

## Research Article

# Reactive Silica Sand Powder Concrete (RSSPC) Uniaxial Compressive Strength Investigation

Hossein Kabir and Mojtaba Sadeghi

*Department of Civil Engineering, Sharif University of Technology, Tehran, Iran*

**Abstract.** Nowadays, high-strength concrete is an integral part of so many high-rise buildings. In accordance with the ACI 211.1-91 the mixture aggregate size should be less than 0.5 inches in order to achieve a uniaxial compressive strength greater than 9000 psi. On the other hand, finding a suitable aggregate grading distribution of concrete mix design is a big deal; hence force, the authors propose a mix proportion with no coarse aggregate still withstand enough strength. Silica sand powder concrete is a type of concrete with actually no coarse material in its own composition. In this concrete, the only aggregate is silica sand powder in which its size is less than 150  $\mu\text{m}$  that is very small in size. According to the ASTM C 33, this concrete is classified as an ultra-fine aggregate concrete. The research interest is to find the compressive strength of this particular concrete under different conditions of curing and consolidation to compare each approach with each other. In this article, the young concrete specimen was compacted with a pressing or vibrating process. It is worthwhile to mention that to show the role of temperature on the curing process, the concrete specimen was cured both in 20°C lime water or autoclaved in 90°C oven.

**Keywords:** Reactive Silica Sand Powder Concrete (RSSPC); Consolidation; Compressive Strength; Normal Curing; Thermal Accelerated Curing

Corresponding Author:  
Hossein Kabir; email:  
94kabir@gmail.com

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## 1. Introduction

The main factors that increase the compressive strength of concrete is using low water to cement (w/c) ratio, increasing fine fillers, compacting wet concrete and removing voids (Brandt A.M. 1998) [4]. One of the effective fine fillers is a silica fume, that is an amorphous (non-crystalline) polymorph of silicon dioxide (S.A. Abo-El-Enein et al. 2015) [1]. So many articles being published about the silica fume concrete. Silica fume can be utilized as a material for supplementary cementations to increase the strength and durability, Conforming to the AASHTO M 307 or ASTM C 1240. In accordance with the Florida Department of Transportation (Byron, T. et al. 2004) [5] it is recommended that the quantity of cement replacement with the silica fume should be between 7% and 9% by mass of cementations materials. The Pozzolanic reaction of silica fume is just being activated by increasing the temperature in concrete at an early age, which is strongly suggested to be cured in an oven at 90°C (Emre Sancak et al. 2008) [10]. The basic principles for the development of RSSPC are listed as follows:

1. There is no coarse aggregate in this concrete and the maximum aggregate size is less than 150  $\mu\text{m}$ .
2. Silica Sand Powder is carefully optimized to achieve compactness.
3. Using low water to cement ratio and high cement content.



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)

**Table 1:** Curing and Consolidation Types.

4. Suitable pozzolanic material such as Silica Fume can be added to the mix design.
5. High-performance concrete is achievable by using enough super-plasticizer.
6. The chemical process can be improved by heat treatment.

It should be noticed that silica powder is ultra-fine aggregate sand, so it has a large effective area; thus, enough cement should surround aggregates properly. Using this great amount of cement demands a high ratio of W/C, but this ratio must be lowered because of the concrete shrinkage; therefore, the role of superplasticizer is so important. The superplasticizer affects the various properties of concrete both in fresh and hardened forms mainly due to the following facts that commented by M. Collperdi:

1. Reduction in the interfacial tension.
2. Releasing of the water trapped between the cement particles.
3. Retarding the effect of cement hydration.
4. Changing the morphology of hydrated cement.

(WANG, C et al. 2012; Amjad Alrifai et al. 2013; Ehsan Ghafari et al. 2015; Collepradi, M. 1995) [2, 6, 7, 12]. In former studies, the compaction removes the voids and extra water from the wet concrete and increases the compressive strength, but in RSSPC, as the results show, it has a converse consequence (J.L. Amorós et al. 2008; Konstantin Kovler et al. 2011) [3, 9].

## 2. Experimental Program

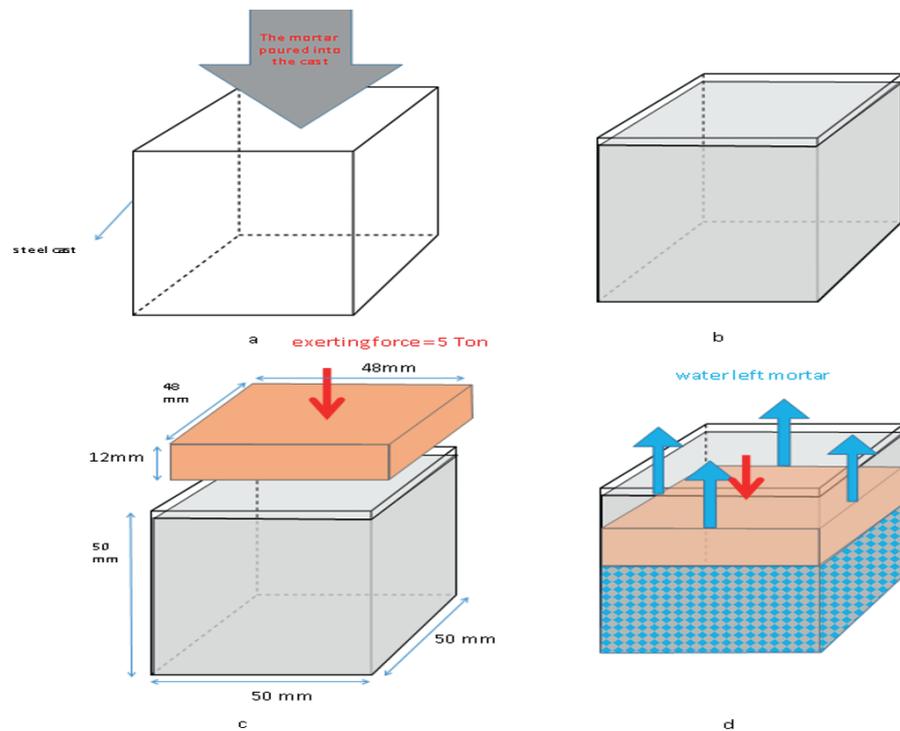
To consider the effect of curing and consolidation process on the uniaxial compressive strength of RSSPC it has designed four processes of curing (i.e. Listed in Table 1).

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, that is why this process called thermal accelerated curing. In the entire process of thermal curing, the temperature was 90°C (194°F) and samples were exposed to humidity as well. Besides, in all normal curing the concrete samples were put in the lime-water of 20°C (68°F). These processes are explained in Table ??.

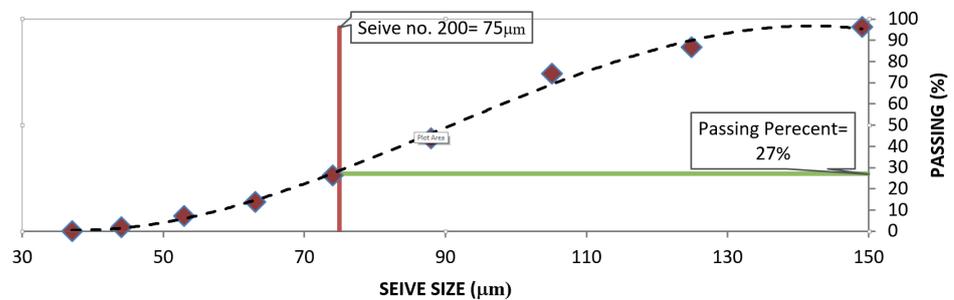
As it was mentioned in table1, samples were consolidated with either vibrating or pressing. To clarify the pressing compaction, its procedure is shown in Figure 1.

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

**Table 2:** Types of Curing.



**Figure 1:** Pressing Wet Concrete.



**Figure 2:** Silica Powder Grading Distribution.

The silica powder which applied as an ultra-fine aggregate has the range particle size of 37–150  $\mu\text{m}$  in which its grading is shown in Figure 2.

As the Figure 2 suggests, the distribution has an “S” shape indicates that the aggregate implemented was well-graded, and this beneficial feature helps the concrete achieving strength significantly which is desirable. Another feature of this aggregate is that about 27% of silica

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	Silica fume	Cementitious Materials	Aggregate	Water	Super plasticizer
	(kg/m <sup>3</sup> )	(kg/m <sup>3</sup> )	(kg/m <sup>3</sup> )	(kg/m <sup>3</sup> )	(kg/m <sup>3</sup> )	(Solid content) (kg/m <sup>3</sup> )
	991.5	247.87	1239.37	892.35	218.13	15.8

**Table 3:** RSSPC Recommended Mix Designs.

Material	Characteristic	Density (g/cm <sup>3</sup> )
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

**Table 4:** Material Properties.

powder pass through sieve no. 200 showing that this material has a great amount of effective area.

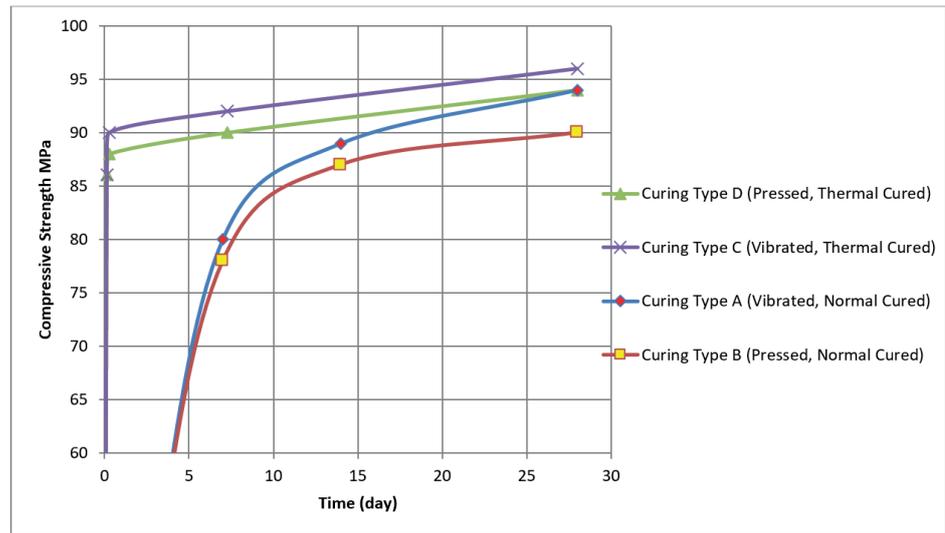
### 3. RSSPC (Mix Design and Material Properties)

The RSSPC mixed proportions are represented in Table 3.

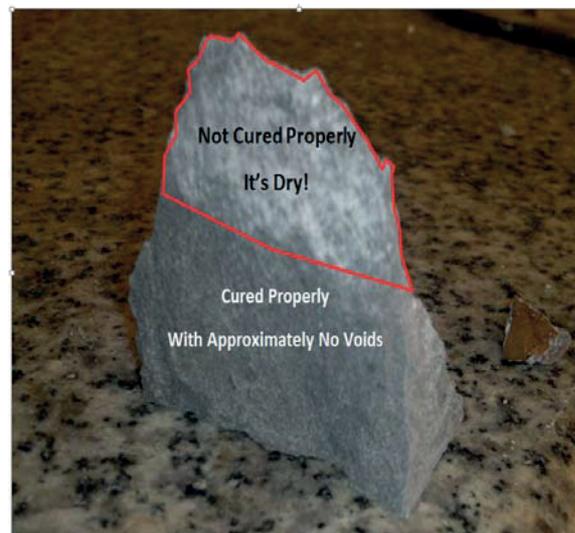
The polycarboxylate-based superplasticizer (Ferkoplast P100) was used with the capability of achieving strength at the very young age of concrete. Other characteristics are listed in Table 4.

### 4. Results

As the Figure 3 represents, both in the normal and thermal accelerated curing the vibrated samples withstand much compressive strength regarding the pressed samples, i.e. the compressive strength of type C > D and A > B. These results are different from the Reactive Powder Concrete (RPC) being considered by Richard P. and Cheyrez M. (1995) [11] in which they found that in RPC pressing the young age concrete increases the uniaxial compressive strength by 38%; however, in the present RSSPC with actually the same mix design except its aggregate material/size, as the results suggest, the pressing process would reduce the specimen strength by 4% in the normal curing and 2% in the autoclaved process or thermal accelerated curing. So, unlike the RPC, pressing the RSSPC has both counter effects on the curing quality moreover it is a costly process. Furthermore, it should be noticed that in the pressing process, the water removes from the concrete and left it dry. That is why the curing stops in some parts of the specimen earlier than the other parts and makes a considerable defect in concrete. In this specific figure, the role of temperature is being observed. As it was mentioned before, the pozzolanic reaction of silica fume is activated by increasing the temperature in young age concrete. That



**Figure 3:** Normal and Thermal Accelerated Curing Uniaxial Compressive Strength.



**Figure 4:** Pressing the Samples by Exerting 5 Tons.

is why thermally cured samples withstand much uniaxial strength than normally cured sample, i.e. the compressive strength of type C > A and D > B.

The pressed specimen is illustrated in Figure 4. Because it has compacted properly, the voids and water are removed from the mortar. When the water leaves the young concrete, the curing process stops after short time makes a defect in the specimen as well.

In the vibration consolidating process, instead, the specimen has some remarkable voids that may reduce its strength, but it has been cured properly, that is why it can withstand much strength than pressed samples. As Figure 5 illustrates, no dry parts being observed in this figure.

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.



**Figure 5:** Vibrating Samples by Shaking Table.



**Figure 6:** Scanning Electron Micrograph of 7-day cured specimens in the absence of steel fibers. A: Normal cured samples and B: Thermally cured samples.

## 5. Additional Test (Scanning Electron Micrographs, SEM)

In order to understand the role played by the curing process in determining the performance of the material, the microstructure of RSSPC was studied by SEM. To facilitate the observation of the cement matrix, specimens without steel fibers were manufactured. Figure 6 shows typical fracture surfaces of RSSPC normal cured at 20°C and thermal-cured at 90°C. All specimens were observed at 7 days. The microstructure of the thermal-cured specimen (Figure 6B) was much denser than that of the RSSPC normal-cured samples (Figure 6A). Also Collepradi, M. achieved the same results for RPC with the same concrete mix proportion except for its aggregate particles.

While in thermal-cured samples (as SEM suggests) the concrete microstructure is much denser, it can withstand much uniaxial compressive strength than normal-cured samples in both types of consolidations thus, the results of Figure 5 are verified.

## 6. Conclusions

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

1. In thermally accelerated curing, the RSSPC achieves its 90% of its final compressive strength within 3 hours while in normal curing it requires between 7 to 14 days to achieve this strength.
2. Pressing has an adverse effect on the compressive strength of RSSPC also it is a costly process, so vibration in RSSPC would be more desirable. Also in RSSPC the thermal accelerated cured compressive strength is greater than normal curing.
3. By choosing an appropriate mix proportion, RSSPC could be classified as a high strength concrete as the American Concrete Institute (ACI 363R-92) defines high-strength concrete, as a concrete with uniaxial compressive strength greater than 8,000 psi (55 MPa). In the current research, the RSSPC compressive strength reached about 14,000 psi (96 MPa) 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 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 RSSPC by an equal volume of well graded normal aggregate RPC did not change the compressive strength of the RSSPC at the same water-cement ratio. These results are not in agreement with the model proposed by Richard and Cheyrezy since they attributed higher compressive strength level of RPC to a better homogeneity of the mixture in the absence of coarse aggregate.

## Competing Interests

The authors declare that they have no competing interests.

## Acknowledgment

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