

# Effect of silica fume/binder ratio on compressive strength development of reactive powder concrete under two curing systems

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**Abstract.** This paper aims to investigate the influence of Silica fume proportion ratio in respect to the total amount of binder on compressive strength of reactive powder concrete cured in two curing systems. Four ratios of Silica fume (0%, 15%, 25% and 35%) as replacement of cement weight were considered. After demolding, two curing systems were used: the first included immersing the cubic specimens in water at  $24 \pm 2$  °C until the test. In the second, the specimens were immersed in hot water at  $105 \pm 5$  °C (accelerated curing) for 48 hours, then in water at  $24 \pm 2$  °C until the test. The results show that mix which contains 25% Silica fume imparts more enhancement on compressive strength as compared to the control mix. Also, it was found that the second system of curing has more influence on compressive strength development than the first one, especially at earlier ages.

## 1 Introduction

Reactive powder concrete (RPC) that was developed in Paris in 1990 is a special type of concrete that has two main properties: high strength and high performance. The gradation in its materials gives a low percent of voids with high density when compared with traditional concrete [1]. Coarse aggregate is absent in reactive powder concrete, therefore, the microstructure is far from non-homogenous between the cementitious materials and fine aggregate [2].

Different curing systems were applied in the literature in the production of RPC. For activity accelerating, heat treatment may be adopted to improve the microstructure and enhancing the earlier strength of RPC when silica fume is used in the mix [3]. Talebinejad et al. [4] indicated that the heat curing at (90-200)°C modified the pozzolanic activity, while, Cheyrez et al. [5] showed that heat curing was essential at (200-250) °C for getting excellent compressive strength, especially at earlier ages. Treatment using static pressure was also used and led to enhance the compressive strength by about 33% in comparison to others without the static pressure [6]. A study by Yazic et al. [7], found that some reduction in bonding (paste and fiber) happened after using of autoclave and steam curing when compared with normal curing.

The goal of this study is to investigate the influence of silica fume/ binder ratio on compressive strength of RPC using two curing systems: accelerated and normal curing. Additionally, due to that previous work [8] showed that the smaller the maximum particle size and the better the packing degree of fine aggregate, the

higher the compressive strength of RPC, so, sand with a maximum grain size of 0.3 mm is used to achieve the aim of this study.

## 2 Experimental Program

### 2.1 Materials

Ordinary Portland cement, commercially called "Kar", was used in this study. The chemical composition of the cement, which conforms to Iraqi specifications No.5/1984 [9], is illustrated in Table 1. Silica fume purchased from "BASF" company was used as a pozzolanic material, see Table 2. Natural sand with single size (0.15 - 0.3 mm) was used as fine aggregate. In order to enhance workability, third generation superplasticizer (Gelnium 54), based on polycarboxylic ether was added.

### 2.2 Mix proportions, mixing and casting

A total of four mixes were made to achieve the goals of this investigation. Three of them include replacing of cement (by weight) with silica fume in proportions of 15%, 25%, and 35%. The other mix, without adding, was considered as control. The sand/ binder and water/ cementitious ratios for all mixes were 1:1 and 0.18, respectively. The details of mix proportions per one cubic meter are shown in Table 3.

Due to the low water content and high cementitious materials that are usually used in reactive powder concrete, it required relatively a long mixing time. The depended mixing procedure in this research was as follows:

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- All dry materials were fed into the mixer and mixed at a low-speed rate (140 r/min) for one minute;
- The mixing water and superplasticizer, which were previously mixed, were then added, and all materials were mixed for one minute at low-speed rate;
- After that, the mixer was stopped for one minute and the speed was changed to a moderate rate (285 r/min);
- Then, the mixer was operated at this rate for eight minutes.

After the mixing was complete, the fresh RPC was placed in standard cube molds. The following casting and tamping procedures were as described by ASTM C109 standard [10].

**Table 1.** Chemical composition of cement.

Oxides Composition	Content, %	Iraqi specifications (No.5/1984), %
CaO	61.8	-
SiO <sub>2</sub>	20.3	-
Al <sub>2</sub> O <sub>3</sub>	4.16	-
Fe <sub>2</sub> O <sub>3</sub>	3.9	-
MgO	3.4	<5
SO <sub>3</sub>	2.4	<2.5
Free lime	3.01	-
L.O.I.	0.03	<4
L.S.F.	0.96	0.66- 1.02
Insoluble residue	1	<1.5

**Table 2.** Properties of silica fume.

Property	Value or description
Unit weight	2300 kg/m <sup>3</sup>
Fineness (blain)	> 15 m <sup>2</sup> /g
SiO <sub>2</sub>	> 85 %
CaO	< 1 %
Chloride content	< 0.1 %
Activity index	112 %

**Table 3.** Details of mix proportions.

Mix symbol	Cement, kg/m <sup>3</sup>	Silica fume, kg/m <sup>3</sup> (%)	Sand, kg/m <sup>3</sup>	Water, kg/m <sup>3</sup>	Superplasticizer, % of binder
M0	1150	0	1150	207	2.58
M15	977.5	172.5 (15)	1150	207	2.58
M25	862.5	287.5 (25)	1150	207	2.58
M35	747.5	402.5 (35)	1150	207	2.58

## 2.3 Curing

After 20-24 hours of casting, the specimens were demolded. Thereafter, two systems of curing were applied: the first (SC1) included immersing the specimens in water at °24 ±2 until the test. In the second (SC2), the specimens were cured in hot water (accelerated) at °105 ±5 for 48 hours, then immersed in water at °24 ±2 until the test. The curing systems were not applied until the end of 24 hours from casting.

## 3 Tests

### 3.1 Compressive Strength Test

The compressive strength test was performed using standard 50×50×50 mm cubic specimens at three ages: 7, 14 and 28 days. Three specimens were taken into account for each mix at the specified age, so, a total of 72 specimens was made in this study.

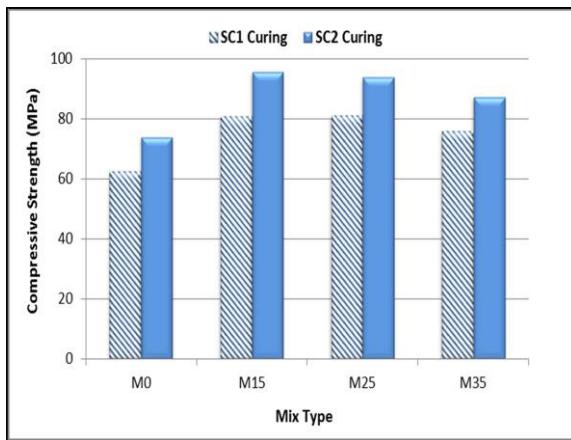
## 4 Results and discussion

### 4.1 Compressive Strength Results

Compressive strength results of the RPC mixes at 7, 14 and 28 days ages are clarified in Figures 1 to 5. In general, results showed that mixes which contained silica fume awarded higher strength at the specified age than without adding mix for SC1 (except M35 at 28 days age) and SC2 curing systems. The pozzolanic reaction, well packing in between cement particles and the densifying of the microstructure that provided by silica fume, could interpret this behavior.

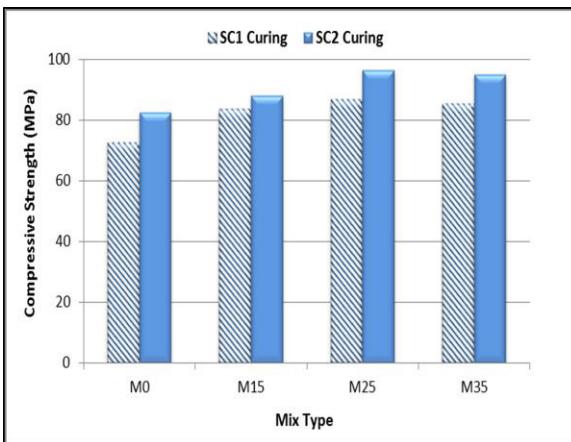
At 7 days ages, for SC1 curing, maximum compressive strength (81.28 MPa) was reached at 25% replacement of silica fume compared with control mix. For SC2 curing, results showed that the higher the silica fume/binder ratio the lower the compressive strength of RPC. Where, higher strength (95.73 MPa) was gained by replacing 15% of cement with silica fume, while minimum strength (87.37 MPa) was obtained at 35% replacement. At 14 days age, mix that contained 25% of silica fume gave maximum compressive strength in comparison with other mixes for both SC1 and SC2 curing systems (86.87 MPa and 96.6 MPa, respectively). Also, this behavior could be seen in the M25 mix at 28 days age for SC2 curing system, where it folded maximum arising in compressive strength (21%) with respect to without adding mix. While, for the SC1 system, the increment in compressive strength decreased with increasing of silica fume/binder ratio. The compressive strength of M35 mix was less than the control mix by about 2%.

For comparison between the two curing systems, results indicated that SC2 system, which included hot water curing, had more effect on strength development at 7 days age than later ages. This might be as a result of temperature increase which speeded up the reactions, and consequently the hydration products formation, and

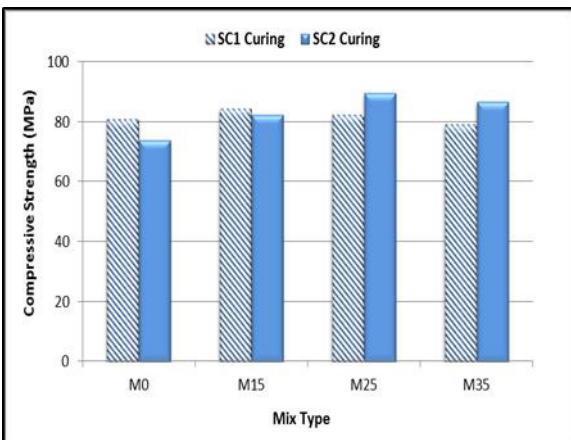


**Fig. 1.** Compressive strength results at 7 days.

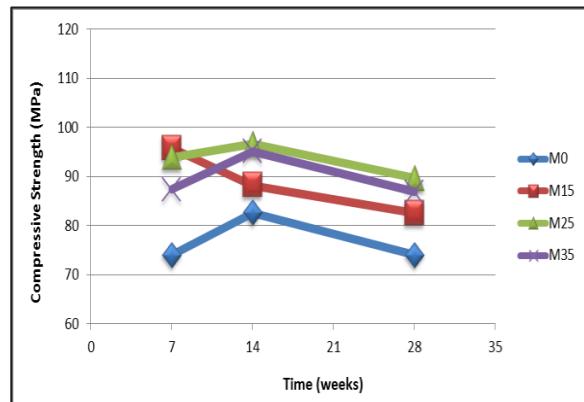
led to increasing the early strength [11]. Similar behavior was also found in the literature [12]. Furthermore,



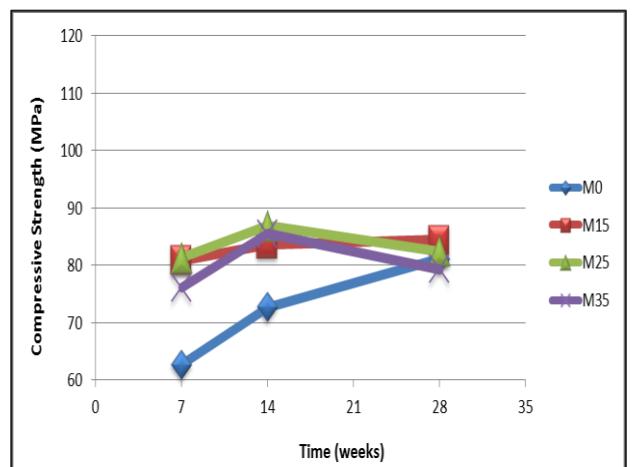
**Fig. 2.** Compressive strength results at 14 days.



**Fig. 3.** Compressive strength results at 28 days



**Fig. 4.** Compressive strength development with time (accelerated curing system).



**Fig. 5.** Compressive strength development with time (normal curing system).

though that compressive strength showed higher initial values at early ages (7 and 14 days), it tended to decrease at later ages (28 days), but it remained higher than control mix. At 28 days, for M0 and M15 mixes, compressive strength values of the normal curing system (SC1) were higher than that in the SC2 system. Also, the influence of accelerating curing (SC2) was more pronounced for higher replacements of silica fume (25% and 35%) than that for lower replacement (15%).

Figures 4 and 5 illustrate the compressive strength development with time for all mixes. It can be seen that, for accelerated curing systems (Figure 4), all mixes except M15 showed strength increasing at 14 days age in comparison with beginning age (7 days) then tended to decrease at the later age (28 days). This action could result from the non-homogeneous distribution of hydration products within the matrix due to the accelerated effect of hot water curing that caused, finally, the strength to be decreased at later ages. On the other hand, the M15 mix showed permanent decrease with time for all considered ages. For normal curing system (Figure 5), the results revealed that control and M15 mixes had a comparable exhibition, continual increase in strength with time. However, the other mixes (M25 and M35) showed similar behavior as for the accelerated curing system.

## 5 Conclusions

Based on the results of this investigation, the following conclusions can be obtained:

1. Replacing of cement with silica fume up to 35% enhances the compressive strength of RPC, but in different rates with time.
2. The best compressive strength result, for SC1 and SC2 curing, is obtained when replacing of cement by 25% of silica fume.
3. The influence of accelerated curing is more obvious on strength development of RPC at early ages than later ages, especially for M25 and M35 mixes.
4. The influence of SC2 curing becomes more clarity at 25% and 35% replacements of silica fume than that for 15%.

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