Are specifications impeding sustainability of concrete?

Discussion by M.C Nataraja

Reply by Chetan Hazaree, Shashank Vaidya, Peter Taylor, Ashok Kr. Tiwari and Rajesh Gupta

Dear Sir,

This has reference to the paper titled 'Are specifications impeding sustainability of concrete?' by Chetan Hazaree, Shashank Vaidya, Peter Taylor, Ashok Kr. Tiwari and Rajesh Gupta ', published in ICJ July 2015 issue (Vol 89, No. 7, pp. 52-63).

In this paper the authors have mainly discussed the sustainability issues related to concrete and the drawback of current specifications of codes of practices. Though the paper is on sustainability of concrete, the authors focus mainly on the utilisation of fly ash and the associated sustainability benefits. The authors have made excellent studies on the effective utilisation of fly ash in concrete and addressed some of the concerns impeding full scale usage of fly ash concretes including high volume fly ash concrete. In addition the authors have discussed in length the provisions in codes, construction specifications, fly ash classification systems, variability in the fly ash, design issues and construction challenges the engineers are facing at present.

The discusser congratulates the authors for their sincere efforts in highlighting the various beneficial effects of fly ash and high volume fly ash concrete. The discusser is suggesting many other ways of achieving the sustainability and satisfying code specifications. The discusser seeks the reaction of the authors in the following points.

1. Use of ground granulated blast furnace slag.

At present in India, many cement companies are producing slag blended cement and the amount of slag is increasing day by day. At present many cement companies are producing blended cement using 50% of clinker and 50% of GBFS. This is one of the best alternative ways of reducing cement clinker and to reduce the associated ill effects. In many of the laboratory studies, high volume slag is used to an extent of 70 to 80%. In slag concrete, most of the strength is gained within 28 days and the strength gain at later ages is not that significant. Slag concrete also has all the beneficial effects similar to fly ash concrete. Keeping this point in mind, use of slag as a supplementary material in concrete should be encouraged similar to fly ash concrete [1]. In addition, authors are requested to provide data on GGBFS sampling similar to fly ash data presented in Table 2 of their paper.

2. Contemporarily unscientific craze for 28-day strength

The discusser fully agrees with this statement and this craze is only to satisfy the code requirements. The acceptance criteria of quality of concrete is laid down in IS 456:2000 [2]. The criteria are mandatory and various provisions of the code have to be complied before the quality of concrete is accepted [3, 4]. In all the cases, the 28-days compressive strength shall alone be the criterion for acceptance or rejection of the concrete. According to the discusser, ensuring the adequate strength at any age should be the criteria rather than achieving the target strength at 28 days. The authors are of the opinion that in case of fly ash concrete, the long term gain in strength is unused, due to this restriction. Knowing that the structural component is subjected to full design load at a later age, say 56 days, it is rather advisable to use 56 days strength from the point of economy and sustainability as well. In the same way, in case of early strength concrete containing combinations of admixtures in the presence of silica fume and chemical admixtures, early age strength say at 7 days should be the criteria and the design load can be allowed at this stage. Keeping this point in mind, the definition of characteristic strength should be modified

for any specific age and not necessary corresponds to 28 days. The Bureau of Indian Standards should re look at these points in the next revision.

3. Another way of exploring the later age strength of fly as concrete.

In any concrete mix with or without mineral admixtures, it is good to know its strength potential. Considering the mix suggested by the authors in Figure 2 developed for 35% FA concrete, the minimum strength is about 20 MPa at w/c=0.6 and about 60 MPa at w/c=0.35. From this it is clear that this concrete develops strength in the range of 20 to 60 MPa depending on the w/c ratio. Thus the strength potential is between 20 and 60. Let us consider the strength at w/c=0.5. It is 33 MPa and 42 MPa at 28 and 56 days respectively. To achieve the additional strength of 9 MPa, one has to cure concrete for another 28 days there by exploring the long term strength of fly ash concrete. Instead of this, if the same concrete is processed from a lower w/c ratio, the same strength of 42 MPa can be achieved in 28 days. For this the equivalent lower w/c is required. From the same Figure 2, this w/c ratio is approximately 0.42 and hence the amount of water for the same cementitious materials can be found. With this new mix, the desired strength of 42 MPa can be achieved. The only issue is to get the required workability which can be achieved by using proper type and dosage of chemical admixture. This type of mix design and concrete analysis has been reported by the discusser by way of generalised Abrams' law [5]. This exercise is designated as 'Re-proportioning Method' [6]. The two equations proposed for the re-proportioning method are as follows.

$$S/S_{0.5} = -0.2 + 0.6\,(c/w) \quad \text{for } S_{0.5} > 30 \text{ MPa} \quad ...(1)$$

$$S/S_{0.5} = -0.73 + 0.865\,(c/w) \quad \text{for } S_{0.5} \leq 30 \text{ MPa} \quad ...(2)$$

where, S = Compressive strength at any water-to-cement ratio; $S_{0.5}$ = Compressive strength at water-to-cement ratio of 0.5; w/c = water-to-cement ratio.

From equation (1), $S_{0.5}$ = 33 MPa, to get 42 MPa, S = 0.41 which is almost equal to 0.42 obtained from Figure 2 of authors.

What is required is to obtain the w/c ratio for any strength knowing the strength of any concrete at w/c = 0.5. Later workability should be adjusted with chemicals. This re-proportioning method using generalised Abrams law is valid for all types and combinations of ingredients [7, 8].

4. Importance of geopolymer concrete

At present lots of research is going on in the area of geoplolymer concrete (GPC) in India and abroad. This concrete is used in many practical applications in Australia and its use has already started in Chennai (SRM university). In case of slag based GPC, its full potential in terms of strength can be achieved in few hours or within one day depending on the molarities of the activators. In fact, GPC is more sustainable as it is produced from slag or fly ash alone without any cement. It is more eco-friendly possessing superior qualities [9]. In case of fly ash GPC, any level of strength can be attained at any age depending on the degree of polymerisation. Here the concept of 28 days strength is really meaningless. How to designate characteristic strength in this case? Authors are discussing about high volume fly ash concrete with certain percentage of cement in Table 1 and 3. But with this technology of GPC, many issues related to the use of fly ash as discussed by the authors in their paper can be taken care off. I sincerely request the opinion of one of the authors of the paper who is a well known researcher at M/s UltraTech Cement Limited about promoting this GPC through their RMC.

5. Quantity of fly ash

The discusser is also of the opinion that the maximum limit of fly ash in IS 456 should be increased suitably. Suggestions of the authors to increase this limit are quite encouraging. Fly ash to an extent of 40 to 50% has been effectively used in many projects. Still a higher percentage is used in many pre cast industries. BIS should view this seriously in the next revision of IS 456. What maximum percentages of fly ash the authors can recommend based on their studies, in context to Indian application?

6. Durability of concrete

Cube testing alone is not the criteria for the durability of concrete structure. A durable concrete is one that perform satisfactorily in the working environment during its anticipated exposure conditions during its entire service life. The materials and mix proportions specified and used should be such as to maintain its integrity and if

applicable, to protect embedded steel from corrosion. It is essential that every concrete structure should continue to perform its intended functions of maintaining its required strength and serviceability, during the specified or traditionally expected service life. It follows that concrete must be able to withstand the processes of deterioration to which it can be expected to be exposed. Such concrete is said to be durable. Both strength and durability have to be considered explicitly at the design stage. The emphasis is on the word 'both' because it would be a mistake to replace overemphasis on strength by overemphasis on durability.

7. It is high time that BIS should come out with better specifications

In Table 3 of paper and also in IS 456, for severe, very sever and extreme exposure, the grade of concrete recommended is M30, M35 and M40 respectively. Further, the w/c is also reduced accordingly. With the availability of good quality materials and by using PC based admixtures, above grades can be designed at any level of w/c ratio. If w/c ratio is higher, the concrete is non durable as it has many capillaries inside. To have an indirect check on this, IS code is restricting on minimum w/c ratio depending on the exposure condition. With w/c of 0.35 for severe exposure, the cement content works out to be higher, even by using 35% of fly ash as suggested by IS 456. The resulting mix is obviously uneconomical. Keeping these things in mind, the durability Table of IS 456 needs to be modified. It is not the prescriptive specifications and should be the performance specifications for acceptance of concrete.

8. Changes to be incorporated to IS 456 and IS 10262

Presently the Indian practice for mix design is based on IS 456 which emphasis only on certain prescriptive specifications namely limits on minimum cement content, maximum water cement ratio and minimum grade of concrete for different exposures. However no performance specifications are imposed for quality checking. Acceptance of concrete based on the specifications of strength, minimum water cement ratio and amount of cementitious content should go out of practice keeping in mind the stringent durability requirements. Also the present exposure classifications of IS 456 do not correctly address many of the durability issues especially for severe exposure. What is important in future concrete mix design is to ensure certain minimum performance requirements to be satisfied with regard to durability (performance approach). One such simple durability test that can be conducted on concrete in any site or laboratory is the rapid chloride permeability test (RCPT). Certain minimum permeability of concrete should be recommended along with concrete grades irrespective of prescriptive specifications. This serves as a tool for selecting suitable combinations of SCMs depending on what type of cementing materials are available in the site to achieve certain range of chloride permeability and the target strength. In addition, use of unconventional aggregates is also becoming common as natural aggregates are depleting [10]. With this economical concrete can be designed which is not only eco-friendly and sustainable as well.

Remarks: The discusser sincerely thank the authors for their efforts in addressing some of the concerns impeding full scale usage of fly ash concretes and also to highlight on many issues related to sustainable concrete design. The discusser fully agree with the statement made by the authors - 'The biggest challenge in bringing sustainability into practice and not retain it as another engineering jargon is willingness to change and accept change. An appreciation of what is really required is essential'. Let us hope that our future concrete will be designed based on performance specifications leading to sustainable and eco-friendly concrete.

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THE AUTHORS REPLY

The authors appreciate the interest and discussion on their paper. This paper was written from practice point of view and taking fly ash as an example. The points discussed in the paper can very well be applied to similar materials needing changes in the existing codes of practice and/ or specifications. The point-wise reply to the discussion is as follows:

Reply to comment No. 1
Use of slag in India is restricted by geo-commercial reasons, while fly ash sources are accessible in almost all the parts of India. Albeit slag is an effective self-cementing material, its generalised use similar to fly ash may not be possible. Authors have not conducted similar studies on slag.

Reply to comment No. 2
This is already discussed in the paper.

Reply to comment No. 3
This could offer a solution, but cannot be generalised based on limited data.

Reply to comment No. 4
Geopolymer concrete is not in "as much practice" as is fly ash in India or for that matter anywhere in the world. GPC technology is yet to mature for practice in India. Although to maintain uniformity, 28-day strength could be checked, the definition of characteristic strength and the age at which it should be achieved in increasingly a matter of discussion between the owner and contractor.

Reply to comment No. 5
The quantity of fly ash to be used will be application specific. If there is implementation of a good quality assurance regime, the quantity of fly ash could be discretionarily used upto 50%.

Reply to comment No. 6
This is already built-in the code of practice in terms of strength and serviceability. The main thing is to apply the concepts properly with "relevant to structure" specifications rather than using generalised specifications.

Reply to comment No. 7
This is a point to be discussed with the BIS. Specifications are mostly a part of contract document, while the BIS could offer guidance documents and/ or code of practice.

Reply to comment No. 8
This is a point to be discussed with the BIS.

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Prof. Ashok Kr. Tiwari, UltraTech Cement Ltd., Mumbai
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