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Unconfined Strength of Nano Reactive Silica Sand Powder Concrete

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***Abstract*—**Nowadays, high-strength concrete is an integral element of a variety of high-rise buildings. On the other hand, finding a suitable aggregate size distribution is a great concern; hence, the concrete mix proportion is presented that has no coarse aggregate, which still withstands enough desirable strength. Nano Reactive Silica sand powder concrete (NRSSPC) is a type of concrete with no coarse material in its own composition. In this concrete, the only aggregate found in the mix design is silica sand powder with a size less than 150 μm that is infinitesimally small regarding the normal concrete. The research aim is to find the compressive strength of this particular concrete under the applied different conditions of curing and consolidation to compare the approaches. In this study, the young concrete specimens were compacted with a pressing or vibrating process. It is worthwhile to mention that in order to show the influence of temperature in the curing process, the concrete specimen was cured either in 20 ^{0}C lime water or autoclaved in 90 ^{0}C oven.

***Keywords*—**Nano reactive silica sand powder concrete, consolidation, compressive strength, normal curing, thermal accelerated curing.

I. Introduction

THE main factors that increase the compressive strength of concrete are using a low water to cement (w/c) ratio, increasing fine fillers, compacting wet concrete, and removing voids [1]. One of the effective fine fillers is silica fume that is an amorphous (non-crystalline) polymorph of silicon dioxide [2]. According to ASTM C 33 [3], silica sand powder concrete is classified as an ultra-fine aggregate concrete. Furthermore, regarding ACI 211.1-91 [4], the mixture aggregate size must be less than 0.5 inches in order to achieve a uniaxial compressive strength greater than 9000 psi. Enormous research studies about silica fume concrete have been published. Silica fume can be utilized as a supplementary cementation material to increase the strength and durability of concrete, conforming to AASHTO M 307 or ASTM C 1240 [5]. In accordance with Florida Department of Transportation [6] it is recommended that the quantity of cement replacement with silica fume should be between 7% and 9% of the mass of cementations materials. The pozzolanic reaction of silica fume can be activated by increasing the temperature of concrete at an early age, which is strongly suggested to be cured in an oven at 90 ºC [7]. The basic principles for the development of NRSSPC are listed as follows:

- There is no coarse aggregate in this concrete and the maximum aggregate size is less than 150 μm.
- Silica sand powder is carefully optimized to achieve the desired compactness.
- The water to cement w/c ratio is kept in its minimum value.
- Suitable pozzolanic material such as silica fume can be added to the mix design.
- High-performance concrete is achievable by using enough super-plasticizer.
- The chemical process can be improved by heat treatment.

It should be noticed that silica powder is ultra-fine aggregate sand [8], so it has a large effective area [9]; thus, relatively more cement should surround aggregates. Using such a great amount of cement demands a high ratio of W/C [10], but this ratio must be maintained low because of the concrete shrinkage; therefore, the role of superplasticizer is significant [11]. Superplasticizer affects the various properties of concrete both in fresh and hardened forms, mainly due to the following facts that are asserted [12]:

- Reduction in the interfacial tension.
- Releasing of the water trapped between the cement particles.
- Retarding the effect of cement hydration.
- Changing the morphology of hydrated cement.

In past studies, it was shown that applying the compaction to the young age concrete would increase the uniaxial compressive strength of the specimen, however in NRSSPC, as the current experimental results indicate, this compaction has a converse effect [13], [14].

II. Experimental Program

We considered the effect of consolidation and curing types on the uniaxial strength of NRSSPC as listed in Table I.

TABLE I
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)

The curing time is accelerated by putting the concrete in the oven, and the research results indicate that by heating the young concrete in six hours, the concrete achieves 90% of its own final compressive strength, explaining why this process is called thermally accelerated curing. In the entire process of thermal curing, the temperature was set to be 90 ºC (194 ºF),

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and the samples were exposed to humidity as well. Also, for the normal curing type, the concrete samples were put in the lime-water of 20 ºC (68 ºF). These processes are explained in Table II. As it was mentioned in Table I, samples were consolidated with either vibrating or pressing. To clarify the pressing compaction, Fig. 1 shows the procedure.

TABLE II
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 and 7 days in lime-water	6 hours heat and 28 days in lime-water

The silica powder which was applied as an ultra-fine aggregate has the range particle size of 37-150 μm in, which its particle size is shown in Fig. 2.

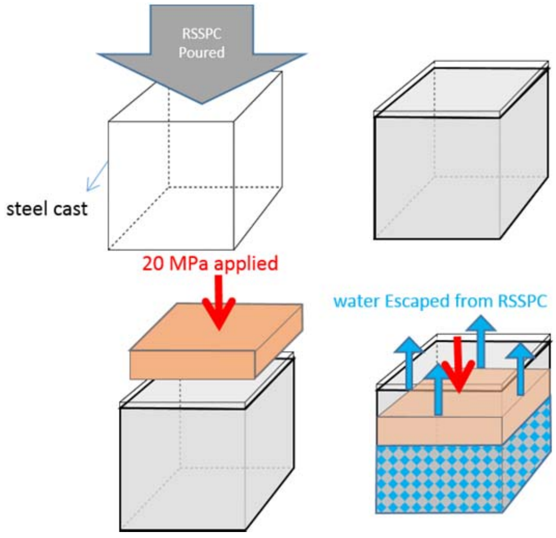


Fig. 1 Pressing Wet Concrete

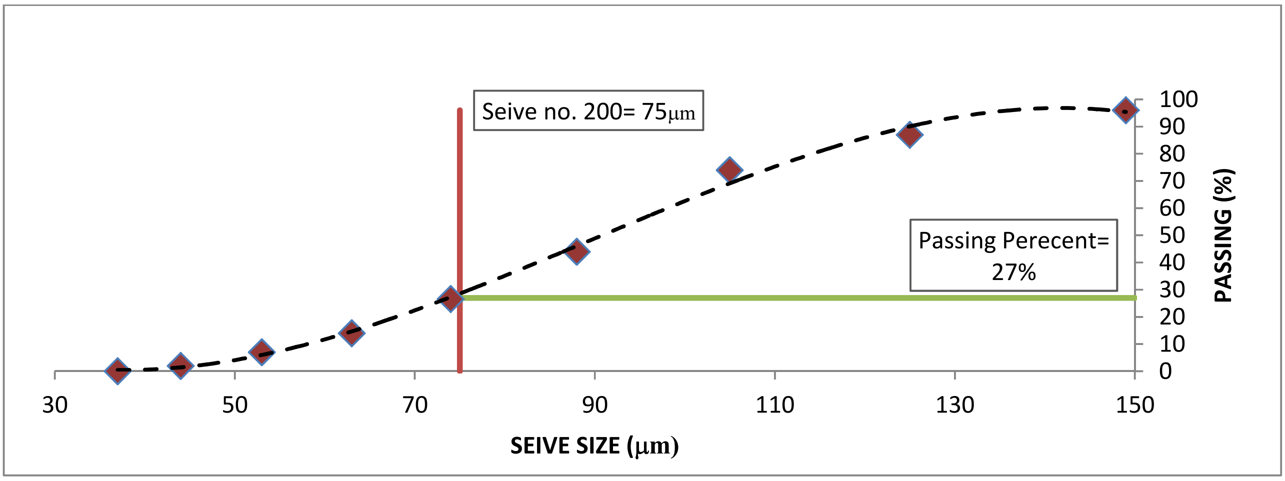


Fig. 2 Silica Powder Particle Size Distribution

As Fig. 2 represents that the distribution has an "S" shape indicating that the implemented aggregate was well-graded, and this beneficial feature helps the concrete achieving a significant strength which is desired. Another feature of this aggregate is that approximately 27% of silica powder passes through sieve no. 200 showing that this material has a great amount of effective area.

III. NRSSPC MIX PROPORTION

The polycarboxylate-based superplasticizer (Ferkoplast P100) was used with the capability of achieving strength at the very young age of concrete. Other noteworthy characteristics are listed in Table IV.

The NRSSPC mix proportions are represented in Table III.

TABLE III
NRSSPC RECOMMENDED MIX DESIGNS

Components ratio (in weight)	W/C	SF/C	W/(C+SF)	A/C	SP/C	SP/(C+SF)
	0.22	0.25	0.18	0.9	1.60%	1.27%
Compositions	Cement (kg/m^3)	Silica fume (kg/m^3)	Cementitious Materials (kg/m^3)	Aggregate (kg/m^3)	Water (kg/m^3)	Super plasticizer (Solid content) (kg/m^3)
	991.5	247.87	1239.37	892.35	218.13	15.8

IV. RESULTS

As Fig. 3 represents, for both normal and thermal accelerated curing methods, the vibrated samples withstand much more compressive strength regarding the pressed samples, that is the compressive strength of type C > D and A > B. The results of the current study differ from that of the original Reactive Powder Concrete RPC [15], which indicates that pressing the young age concrete would increase the uniaxial compressive strength of concrete by 38%. However, in the present NRSSPC with the same mix design except its aggregate type/size, the pressing process would reduce the specimen strength by 4% in the normal curing and 2% in the autoclaved process or thermally accelerated curing. Thus, unlike the RPC, pressing NRSSPC has counter-effects on the curing quality, in addition to its costly process. Furthermore, it should be noticed that in the pressing process, the water was removed from the young age concrete. Thus, the curing process stops in some parts of the specimen much earlier than the other parts making a considerable defect in the concrete specimen. Also, in Fig. 3, the role of temperature can be observed. As it was mentioned before, the pozzolanic reaction of silica fume is activated by increasing the temperature in young age concrete. That is why the thermally cured samples withstand much uniaxial strength than the normally cured sample, that is the compressive strength of type C > A and D > B.

TABLE IV
MATERIAL PROPERTIES

Material	Characteristic	Density ($\frac{g}{cm^3}$)
Water	Drinking Water	**1**
Cement	Tehran Portland Cement Type 1	**3.15**
Silica Fume	Semnan Ferro Silicon	**2.2**
Super Plasticizer	Ferkoplast P100-3R	**1.05**
Silica Powder	Recycled of iron ore	**2.6**

The pressed specimen is shown in Fig. 4. Since it has been properly compacted, the voids and water are removed from the mortar. When the water leaves the young concrete, the curing process stops after a short time causing a defect in the specimen as well.

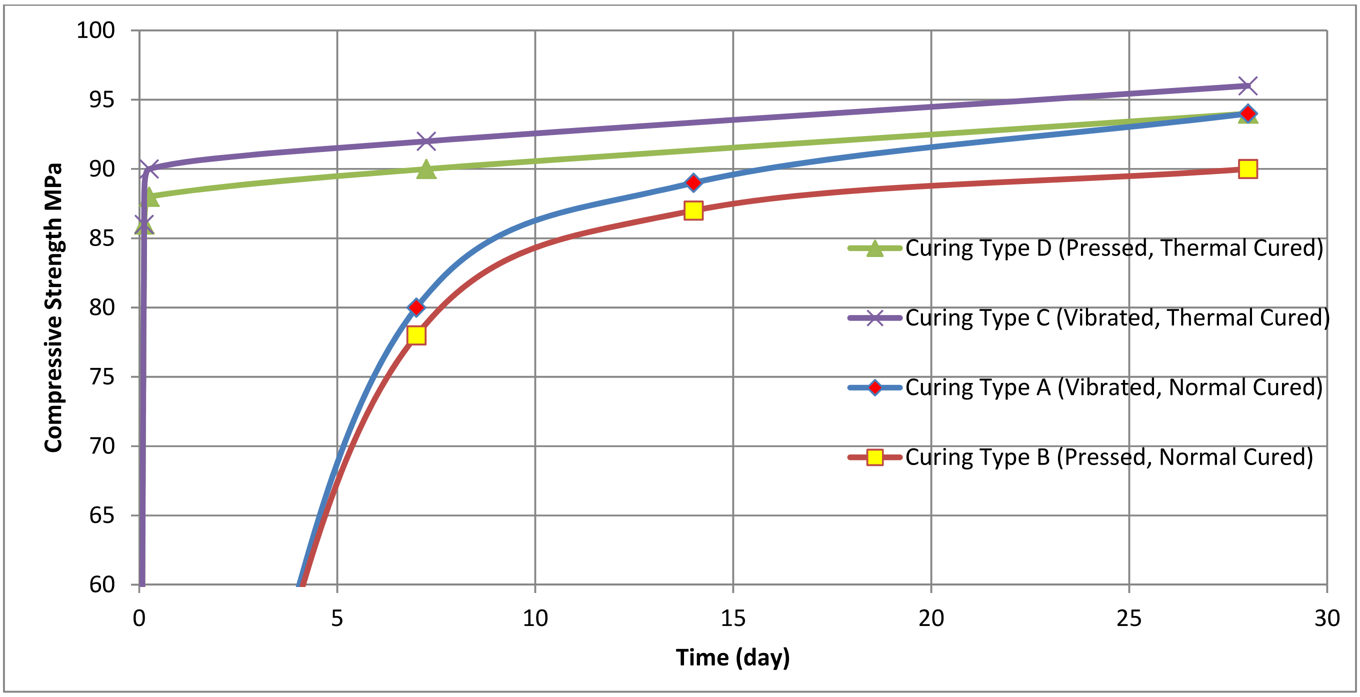


Fig. 3 Normal and Thermal Accelerated Curing Uniaxial Compressive Strength, Data were Normalized

Fig. 4 Pressing the Samples by Applying 20 MPa

In the vibration consolidating process, the specimen has numerous voids that may reduce its strength, but it has been cured properly, that is why it can withstand much strength than the pressed samples, illustrated in Fig. 5.

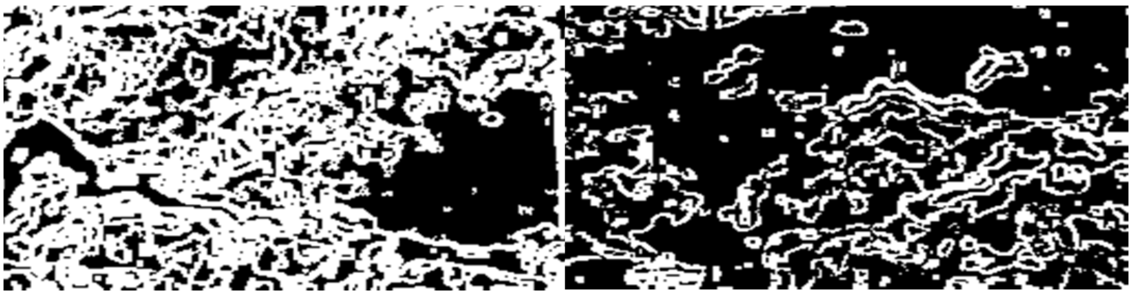
In the vibrating method, the concrete is more homogeneous, and approximately all parts have the same moisture at the same time during the curing process.

V. Additional Test: Scanning Electron Micrographs, SEM Test

In order to understand the role of the curing process in determining the performance of the material, the microstructure of RPC was studied by SEM by Collepradi. To facilitate the observation of the cement matrix, the specimens without steel fibers were manufactured. Fig. 6 shows the typical fracture surfaces of NRSSPC normally cured at 20 °C and thermally cured at 90 °C. All specimens were observed at 7 days. The microstructure of the thermally cured specimen (see Fig. 6 (b)) was much denser than that of the NRSSPC normally cured samples (see Fig. 6 (a)).

While in the thermal-cured samples, as SEM suggests, the concrete microstructure is much denser, it can withstand much uniaxial compressive strength than the normal-cured samples for both types of consolidations.

Fig. 5 Vibrating Samples by Shaking Table



(a) (b)

Fig. 6 Scanning Electron Micrograph of 7-day cured specimens in the absence of steel fibers: (a) Normal cured samples and (b) Thermally cured samples

VI. Conclusions

Based on the results of the experimental work, the following results were found:

1- In thermally accelerated curing, NRSSPC achieves 90% of its final compressive strength within three hours while in the normal curing, it required 7 to 14 days to achieve this strength.
2- Pressing has an adverse effect on the compressive strength of NRSSPC. Also, it is a costly process, so vibration in NRSSPC would be more desirable. For NRSSPC, the thermal accelerated cured compressive strength is greater than the normal curing's strength.
3- By choosing an appropriate mix proportion, NRSSPC could be classified as a high strength concrete as American Concrete Institute (ACI 363R-92) defines high-strength concrete as a type of concrete with uniaxial compressive strength greater than 8,000 psi (55 MPa). In the current research, NRSSPC compressive strength reached about 14,000 psi (96 MPa) within 28 days curing, so it could be utilized in the future for the construction of high-rise structures, main road bridges, etc. Also, it is a durable concrete because of the low permeability and the fine fillers used in it.
4- The replacement of the fine silica sand in NRSSPC by an equal volume of well graded normal aggregate RPC did not change the compressive strength of NRSSPC at the same water-cement ratio. These results are not in agreement with the model proposed by Cheyrezy [15] since they attributed the higher compressive strength level of RPC to a better homogeneity of the mixture in the absence of coarse aggregate.

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