Discussion Forum

Fly ash as a sand replacement material in concrete – A study

Dear Sir,

This has reference to the paper titled 'Fly ash as a sand replacement material in concrete - A study' by N.P. Rajamane and Ambily P.S., published in The Indian Concrete Journal (July 2013, Vol. 87, No. 7, pp. 11-17). In this paper, the authors have made an attempt to study the performance of fly ash as a sand replacing material (SRM) in concrete. They have discussed the many advantages of such concretes including the durability characteristics. Their data analysis suggests that this concrete has a better strength to weight ratio and strength to energy ratio and hence it is a more eco-friendly and less energy intensive material. The paper is well written and lots of experimental results are presented which according to the discusser will help other researchers working in this area. However, this discusser would like to clarify a few points on the use of fly ash as sand replacing material and seek some clarification about the results.

The authors have discussed the performance of four concrete mixes designed based on sand replacement method. The discusser has a question regarding the maximum cement used. The amount of cement in each of the four mixes is in the range of 455 to 562 kg which is very high for the target strength of 44 to 46 MPa. IS 456:2000 does not permit more than 450 kg cement in standard concrete of strength up to 60 MPa (amendment).[1] The authors have used little superplasticiser and high water content of 196 litres. The target workability though not mentioned should be low to medium. Authors should have reduced both water and cement contents to economise the mix and to get the target workability by modifying the dosage of admixture.[2-4] Such concrete will be more eco-friendly as less cement is used. The eco-friendliness is discussed with regard to fly ash being used as SRM but without considering the high cement content. This needs to be justified when the overall advantages from sustainability and carbon footprint are discussed. Authors can recommend fly ash for both sand and cement replacement keeping in mind the limits of IS 456:2000.

Coming to the durability tests, authors have conducted several tests to substantiate the performance of sand replaced concrete (SRC). Few of the results are quite encouraging. Though the porosity is higher for such concrete, the authors claim the superiority of such concrete as the pores are refined and discontinuous. Pore refinement takes place only if hydration is continuous and its duration is long. The fineness and pozzolonic activity of fly ash play an important role.[5-6] To produce such concrete curing beyond 28 days is needed. Micro studies are recommended to substantiate the durability performance.[7-9]

The w/c ratio increased substantially from 0.35 to 0.49 in concrete as the replacement level increased from 0 to 60%. Though the cement decreases marginally, the amount of cement undergoing hydration has a relatively high water content leading to a 'weak' microstructure. This point needs justification.

Sorptivity of SRC is high. It means the concrete is not as durable as control concrete. If the sorptivity test is conducted at later ages, beyond 28 days, then the early age performance is questionable.[10]

The chloride penetration defined in different ways by the authors is lower for SRC. So, the authors claim that the concrete is better than control concrete. The reduction in Rapid Chloride Permeability Test (RCPT) value may be due to the presence of fly ash (FA) which might have reduced the potential of pore solution. The pore structure and the pore size distribution may or may not be better than that of control concrete as indicated by other results. RCPT alone may not justify the superiority of the SRC. This needs to be discussed for the benefit of readers.[11,12]

Strength to density ratio is a good indicator of the enhanced performance. Density reduction is achieved by increasing the paste content and decreasing the coarse aggregate content. The cementitious content in the four mixes is 562 kg, 634 kg, 709 kg and 776 kg respectively. conventional concrete do not use cement in these large quantities essentially to control shrinkage and creep .[13] The plastic shrinkage is obviously larger and the drying shrinkage is significantly higher than control concrete. In addition, the reduction in coarse aggregate further increases the strain. By 28 days the concrete might have developed shrinkage strains that lead to micro cracks though the concrete appears better from other mechanical characteristics. Such concrete should be used with care especially in large pours and in prestressed concrete applications. These problems can be appreciated from the following discussion from the literature.[13-15]

Shrinkage: Shrinkage of concrete is affected by several factors, the most important being the aggregate, which restrains the shrinkage of the hardened cement paste. The influence is quantified as follows:

$$Sc = Sp[1 - a]n$$

where Sc = shrinkage of concrete, Sp = shrinkage of cement paste, a = aggregate volumetric content (fine + coarse) and n = constant for mixes of constant water/cement ratio which is approximately given by $2Ea \div [Ea + Ec]$. where Ea = elastic modulus of the aggregate and Ec = elastic modulus of the concrete.

This equation indicates that the lesser the volume of aggregate, the higher the shrinkage. In addition, less stiff mortar increases the shrinkage substantially as fine aggregate (high Ea) is decreased in SRC. Thus, SRC has a higher shrinkage than normal weight concrete. As could be anticipated, for a constant volume of aggregate, shrinkage increases as the free water/cement ratio increases. Here in SRC w/c is higher as more sand is replaced which further increases the shrinkage. Shrinkage produces shrinkage cracks and shrinkage strains leading to premature failure.

Creep: It is stated in the literature that cement paste by volume was the main factor in determining the creep of concrete, because it is restrained by the aggregate. However, in practical mixes having the same workability, the cement content variation is small. Consequently, creep is not likely to get affected to a great extent. But this is not the case in SRC since the water/cement ratio influences creep considerably. The effect of water/cement ratio can be perceived in terms of strength, although the fundamental influencing property is porosity. A lower water/cement ratio lowers the porosity, increases the strength and , applying the inverse strength rule, reduces the creep.

In general, the effects of creep are disadvantageous to concrete structures, although there are some benefits. Creep increases the deflection of reinforced concrete beams and causes a loss of prestressing force in prestressed concrete beams. In reinforced concrete columns, creep causes a gradual transfer of load from the concrete to the reinforcement. Once the steel yields, the concrete takes any increase in load, so the full strength of concrete and steel is developed before failure occurs. Creep increases the deflection of eccentrically slender columns and can lead to buckling. In mass concrete, creep may be a cause of cracking when restrained concrete undergoes a cycle of temperature due to heat of hydration and subsequent cooling. Creep may also cause an excessive deflection in tall buildings and long bridges. These factors are very critical in extreme environmental conditions. To an extent the problem of creep and shrinkage can be reduced by incorporating suitable fibers in to concrete. That is why steel fibre reinforced concrete (SFRC) perform better under dynamic conditions.[16]

From the point of utilising fly ash, the work is quite encouraging. The use of FA in concrete should be encouraged.[17] The discusser congratulates the authors for taking up this work at a time when India is facing acute shortage of natural sand.

References

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The authors' response

[1] The authors appreciate the interest shown by the discusser on our paper on 'Fly as a sand replacement material in concrete – A study'.

[2] The discusser states that '*The amount of cement in each of the four mixes is in the range of 455 to 562 kg which is very large compared to the target strength of 44 to 46 MPa*'. But, it is difficult to connect cement content to strength. Among the many parameters, cement strength is an important parameter besides others such as type and dosage of superplasticiser, curing type and duration, etc.

[3] In the present case, w/c ratio of 0.35 has produced a concrete strength of 44 MPa. Let us see whether, this is reasonable. For this, we can use the A to F curves of SP 23(S&T) of BIS which gives the relationship between water-cement ratio, wc, cement strength, f_{cem}, and 28-day concrete strength, f_{c28}. These curves were reduced to the following equation[21]:

$$f_{c28} = 0.39*f_{cem}*\{\ (1/wc) - 0.50\ \}$$

From this, we can get,

$$f_{c28} = 0.39*45*\{\ (1/0.35) - 0.50\ \} = 41.4$$

Thus, the test result of 44 MPa can be considered as reasonable and moreover, the above mentioned equation can be expected to give only a reasonable estimate.

[4] The discusser has rightly pointed out that '.. *IS 456:2000 does not permit more than 450 kg cement in standard concrete having strength up to 60 MPa (amendment)*'.

One may note that the Para 8.2.4.2 of IS 456 states 'Cement content not including fly ash and ground granulated blast furnace slag in excess of 450 kg/m^3 should not be used unless special consideration have been given in design to the increased risk of cracking due to drying shrinkage in thin sections, or to early thermal cracking and to the increased risk of damage due to alkali silica reactions.'

This statement should not be taken to mean that one should **never use** cement content more than 450 kg/m^3. It is only a caution with regards to cracking and drying shrinkage. Actually, Portland cement content of much more than even 600 kg/m^3 is quite commonly used in many new composites such as super strength concrete, reactive powder concrete, ultra high performance concrete, etc.[22 to 26]

Cook had reported from test data on temperature rise studies on RCC columns that the temperature rise at the centre of a 1 x 1 x 2.4 m column was the highest, but, the temperature itself was nearly identical in three such columns, even though the cement content varied in the the mixes from 355 to 540 kg/m^3.[27] Thus, though there could be temperature rise due to cement hydration, the actual value could be very low or even almost zero also when the amount of heat generated within the concrete equals the heat losses through the surface of the concrete and through the forms.[28]

However, it is recognised that high cement content needs special attention when the dimensions of structural components are massive as the temperature gradient, rather the temperature rise itself, often become more relevant. Thus, there could be many situations where cement contents more than that suggested in IS 456:2000 become acceptable and experimental work on such concretes needs to be carried out. However, in general, it is always a good idea to use as little cement as possible from ecology and economical considerations and to check for shrinkage and temperature rise.

[5] In our study, w/c was 0.35 which can be considered to be low and therefore, shrinkage is likely to be low as water content relative to cement was also low, especially because early curing was done or the moisture was not allowed to be lost. Autogenous shrinkage (due to desiccation) occurs in very low w/c ratio matrices (say around w/c 0.25) and drying shrinkage is more common in high w/c ratio matrices. Although, in the present case, shrinkage and temperature rise related defects were not observed in the test specimens, shrinkage and temperature related measurements should be carried out with reference to actual dimensions of the structural member when high cement content matrix is used in actual field.

[6] Regarding the use of little SP and high water content of 196 litres, these were arrived at after trials with the w/c ratio selected and materials on hand. Since a Sulphonated Naphthalene Formaldehyde (SNF) based super plasticiser was used, it was necessary to adopt a dosage as low as possible so that cement hydration rate is not affected severely. The workability of about 100 mm was achieved which is sufficient for compaction by vibration. With the presently available PCE based SPs and high strength cement, mix details would work out to be different.

[7] It is agreed that by saving both water and cement with the use of a suitable SP dosage, concretes become more eco-friendly. In the present case, however, the eco-friendliness is discussed with regard to fly ash as a Sand Replacement Material (SRM) and actual cement content. It may be noted here that the concepts developed in the present work can be applied to any concrete mix; density of concrete mix gets reduced due to the use of fly ash as an SRM, thereby lowering the ingredient contents of concrete.

[8] Any limits prescribed in IS 456:2000 should be considered as general guideline for adoption in usual field conditions. However, as and when actual test data are available, they should get preference over the provisions of IS 456:2000. Experimental investigations can go beyond the limits so that rationality of the limits is confirmed or the need for revising the limits is established.

[9] The discusser thinks that pore refinement takes place only if there is continuous hydration for long period depending on the fineness and pozzolanic activity of fly ash and curing beyond 28 days is needed. But, it can be noted here that rather the continuous presence of water for curing, actual presence of a certain level of humidity within the microstructure is sufficient for pore refinement. After initial curing of say 28 days, further application of water for curing may not be always necessary, since the improved microstructure near the external surface would reduce substantially the loss of moisture from the concrete and thereby ensure the continuity of hydration of cement and pozzolanic activity of fly ash as seen by the widely reported refinement of pores by fly ash in the long run. In this regard, it is also agreed that micro-structure studies would confirm the observed improved durability performance.

[10] Regarding the increase of w/c ratio from 0.35 to 0.49 in concretes containing fly as SRM, when the sand replacement level is increased from 0 to 60%, the discusser feels that here higher water would lead to weak microstructure. However, it may be noted here that though there is an increase in w/c ratio, actual water-binder ratio has decreased from 0.35 to 0.309. Thus, there is indeed a chance for improving the microstructure though time required for this to occur could be more than usual.

[11] Though the water Sorptivity of Sand Replaced Concrete (SRC) seems to be higher numerically, the values themselves are of the same order qualitatively. Thus, the partially Sand Replaced Concrete is almost similar to control concrete from Sorptivity considerations. It may be noted that any deterioration phenomenon in the field is usually slow and its effect is seen after prolonged exposure. Thus, there is a chance for improvement in the microstructure beyond 28 days even if the concrete gets exposed to aggressive environment. Thus, a few weeks are not so relevant for the long term durability evaluation.

[12] The authors agree with the discussers that reduction in RCPT value is due to the presence of FA which reduces the OH^- ion concentration of the pore

solution, thereby increasing the electrical resistivity. The pore structure and the pore size distribution may not be well indicated by lower RCPT values. But, a lower RCPT compared to control concrete is due to the higher electrical resistivity of pore solution and it is also a good comparative indicator of the durability since the electrochemical corrosion current would then face higher resistance and thereby reducing the corrosion rate.

[13] As discussed earlier, SRC's high paste content did not cause observable shrinkage and temperature related defects in the present study, probably due to low w/b ratios adopted.

[14] The coarse aggregate content reduction in our study is only marginal though sand content decreases significant. Hence, the effect of matrix stiffness could be lower. But, very substantial reduction in aggregate content by fly ash is not advisable. Therefore, we have restricted the sand replacement level to 60%.

[15] The discusser's suggestion on creep is interesting and informative. As in the case of other new materials, there is a need for creep studies on the sand replaced concretes also.

[16] The authors are aware that the work carried out is not very exhaustive and the results obtained should be considered as indicative of the potential of fly ash as a partial sand replacement material. There is indeed a need for further systematic investigation considering the test results of this study and the technical points presented by the discussers.

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This has reference to the paper titled 'Fly ash as a sand replacement material in concrete - A study' by N.P. Rajamane and Ambily P.S., published in The Indian Concrete Journal (July 2013, Vol. 87, No. 7, pp. 11-17). On page 14 under compressive strength it has just been casually stated that 7 days strengths are lower but the values have not been tabulated in Table 3, 7-day strength is a very important figure for stripping time of shuttering. Could you kindly seek the figures from the author ?

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The authors' response

The authors agree that age lower than 28 days, say 7 days, is also important sometimes, when stripping time become critical. However, while comparing two mixes at lower ages, instead of considering the concrete strength values, it would be reasonable to examine the actual values of strength values with the desired level of strength at that age. It may be further noted that it is possible to design a concrete mix to achieve a desired strength level at any age. It is not possible to design to design a concrete mix so that it satisfies the strength at all ages. In the present case, the concretes were mixed to get similar strength levels at 28 days which resulted in lower strengths in fly ash containing concretes compared to concrete without fly ash. The actual strengths at 7 days for mixes A, B, C, and D were 35.9, 34.5, 31.7, 28.1 MPa. Thus, when emphasis was on equal 28 day strength, 7 day strength of concrete decreased with fly ash content. This is obviously due to lower pozzolanic rates of reaction compared with cement hydration rates.

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