UNIAXIAL COMPRESSIVE STRENGTH OF REACTIVE SILICA SAND POWDER CONCRETE (RSSPC)

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Abstract: Silica sand powder concrete is a concrete with actually no coarse material in its own composition. In this concrete the only aggregate is silica powder and its size is less than 150 µm which is classified as 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 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.

[Hossein Kabir. UNIAXIAL COMPRESSIVE STRENGTH OF REACTIVE SILICA SAND POWDER CONCRETE (RSSPC). *Rep Opinion* 2025;17(11):20-28]. ISSN 1553-9873 (print); ISSN 2375-7205 (online). http://www.sciencepub.net/report. 04. doi:10.7537/marsroj171125.04

Keywords: Reactive Silica Sand Powder Concrete (RSSPC); 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 (Brandt A.M.1998). One of the effective fine fillers is silica fume (S.A. Abo-El-Enein et al.2014). 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(Emre Sancak et al.2008). The basic principles for the development of RSSPC 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.
- Heat treatment during curing can improve the chemical process and strength gain.

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.

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- Release of water trapped amongst the cement particles.
- Retarding effect of cement hydration.
- Change in morphology of hydrated cement.

(WANG, C et al.2008; Amjad Alrifai et al.2013; Ehsan Ghafari et al.2015; Collepradi, M.1995). In former studies it has been turned out that the compaction would remove the voids and extra water from the wet concrete and increases the compressive strength, but in RSSPC (as the results show) it has an adverse consequence (J.L. Amorós et al.2008; Konstantin Kovler et al.2011; Subhash C. Yaragal,et al.2015).

2. Experimental programs

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

Table 1- 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)

Accelerating the curing process, by putting the concrete in the oven, the research results have shown that by heating the concrete in six hours the concrete achieves 90% of its own final compressive strength, that is why this process is 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 2.

Table 2-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

As it was cited before (in table1) samples were consolidated with either vibrating or pressing. To clarify the pressing compaction process its procedures are sketched as follows (Fig1):

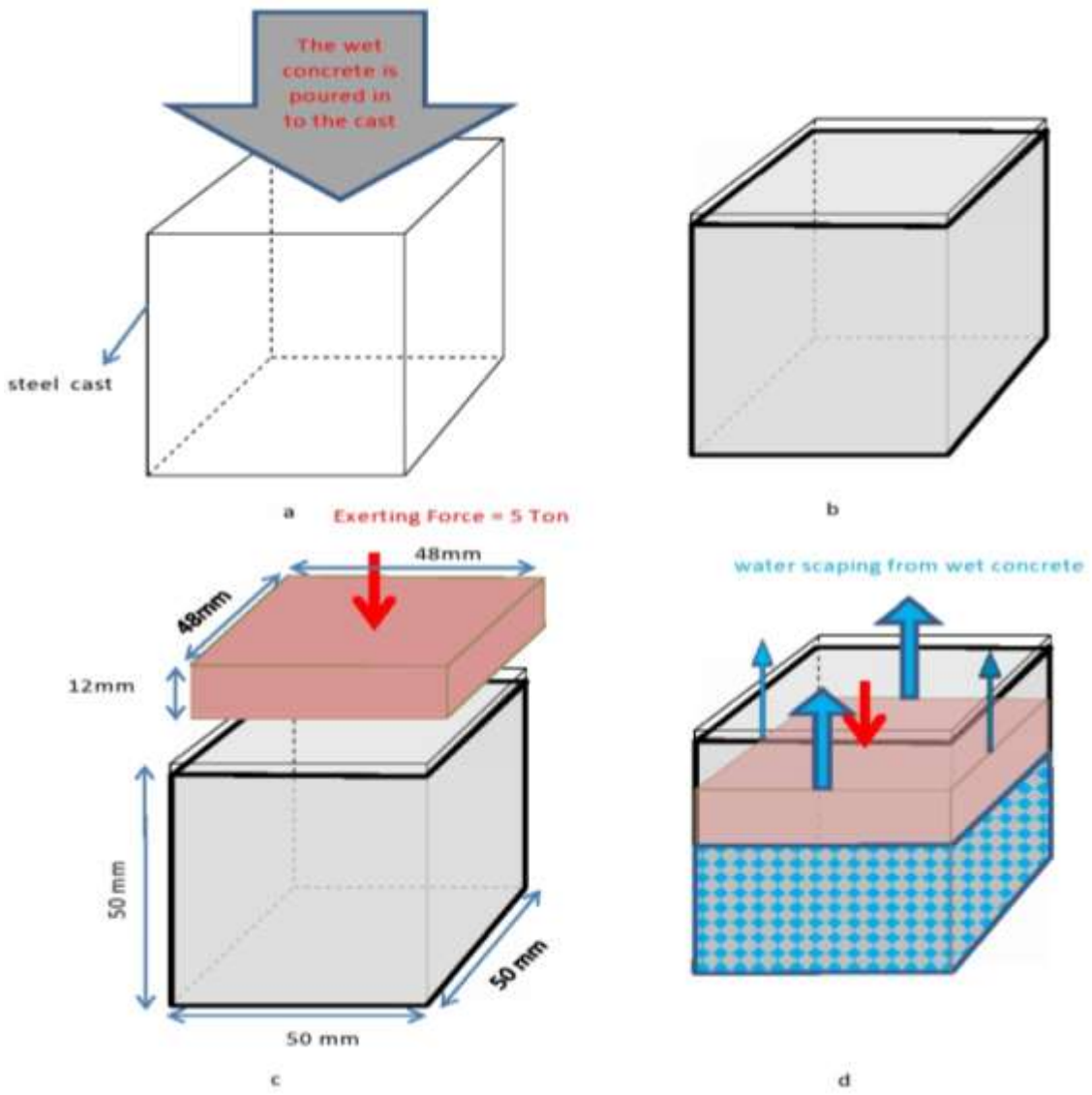


Fig.1- Pressing Wet Concrete

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

Fig. 2- Silica Powder Grading Distribution

As the Fig. 2 indicates, the distribution is like an S shape which shows that the aggregate (silica powder) used was well-graded, and this beneficial feature helps the concrete to heighten its compressive strength significantly, which is desirable. Another feature of this aggregate is that about 26% of silica powder pass through sieve no. 200 (#200 = 74 µm=0. 0029in.) which shows that this material has a great amount of effective surface.

3. Mixture proportions of RSSPC (MIX DESIGN):

The RSSPC mixed proportions is represented in table3.

Table 3: RSSPC 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

For modified RPC (RSSPC) mixtures, well graded natural silica sand aggregate (maximum size: 150 µm , and specific gravity 2.6 (g/cm3) was used to replace a part or the whole volume of the fine sand and/or a part of the cementitious binder.

3.1.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 4.

Table 4- Material Properties

Material	**Characteristic**	**Density** $(\frac{gr}{cm^3})$
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**

4. Results

As the figure3 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, buy using a unidirectional pressing, the compressive strength will be increased by 38%, but in RSSPC with actually the same mix design except its aggregate material, as the results suggest, pressing reduces compressive strength 4% $((\frac{94}{90}-1)\times 100))$ in normal curing and 2% $((\frac{96}{94}-1)\times 100))$ in thermal accelerated curing. So unlike the original RPC, in RSSPC pressing has an adverse 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 major defect in the concrete.

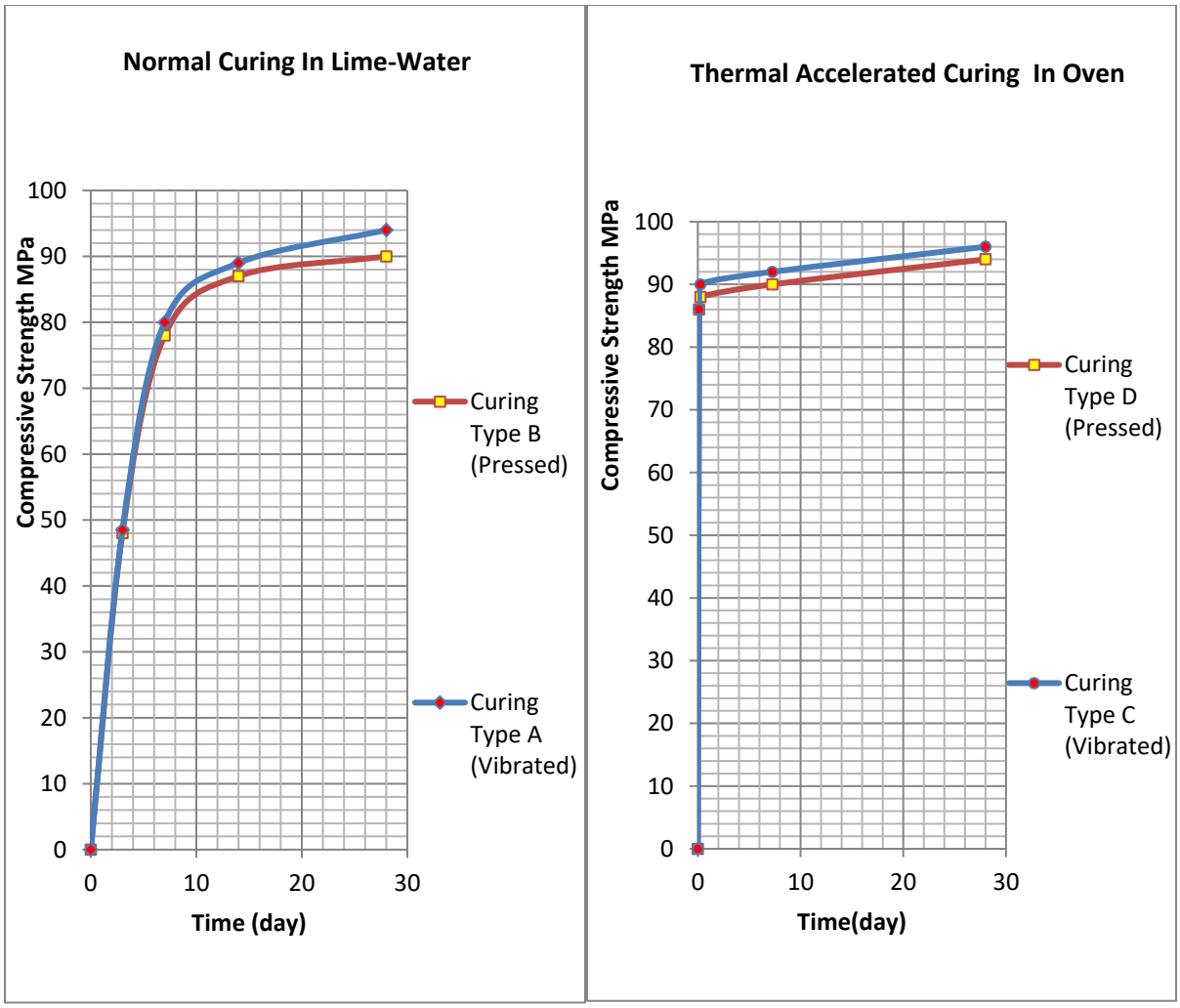


Fig.3.Normal and Thermal Accelerated Curing Uniaxial Compressive Strength

The pressed specimen is illustrated in Fig.4.Because it has compacted properly, it has actually no voids, but the water left the concrete in some parts (especially the top parts), this major defect lowers its compressive strength under uniaxial loading.

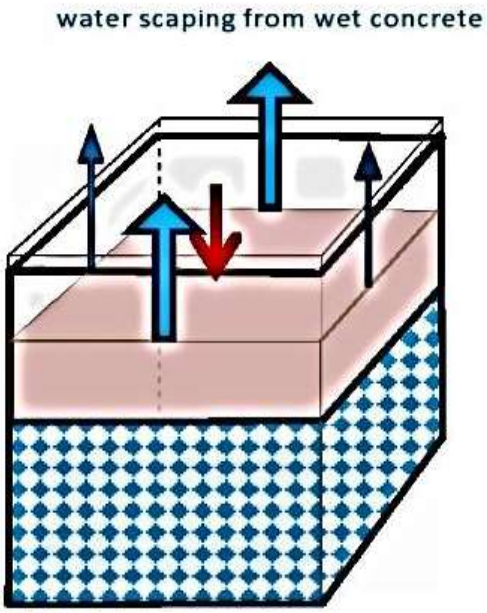


Fig.4- Pressing Samples by Exerting 5 Tons.

In the vibrating process, 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 5 illustrates, no dry parts being observed in this figure.

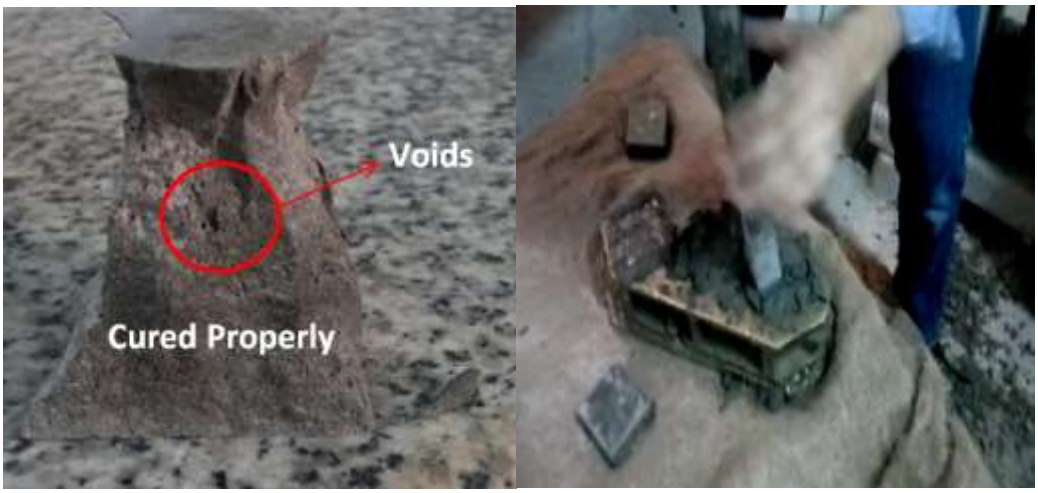


Fig.5-Vibrating Samples by Shaking Table.

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

In figure 6 the role of temperature is being observed. In both pressed and vibrated samples thermal cured samples (types C and B) strength is greater than normal cured samples (types A and D) by 2% $((\frac{96}{94}-1)\times 100))$ in vibrated compaction and 4% $((\frac{94}{90}-1)\times 100))$ in pressed compaction. As it was 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.

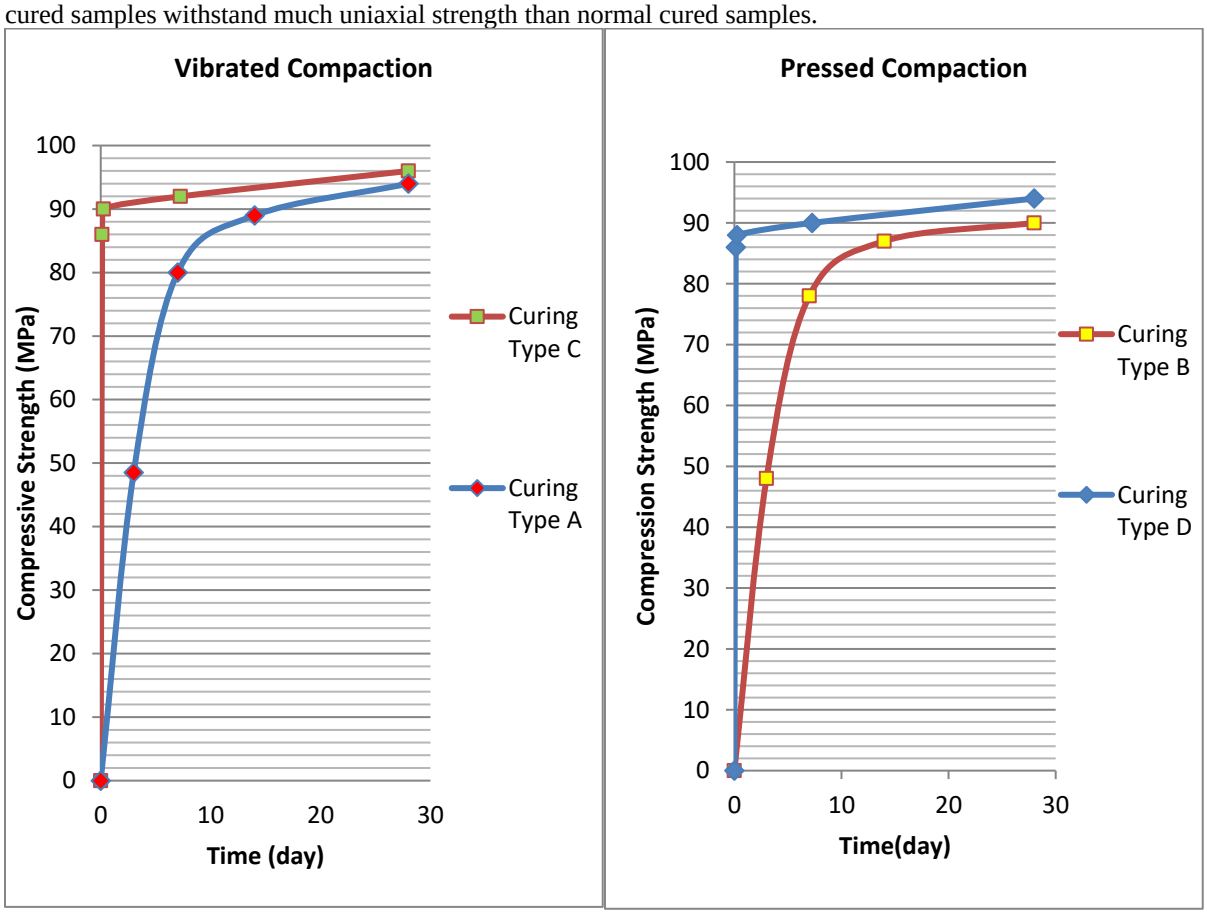
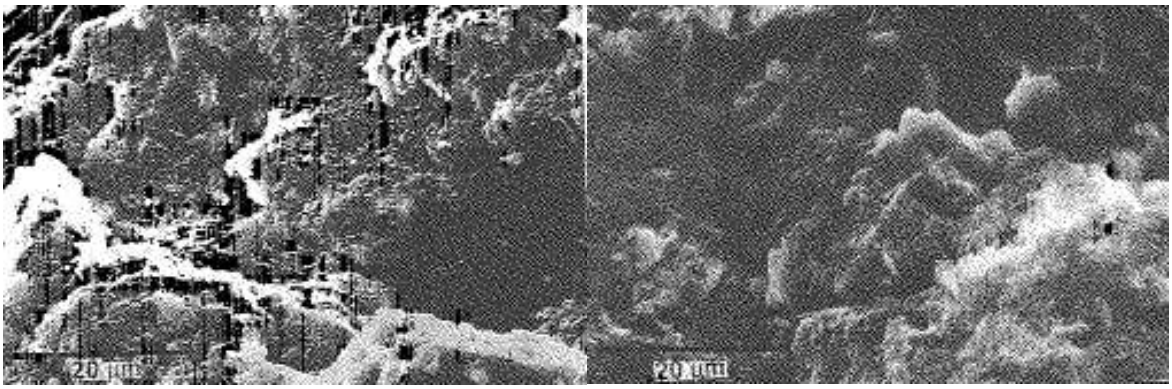


Fig.6. Vibrated and Pressed Cured Samples Uniaxial Compressive Strength

So in RSSPC it performs better - in terms of higher strength and lower drying 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. Additional Tests - Scanning Electron Micrographs (SEM).

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. In order to understand the role played by the curing process, the microstructure of RSSPC was studied by SEM. To facilitate the observation of the cement matrix, specimens without steel fibers were manufactured. Figure 7 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 (Fig.7B) was much more dense than that of the RSSPC normal-cured samples (Fig.7A). Also Collepradi, M. achieved to the same results for RPC with the same concrete mix proportion except its aggregate particles.



A B

Fig.7.Scanning Electron Micrograph of 7-day cured specimens in the absence of steel fibers.A:Normal cured samples and B:Thermal cured samples.

6. Conclusions

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

1- In thermal accelerated curing the RSSPC 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 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.

2- By choosing an appropriate mix design RSSPC 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 RSSPC 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.

3- The addition of the graded silica sand powder aggregate does not reduce the compressive strength provided that the quality of the cement matrix, in terms of its water-cement ratio,is not changed. This result is in contrast with the model proposed to relate the high compressive strength level of RPC (100 MPa) to the absence of coarse aggregate.

4- The replacement of the fine silica sand (less than 0.15 mm) in RSSPC by an equal volume of well graded natural aggregate (maximum size: 8 mm) 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 the high compressive strength level of RPC to a better homogeneity of the mixture in the absence of coarse aggregate.

5- When the graded aggregate replaced all the fine sand and part of the cementitious binder (cement and silica fume), at a given workability level, there was an increase in the water-cement ratio, due to the reduction in the cement factor, and hence a corresponding decrease in the compressive strength.

6-

Acknowledgment

The author acknowledges the assistance and support of Amir Kabir University of Technology concrete laboratory and Mojtaba Sadeghi (Student of Sharif University of Technology) for preparing the experiment.

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