Performance of recycled aggregates in self compacting concrete

Dear Sir,

This has reference to the paper titled 'Performance of recycled aggregates in self compacting concrete' by Prashant O. Modani and Vinod M. Mohitkar published in The Indian Concrete Journal, October 2014, Vol. 88, No. 10, pp. 57-64.

In this paper authors mainly aims to study the performance of coarse recycled aggregates in self compacting concrete. In this work concrete specimens of different grades were manufactured by replacing natural coarse aggregates (NCA) with recycled coarse aggregates (RCA) in different percentages. Mainly two important properties namely compressive strength and permeability were evaluated. The results are quite interesting and useful for the readers and the researchers interested in SCC. The discusser congratulates the authors for their sincere effect.

In the present investigation, the authors have used very high percentage of silica fume as a replacement to cement and its purpose is not clearly explained. First of all silica fume is not a cement replacement material. Before using silica fume its role in concrete technology should be thoroughly understood.

1. According to authors, in the first mix silica fume is 128 kg and cement is 270 kg and with this silica fume is about 47.4% which is very high. Similarly in the second mix, the silica fume used is about 33%. As the percentage of RCA increases, the dosage of SP also increases to maintain constant slump. This is obvious in RAC for the reasons discussed in the paper. The authors should have tested one more trial mix with 100% cement and natural aggregate to know the dosage of SP and the corresponding compressive strength. These values should definitely be less compared to mix A_0. Authors should have employed binary or ternary blend with 10-15% of silica fume as investigated by many authors [1 to 6]. Authors have not mentioned any reference to substantiate the use of such high percentage of silica fume. Authors are requested to discuss and give their opinion in this direction.

2. The impact strength of aggregate appears to be very high for both NCA and RCA (9.88% and 17.36%). Discusser has tested many samples of NCA and RCA from crushed cubes of medium to high strength. For good aggregates, generally impact value varies from 15 to 25% and for RCA it is still higher and is about 25 to 40% depending on the quality of the aggregates. The discusser is of the opinion that the impact machine may not be mounted firmly on the concrete pedestal and the full impact energy might not have transferred to the specimen while testing. Authors are informed to confirm this point and to give their opinion.

3. Keeping in mind the amount of cementitious materials used (silica fume is 128 kg and cement is 270 kg (53 grade), total =398 kg) with w/cm =0.45 for NCA concrete A_0, the compressive strength of 26 MPa at 28 days appears to be very low. Is it due to very high percentage of silica fume whose ill -effects are discussed below? How to ensure that full silica fume has reacted and contributed? Micro studies might help in this direction. What is the authors' reaction to this?

Discussers reaction

Use of such high percentage of silica fume in concrete is detrimental from many aspects which are addressed elsewhere. A brief review of the problems associated with high percentage of silica fume is discussed here. Before this, let us understand the performance mechanism of silica fume in concrete.

In cementitious compounds, silica fume works on three levels. The first one is a chemical reaction called the "pozzolanic" reaction. The hydration of Portland cement produces many compounds, including calcium silicate hydrates (CSH) and calcium hydroxide (CH). The CSH gel is known to be the source of strength in concrete. When silica fume is added to fresh concrete it chemically reacts with CH to produce additional CSH. The benefit of this reaction is twofold; increased compressive strength and chemical resistance.

The second function of silica fume is a physical one. Because silica fume is 100 to 150 times smaller than cement particle it can fill the voids created by free water in the matrix. This function, called particle packing, refines the microstructure of concrete, creating a much denser pore structure. Impermeability is dramatically increased, because silica fume reduces the number and size of capillaries.

In the third level, cement paste–aggregate interfacial refinement comes in to picture. In concrete the characteristics of the transition zone between the aggregate particles and cement paste plays a significant role in the cement-aggregate bond. Silica fume addition influences the thickness of transition phase in mortars and the degree of the orientation of the CH crystals in it. Hence mechanical properties and durability is improved because of the enhancement in interfacial or bond strength. The higher surface area and amorphous nature of silica fume make it highly reactive. This property plays an important role in RAC.

Thus the silica fume modified concrete is not only stronger, it lasts longer, because it is more resistant to aggressive environments. The bond between the concrete paste and the coarse aggregate, in the crucial interfacial zone, is greatly increased, resulting in compressive strengths that can exceed 100 MPa. The additional CSH produced by silica fume is more resistant to attack from aggressive chemicals then the weaker CH.

Generally silica fume is used at 5 to 20% by weight of cement [1-5]. In most of the applications, it is used along with other supplementary materials such as fly ash and ground granulated blast furnace slag. Most of the studies at the national and international level consist of silica fume in the range of about 5 to 25%.

Use of higher percentage of silica fume is not advocated due to the following reasons.

1) More heat of hydration

The hydration of C_3S, C_2S, and C_4AF are accelerated in the presence of silica fume. Huang and Feldman [1] reported that addition of silica fume accelerates the hydration of ordinary Portland cement at all stages of hydration. During the course of hydration, the cumulative heat evolved due to hydration of ordinary Portland cement containing silica fume was always higher than from ordinary Portland cement paste. At early age, due to fast pozzolanic reaction of silica fume, a greater amount of heat is liberated compared to Portland cement. Ratio of heat liberated by pozzolanic activities of silica fume during the first 2–3 days per gram of silica fume to that of Portland cement is reported to be of the order of 1–2.

2. Increased consistency of cement

Rao [2] determined the influence of silica fume on the consistency of cement pastes and mortars. Specific gravity and specific surface of the silica fume used were 2.05 and 16,000 m^2/kg, respectively. Silica fume was varied from 0 to 30% by weight of cement. Since the SF is finer than the cement, the specific surface increased with increase in SF content. The standard consistency of pure cement paste was found out to be 31.50%; while at 30% SF, it was 44.25%. It was observed that the consistency of cement increased with the increase in SF content. As much as 40% of additional water requirement was observed for cement pastes containing 20–30% SF. Otherwise higher dosage of SP or HP is required to maintain the slump or flow.

3. Increased in setting time

Rao [2] observed that initial setting time decreased with the increase in silica fume content. At smaller contents, the setting time of cement paste did not affect much. However, at higher silica fume contents, the initial setting time was significantly decreased. Therefore, he concluded that silica fume contents result in quick setting of cement. This will affect the performance of fresh concrete or SCC in large pours.

4. Decreased workability

Alshamsi et al. [3] highlighted that addition of silica fume to cement pastes or concretes leads to lower workability. Such effect can result in higher water demand to maintain a constant slump. The combination of a superplasticiser and a mineral admixture (silica-fume) is desirable, since silica fume in the amount exceeding 5% of cement considerably increases the fine fraction volume and hence the water requirement of the binder.

5. Decreased tensile strengths of concrete

Bhanja and Sengupta [4] studied the isolated contribution of silica fume on the tensile strengths of high-performance concrete. The dosage of silica fumes were 0% (control mix), 5, 10, 15, 20 and 25% of the total cementitious materials. Studies clearly exhibited that very high percentages of silica fume (25%) did not significantly increase the splitting tensile strength and increase was insignificant beyond 15%. Hooton [5] reported the splitting tensile strength of silica fume concretes up to the age of 182 days. It can be seen that except at 28 days, the splitting tensile strength was not improved for silica fume concrete mixes. Also it was observed that with increasing replacement of silica fume split tensile strength decreased.

6. Silica fume is not a cement replacing material

Supplementary materials such as fly ash and slag can be used as cement replacing materials up to 50% and beyond. On the other hand silica fume is basically a performance enhancer and it should be used at low percentage level [6]. In the presence of fly ash and slag, silica fume performs still better. In addition its efficiency also matters in binary or ternary blend mixes [7].

7. Silica fume is costlier compared to fly ash or slag

From the point of economy of the mix, it is advisable to use fly ash and/or slag or any such combinations of materials in SCC. Usually using the combination of three cementitious materials will reduce the cost of concrete significantly. Only if the application demands, silica fume can be used. The added advantages of silica fume is, high early compressive strength, high tensile, flexural strength, and modulus of elasticity, very low permeability to chloride and water intrusion, enhanced durability, increased toughness and increased resistance to abrasion, freezing and thawing, alkali–silica reactivity, and so on [5]

8. Silica fume is very fine and more reactive

It is very fine and much more reactive compared to other supplementary materials. As it is very fine, it is little more dangerous though non-hazardous. Proper care should be exercised while using this material in concrete and many health related aspects are discussed in the manufacturer catalogue. Note also the warning regarding the drying of the skin when in contact with the dry silica fume due to its very large surface area [8].

Most of the above observations are based on the studies using 5 to 25% of silica fume. Use of very high percentage of silica fume is uncommon and for SCC from the point of large fines is unpracticable.

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Dr. M. C. Nataraja,
Professor, Civil Engineering Department,
Sri Jayachamarajendra College of Engineering,
Mysore, Karnataka.

THE AUTHORS REPLY

The authors are thankful to the discusser for the efforts taken in investigating the role of silica fume. The inputs of discusser are highly appreciated and praiseworthy.

The main objective behind the presented work was to check the suitability of recycled coarse aggregate in self compacting concrete which is one of the most advanced concrete developed in the recent decades.

SCC can be produced by three ways

1. Power type SCC
2. VMA type SCC and
3. Combined type SCC (Powder +VMA)

In the presented investigation SCC was produced by first method i.e. powder type. In powder type SCC alongwith cement any filler material (mineral/pozzolanic/inert) can be used to increase the rheological properties of SCC. Therefore considering the performance of silica fume in enhancing durablity and strength in concrete it was chosen as a powder material.

Question 1: According to authors, in the first mix silica fume is 128 kg and cement is 270 kg and with this silica fume is about 47.4% which is very high. Similarly in the second mix, the silica fume used is about 33%. As the percentage of RCA increases, the dosage of SP also increases to maintain constant slump. This is obvious in RAC for the reasons discussed in the paper. The authors should have tested one more trial mix with 100% cement and natural aggregate to know the dosage of SP and the corresponding compressive strength. These values should definitely be less compared to mix A_0. Authors should have employed binary or ternary blend with 10-15% of silica fume as investigated by many authors [1 to 6]. Authors have not mentioned any reference to substantiate the use of such high percentage of silica fume. Authors are requested to discuss and give their opinion in this direction.

Answer: The silica fume used in the investigation was an additional powder material and not as a cement replacement material and the maximum content of silica fume was just 32.16% of the total powder content (128 kg/398 kg). Also the main focus of the investigation was only to study the effect of RCA content on the properties of SCC hence the binary or ternary blends had not been used.

Question 2: The impact strength of aggregate appears to be very high for both NCA and RCA (9.88% and 17.36%). Discusser has tested many samples of NCA and RCA from crushed cubes of medium to high strength. For good aggregates, generally impact value varies from 15 to 25% and for RCA it is still higher and is about 25 to 40% depending on the quality of the aggregates. The discusser is of the opinion that the impact machine may not be mounted firmly on the concrete pedestal and the full impact energy might not have transferred to the specimen while testing. Authors are informed to confirm this point and to give their opinion.

Answer: The impact values of aggregates were the actual values obtained and the impact testing machine is firmly founded on the pedestal.

Question 3 : Keeping in mind the amount of cementitious materials used (silica fume is 128 kg and cement is 270 kg (53 grade), total =398 kg) with w/cm = 0.45 for NCA concrete A_0, the compressive strength of 26 MPa at 28 days appears to be very low. Is it due to very high percentage of silica fume whose ill-effects are discussed below? How to ensure that full silica fume has reacted and contributed? Micro studies might help in this direction. What is the authors' reaction to this?

Answer: There is a possibility that full silica fume had not reacted at 28 days and hence the compressive strength produced was low; however 90 days compressive strength has been increased. The authors agree to discussers opinion that micro studies may help in this direction but it was not in the scope of the study.

Prashant O. Modani
Assistant Professor, Department of Civil Engineering,
Babasaheb Naik College of Engineering,
Pusad, Maharashtra