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An Experimental Investigation of Ultra-Fine Aggregate High Strength Concrete (UFAHSC)

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Abstract: *According to ASTM C 33 (AASHTO M 6/M 80) sieves for fine aggregate has openings ranging from 150 µm to 9.5 mm (No. 100 sieve to 3⁄8 in.) while in Ultra-Fine Aggregate Concrete (UFAC) its aggregate size is less than 150 µm. The American Concrete Institute (ACI 363R-92) defines high-strength concrete as concrete with a compressive strength greater than 8,000 psi (55 MPa).The research interest is to optimize the compressive strength of this particular concrete under different conditions of curing and consolidation and make it a high strength concrete, thus we have just achieved to an Ultra-Fine Aggregate High Strength Concrete (UFAHSC). In this research, curing is being held under thermal accelerated curing (in the oven, exposed to humidity) and normal curing (in lime-water) in which the samples are compacted either by pressing or vibrating.*

Keywords: *Ultra-Fine Aggregate High Strength Concrete (UFAHSC), Ultra-Fine Aggregate Concrete (UFAC), Consolidation, Compressive Strength, Normal Curing, Thermal Accelerated Curing.*

1. Introduction

The main factors that increase the compressive strength of concrete is using low W/C ratio, increasing fine fillers, compacting wet concrete and removing voids [1]. One of the effective fine fillers is silica fume [2]. There are over 3000 publications that have been published about silica fume and silica fume concrete. Conforming to AASHTO M 307 or ASTM C 1240, silica fume can be utilized as material for supplementary cementations to increase the strength and durability. According to the Florida Department of Transportation (2004), the quantity of cement replacement with silica fume should be between 7% and 9% by mass of cementation materials. Need to mention also the effect of pozzolanic materials on the strength. Pozzolanic reaction of silica fume is activated by increasing the temperature in concrete at an early age, which is suggested to be cured in oven at 90ºC[3].The basic principles for the development of UFAHSC are listed below:

- There are no coarse aggregate and maximum aggregate size is less than 150 µm.
- Silica powder is carefully optimized to achieve compactness.
- Using high cement content, low water to cement ratio.
- Silica fume or another suitable pozzolanic material can be added to the mix.
- Super plasticizer is needed to get high flowable concrete.
- Pressing during hardening may be helpful to get rid of excess water and to increase the paste density.
- Heat treatment during curing can improve the chemical process and strength gain.

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We should notice that silica powder is ultra-fine aggregate sand so it has large surface area, thus we should use enough cement to surround aggregates properly. Using this great amount of cement needs a high ratio of W/C but we should lower this ratio because of the concrete shrinkage (during water loss) and therefore the role of super-plasticizer is so important. The super-plasticizer affect the various properties of concrete both in fresh and hardened forms mainly due to the following facts as commented by M. Collperd in Concrete Admixtures Hand Book;

- Reduction in interfacial tension.
- Multilayered adsorption of Organic molecule.
- Release of water trapped amongst the cement particles.
- Retarding effect of cement hydration.
- Change in morphology of hydrated cement.

[4-7]. In former studies the compaction lets the voids and extra water go out from the wet concrete and increases the compressive strength, but in UFAHSC (as the results show) it has a converse consequence [8-10].

2. Material Properties

The polycarboxylate-based super plasticizer (Ferkoplast P100) was used with the capability of gaining strength at the very young age of concrete. Other characteristics are listed in table 1.

TABLE 1: Material Properties

Material	Characteristic	Density (gr/cm^3)
Water	Municipal water	1
Cement	Tehran (Iran) Portland Cement Type 1	3.15
Silica Fume	Semnan (Iran) Ferro Silicon	2.2
Super Plasticizer	Ferkoplast P100-3R	1.05
Silica Powder	Recycled of iron ore	2.6

The silica powder which is used as an ultra-fine aggregate (UFA) has the range particle size of 37-149 µm in which its grading is shown in Fig.1.

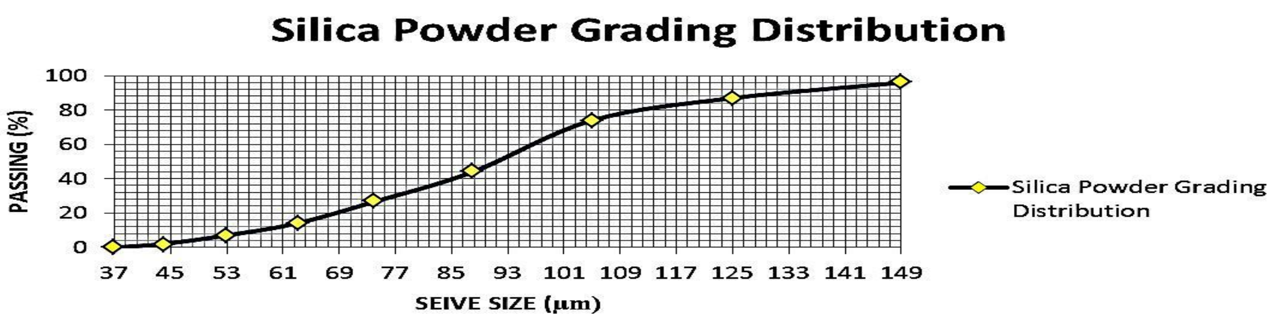

Fig. 1: Silica Powder Grading Distribution

As the Fig. 1 indicates, the distribution is like an S shape which shows that the aggregate (silica powder) we used was well-graded, and this beneficial feature helps the concrete to heighten its compressive strength significantly, which is desirable for us. Another feature of this aggregate is that about 26% of silica powder pass through sieve no. 200 (#200 = 74 µm=0. 0029 in.) which shows that this material has a great amount of effective surface.

3. Experimental Programs

To find the effect of curing and consolidation on the compressive strength of UFAHSC it has designed four processes of curing (i.e. Listed in table 2).

TABLE II Curing and Consolidation Types

Type	Description	
	Curing	Placing
A	Normal curing	Vibration compaction
B	Normal curing	Pressing compaction (20 MPa)
C	Thermal accelerated curing	Vibration compaction
D	Thermal accelerated curing	Pressing compaction (20 MPa)

We can accelerate the curing time by putting the concrete in the oven and our research results have shown that by heating the concrete in six hours the concrete achieves 90% of its own final compressive strength, that's why this process called thermal accelerated curing. In the entire process of thermal curing the temperature was 90ºC (194ºF) and samples were exposed to humidity. Also in all normal curing the concrete samples were put in the lime-water of 20ºC (68ºF). These processes are explained in table 3.

TABLE III: Types of Curing

Type of Curing	#1	#2	#3	#4
A & B	3 days in lime-water	7 days in lime-water	14 days in lime-water	28 days in lime-water
C & D	3 hours heat	6 hours heat	6 hours heat+ 7 days in lime-water	6 hours heat+28 days in lime-water

4. Results

As the Fig.2 represents, both in normal and thermal accelerated curing the vibrated samples withstand much compressive strength. These results are completely different from the original RPC as Richard P. and Cheyrezy M. (1995) found that in RPC pressing increases the compressive strength by 38%, but in UFAHSC with actually the same mix design except its aggregate material as the results suggest, pressing reduces compressive strength 4% (( ) in normal curing and 2% (( ) in thermal accelerated curing. So unlike the original RPC, in UFAHSC pressing has counter effect on the curing also, it is a costly process. We should notice that in the pressing process, the water leaves the concrete and left it dry. That is why the curing process stops in some parts earlier than the other parts and makes a defect in the concrete.

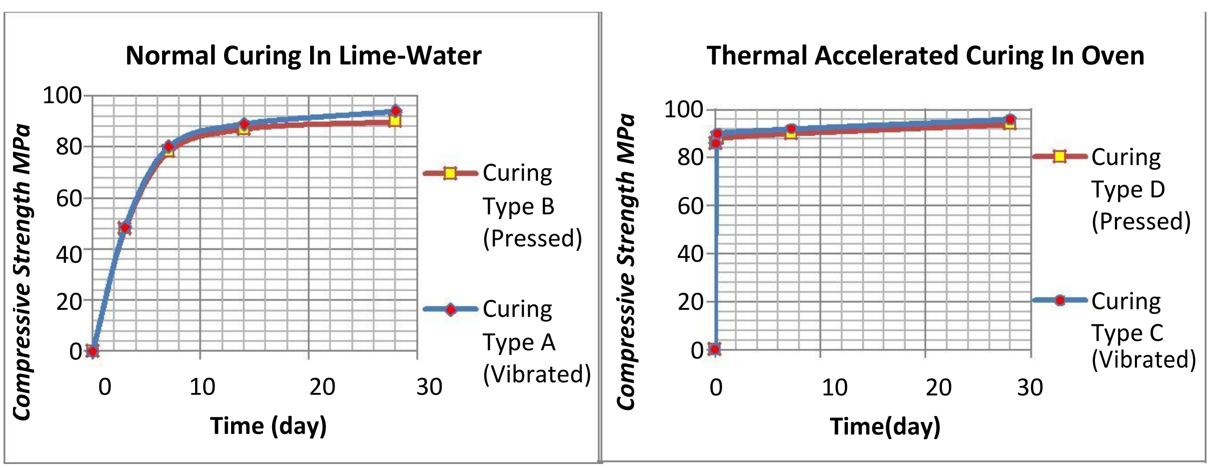

Fig. 2. Normal and Thermal Accelerated Curing Uniaxial Compressive Strength

The pressed specimen is illustrated in Fig.3.Because it has compacted properly, it has actually no voids, but the water left the concrete in some parts (especially the top parts), this defect lowers its compressive strength under uniaxial loading.

Fig.3: Pressing Samples by Exerting 5 Tons.

In vibrating consolidation, instead it has some significant voids that may affect its strength, but it has been cured properly, that is why it can withstand much strength than pressed samples. As figure 4 illustrates, no dry parts being observed in this figure.

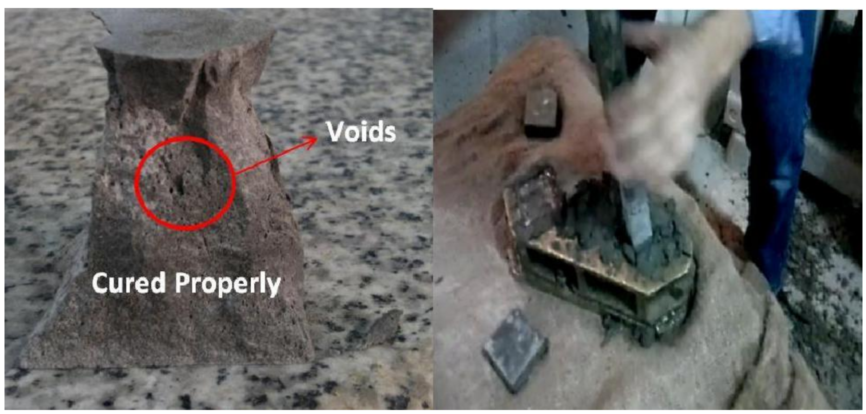

Fig. 4: Vibrating Samples by Shaking Table.

In vibration method, the concrete is more homogeneous and approximately all parts have the same moister at the same time of curing.

In figure 5 the role of temperature is being observed.In both pressed and vibrated samples thermal cured samples (types C and B) are ahead of normal cured samples (types A and D) in terms of compressive strength by about 2% (( ) in vibrated compaction and 4% (( ) in pressed compaction. As it mentioned before, pozzolanic reaction of silica fume is activated by increasing the temperature in concrete at an early age. That is why thermal cured samples withstand much uniaxial strength than normal cured samples.

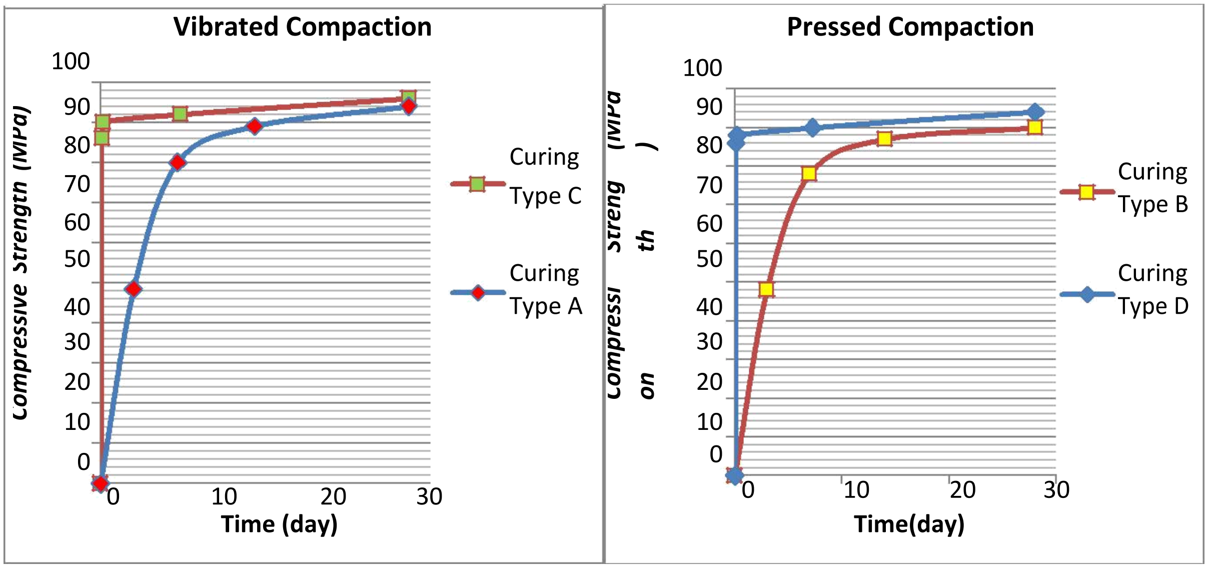

Fig. 5: Vibrated and Pressed Cured Samples Uniaxial Compressive Strength

So in UFAHSC it performs better - in terms of higher strength and lower driying shrinkage or creep strain - when they are steam cured rather than cured at room temperature. This improvement was related to a more dense microstructure of the cement matrix cured at 90°C.

5. Conclusions

Based on the results of the experimental work carried out it was found that:

1- In thermal accelerated curing the UFAHSC achieves it's 90% of its final compressive strength within 3 hours while in normal curing it requires between 7 to 14 days to achieve this strength.

Pressing has an adverse effect on the compressive strength of UFAHSC also it is a costly process so vibration in UFAHSC would be more desirable. Also in UFAHSC the thermal accelerated cured compressive strength is greater than normal curing.

2- By choosing an appropriate mix design UFAHSC could be classified as high strength concrete as the American Concrete Institute (ACI 363R-92) defines high-strength concrete as concrete with a compressive strength greater than 8,000 psi (55 MPa). In this research UFAHSC compressive strength reached about 96MPa within 28 days curing so it could be utilized in the future for the erection of high-rise structures, main road bridges, etc. Also, it's durable concrete because of low permeability and fine fillers used in it.

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