Table IX and Figure 3. Also, Table X and Figure 4 demonstrate that the replacement of cement by fly ash with a different ratio caused a change in the dry density, with the maximum value being a 30% fly ash ratio in the F2M3S3 mix. This occurred owing to the pozzolanic reaction, which caused the filling of the porous in the concrete structure, and therefore increased density.

Fig. 1. Cube specimen under compressive strength test.

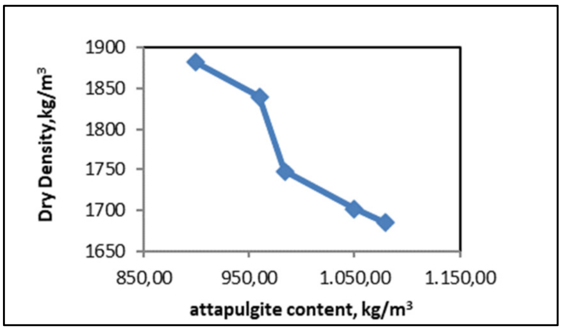

Fig. 2. The relation between the attapulgite content and density.

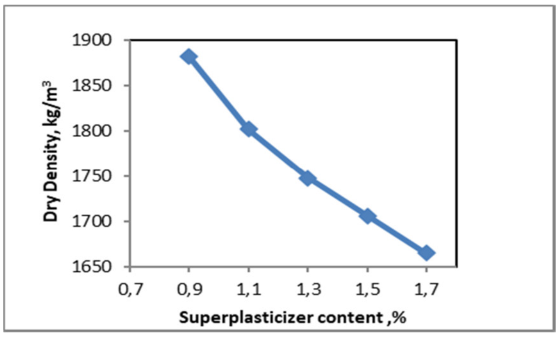

Fig. 3. The relation between the SP content and density.

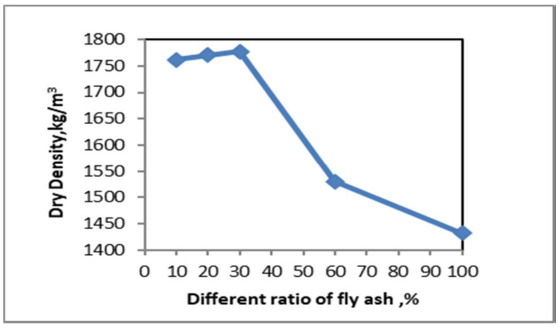

Fig. 4. The relation between the different ratio of fly ash and density.

B. Compressive Strength

Regular patterns in standard specifications rely extensively on the compressive strength because it is a necessary component of concrete mixtures. The third mix (M3), with an attapulgite content of 984 Kg/m^3, exhibited the best performance under various loading conditions, as illustrated in Table IV and Figure 5. The optimal results are described in Table V and Figure 6, and have emerged due to the fact that attapulgite aggregates can enhance the packing of particles within the concrete mix, reducing voids and improving the overall concrete density [24]. This densification contributes to higher compressive strength. Figure 6 displays that the optimal SP dosage was 1.3% by weight of cementitious material. Also, Table X and Figure 7 show the effect of cement replacement by various fly ash ratios. The optimal ratio was 30% by weight of cement materials, which gives a higher compressive strength due to the increased density caused by the pozzolanic reaction.

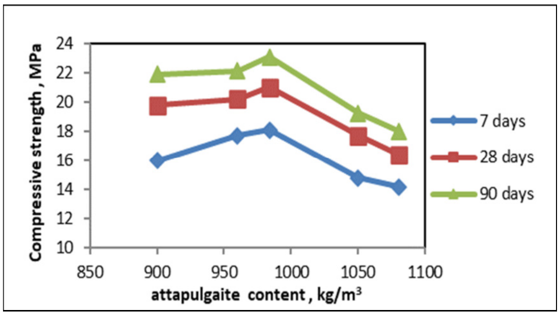

Fig. 5. The relation between the attapulgite content and compressive strength.

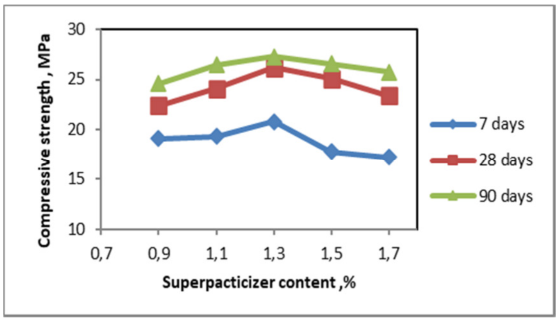

Fig. 6. The relation between the SP content and compressive strength.

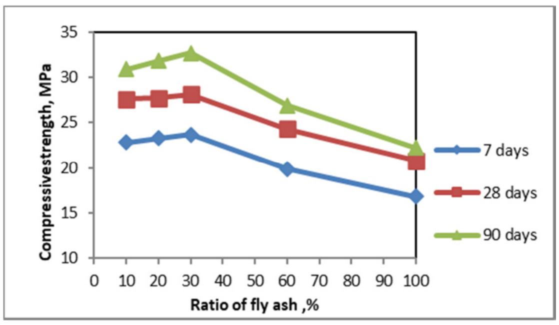

Fig. 7. The relation between the ratio of fly ash and compressive strength.

V. CONCLUSIONS

This work deals with the effect of using attapulgite aggregate (combined fine and coarse aggregate) with Superplasticizer (SP) and fly ash on the compressive strength and dry density. The points of significance in this study were, firstly, the increasing importance of structural Lightweight Concrete (LWC), focusing on alternative materials utilized as the original components. Secondly, the lack of research addressing the comprehensive effect of attapulgite with SP and fly ash on LWC. The findings from the experiments led to the following conclusions.

- The use of combined fine and coarse attapulgite aggregate produced LWC in addition to the acquisition of a good compressive strength of up to 21 MPa after 28 days of curing. Also, this value was increased by using SP and fly ash.
- The magnitude of the slump measurement decreased with an increased attapulgite content.
- The addition of attapulgite aggregate positively correlated with the dry density of specimens for different mixes. Also, the compressive strength significantly developed with an increased attapulgite content. This behavior is well linearly relevant to the estimation of the compressive strength of a specific content.
- A good effect was observed when using SP to reduce the w/c ratio in addition to maintaining the workability of the mixes and increasing the compressive strength. The optimal ratio of the SP was 1.3%.
- The optimal ratio of cement replacement by fly ash was 30% by weight of cement in the F2M3S3 mix, which demonstrated higher compressive strength.
- As a future recommendation, the F2M3S3 mixture is considered to have good results.
- Comparing the current work with another research, [25], many mixtures were studied including the one containing fine attapulgite aggregate, with a content of 500 kg/m^3, and coarse attapulgite aggregate, with a content of 570 kg/m^3, a w/c ratio of 0.36, and a cement content of 345 kg/m^3. The results for the compressive strength were 15.2 MPa at 28 days of curing and the dry density was 1380 kg/m^3. On the contrary, in this work the M3 mixture was composed of combined coarse and fine attapulgite, and a w/c ratio of 480 kg/m3, 984 kg/m^3, and 0.64, respectively. The results for the compressive strength and dry density at 28 days of curing were 21 MPa and 1748 kg/m^3, respectively.
- Authors in [4] concluded that the mixture with cement, fine and attapulgite coarse aggregate, had a content of 365 kg/m^3, 769 kg/m^3, and 408 kg/m^3, respectively and a ratio of 1% steel fiber and 0.48% SP. The results of this mixture regarding density and compressive strength at 28 days of curing were 1700 kg/m^3 and 31.5 MPa, respectively. However, in this work the mixture contained SP at a ratio of 1.3% by weight of cementitious material, and a 30% cement replacement by fly ash. The results revealed that the

dry density and compressive strength at 28 days of curing were 1778 kg/m^3 and 28.1 MPa, respectively.

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