HSC Mix Design by IS, ACI and DOE Methods: A Comparative Experimental Study

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ABSTRACT
One of the things that made High strength Concrete (HSC) an invaluable material in the modern civil engineering is its better mechanical performance, increased durability and capability in streamlining structural design. Good performance however, of HSC is said to heavily rely on precise ratio of mix proportioning because slight change of water-cement proportions, gradation of their aggregates, or dosage of admixtures can cause slight variations in fresh and hardened properties. Within the framework of a systematic experimental program, the present study examines 3 common and popular methods of mix proportioning, namely, IS 10262:2019, ACI 211.4R-08, DOE Method. Each method was then made into trial mixes and tested in terms of workability, compressive strength at seven, 28 and 56 days, tensile strength and flexural strength. IS and ACI methods showed acceptable strength, used additional cement. DOE failed in terms of workability which restricted the usability in terms of applications in the HSC. The ACI 211.4R-08 gave highly competitive values of strength. The ACI 211.4R-08 method was always the best in terms of comparison and higher workability The results indicate that of ACI 211.4R-08 mixes is the best strategy to use in the designing of HSCs in harsh and high stress settings, whereas the weight stuffing is a viable solution to being sustainable. The findings have generated valuable information on the issue of proportioning techniques that engineers should take to ensure that the features of strength, durability, and sustainability are balanced.

Keywords: High Strength Concrete; Mix Proportioning; ACI 211.4R, IS 10262; IS 10262:2019; DOE Method (UK)

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INTRODUCTION

High Strength Concrete (HSC) is one of the highest industry innovations of construction material discovered in recent decades. Contrary to usual concrete, the compressive strengths of HSC concrete are usually tensile and reach above 50 Mpa and most of the time in the range of 70 and above. These high qualities make it very applicable in very important infrastructure like high rises, bridges that cover longer distances, offshore platforms, and precast structures to name but a few. Sustainable and resilient infrastructure as a demand has also raised the interest on HSC as it can be used to have smaller cross-sections, less self-weight, and definite enhancement in service to the latter of the buildings.

The good performance of HSC greatly relies on the mix proportioning method used. Mix proportioning is a process of identifying the proportional amounts of cement, fine aggregates, coarse aggregates, water and admixtures that would give the desired performance parameters. The most common method would be the empirical method which includes the Indian Standard IS 10262 or the American Concrete Institute (ACI) method in conventional concrete. Nevertheless, HSC design must be designed more verbally and scientifically, since slight changes in the water-cement ratio, or the combined gradation with the admixtures or dosage may have significant effect on the strength, workability and durability. Addition of some supplement cementitious materials (SCMs) such as silica fume, fly ash, and ground granulated blast furnace slag (GGBS) makes the mixing design even more difficult and provides enhanced power and stability.

The various approaches towards mix proportioning have been put forward and practiced globally with their respective merits and shortcomings. The IS 10262 method is common and used to apply in India due to its simplicity and flexibility in using the local material whereas ACI 211.4R offers specific guidelines used in designing HSC mixes depending on the ratio of water-cement mixture, and the required strength. The British Department of Environment (DOE) approach emphasizes pro rata the strengths and workability's but frequent modulations on the high-strength implementations are needed.

In spite of these methodologies that are available, no common agreement has been reached on the mix proportioning method to use at all times that will give the best performance to HSC. The reason is that its result would be determined not only by the method itself but also by local materials, the effects of curing and the circumstances of a project. Accordingly, an experimental study comparative to assess varying mix proportioning methods under identical circumstances is crucial in terms of offering some insight to engineers and practitioners.

The current study entails systematic comparison of three mix proportioning approaches, i.e., IS10262:2019, ACI211.4R-08, DOE Method (UK). Trial mixes are prepared and tested by experiments in the lab in regard to every method. The crucial parameters including workability (slump test), compressive strength (7, 28, and 56 days), tensile and flexural strength have been quantified. The results comparison would reveal the strengths and weaknesses of both approaches and what can be named as the most appropriate procedure in attaining a high level of performance in HSC.

The presented study, aside from helping to close the gap between the theoretical guidelines of proportions and experimental results, also contains the scope of practical information regarding the selection of a mix design technique applicable in the realm of high-strength projects. The results of this study are likely to inform fellow civil engineers, contractors, and political authorities to use optimized concrete mix design on future infrastructure projects, where the sustainability, material efficiency, and long-term durability are considered equally high as the structure strength.

2. Materials and Methods

The implementation of high strength concrete (HSC) is a matter which has considered the quality of materials adopted as well as the precision of the mix proportion method employed. This section will provide the information about the chosen materials, mix proportions, which are to be compared, and experimental program, which is intended to help assess the functioning of various trial mixes.

2.1 Materials

i. Cement: Cement was 53 grade Ordinary Portland Cement (OPC) that complies with the requirements of IS:12269-2013. Cement showed a specific gravity of 3.154 and underwent further tests on consistency, initial and blast time and compressive strength and strength.

ii. Supplementary Cementitious Materials (SCM): Two SCMs were used namely; Class F fly ash and silica fume. Workability was increased with fly ash and heat of hydration suppressed and silica fume was added to increase matrix densification and long-term durability.

iii. Fine Aggregate: fine sand which came through a 4.75 mm sieve, was taken as an aggregate of the natural river sand. It conformed partly to IS: 383-2016, Zone II and had a fineness modulus of 2.8.

iv. Coarse Aggregate: 20 mm and 10 mm crushed granite Aggregates were taken in a 60:40 ratio. Their specific gravity and water absorption were 2.7 and 0.5 respectively.

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vi. Water: It was mixed and cured with clean potable water.

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viii. Admixture: Admixtures of the type of polycarboxylate ether based were used to attain high workability with low water-cement ratios

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2.2 Mix Proportioning Strategies Under Consideration

A differentiation of three techniques of mix proportioning were chosen:

1. IS 10262:2019 Method

Indian Standard approach, which is widely employed in India, is based on the empirical relationship between water- cement ratio, desired strength and ratio between the aggregates. Adjustments were also made to take into consideration SCMs.

2. ACI 211.4R-08 Method

High-strength concrete in the world is commonly embraced by the use of the American Concrete Institute approach. It involves statistical modification of the water content to cement ratio and the cement content depending on the compressive strength required.

3. DOE Method (UK)

The British Department of Environment approach is more oriented to balancing the strength and workability. This has been developed in high strength requirements though in the case of normal concrete.

2.3 Trial Mix Designs

To adjust the proportions, three trial mixes were made in relation to each method. A mix of cement, fly ash, silica fume, fine and coarse aggregates, water and admixtures was done in equal weights. Water to cement was maintained at values of 0.31-0.35 based on the procedure. The proportions of an optimized mix when using each of the methods are shown in detail in Table 1.

Table 1: *Mix Proportions by Different Methods (kg/m³)*

Method	Cement	Fly Ash	Silica Fume	Fine Agg.	Coarse Agg.	Water	SP (%)	w/c Ratio	Target Strength (MPa)
IS 10262:2019	450	50	–	650	1200	160	1.2	0.34	60
ACI 211.4R-08	420	80	–	700	1180	150	1.0	0.32	62
DOE Method (UK)	470	30	–	680	1190	155	1.3	0.33	58

i. IS Method: demanded a comparatively more cement to achieve strength.
ii. ACI Technique: Good cement SCM mixture, good strength attained.
iii. DOE Method: These were required or demanded adjustments because it was prone to excessively estimating water preference.

This experimental program contained tests as follows:

i. Workability: Slump test and V- funnel flow test was completed to test the fresh concrete behavior.
ii. Compressive Strength: 150 mm x150 mm x150 mm cubes were casted and tested at 7, 28 and 56 days.
iii. Split Tensile Strength: Testing Cylinders (150 mm x 300 mm) at 28 days.
iv. Flexural Strength: The Beams (100 mm x 100 mm x 500 mm) were tested under one-point load at 28 days.

After 24 hours, all the specimens were demolded and left to cure in water tanks held at 27±2 °C, up to the age of testing. The total number of specimens prepared (originating to exist) was 75 cube specimens, 25-cylinder specimens and 25 beam specimens, it being necessary to do this so that all methods and all test ages might be covered.

3. Results

This part gives out and discusses the experimental findings of the three mix proportioning methods of High Strength Concrete (HSC). The discussion is categorized in terms of workability, strength and on comparison evaluation.

3.1 Workability Results

The workability is very essential in fresh concrete especially in high strength mixes with low ratio of water to cement. Each trial mix was assessed on slump as it is one of the tests of workability.

The average slump value obtained using the IS 10262 method was 88mm showing a moderate level of workability. Workability margins of the ACI technique were higher at an average of 96 mm such that the SCM and superplasticizers were used in a balanced manner. The poorest displayed workability was the DOE method of 80 mm in its average's percentage, as explained by the fact that the content of cement was high and that chemical admixtures were not used enough. The best workability was attained with 96 mm through the performance-based approach, which was because the admixtures dosage had been optimized and water content was controlled.

On the whole ACI approaches offered the most viable combinations without failing to realize the potential of strength, and the DOE one had to make more modifications that enhanced being able to place and compact.

Table 2: *Workability Test Results (Slump Values)*

Method	Trial 1 (mm)	Trial 2 (mm)	Trial 3 (mm)	Average (mm)
IS 10262:2019	85	90	88	88
ACI 211.4R-08	95	100	92	96
DOE Method (UK)	80	82	78	80

3.2 Compressive Strength Results

Composite strength is the first to determine the quality of concrete and this was done at 7, 28 and 56 days. The IS method delivered 42 Mpa in 7 days and 61 Mpa in 28 days responding to the requirements of the strength however at a relatively increased consumption of cement. The ACI method was somewhat superior bringing 44 MPa after 7 days, and 63 after 28 days, and gaining more strength as it progressed to 67 Mpa after 56 days. The DOE method was also standing behind with 40 MPa at 7 days and 59 MPa at 28 days, with the suggestion that it is unlikely to be highly-stressed without adjustment.

Table 3: *Compressive Strength Results (MPa)*

Method	7 Days	28 Days	56 Days
IS 10262:2019	42	61	64
ACI 211.4R-08	44	63	67
DOE Method (UK)	40	59	62

3.3 Tensile and Flexural Strength Findings

Even though compressive strength is the most predominant parameter, tensile and flexural strength play a major role in determining cracking resistance and structural behavior under service loads. The tensile and flexural strength was relatively low with the IS and the DOE methods, as the compressive performance of the methods was low. The value of the ACI method was found to be moderate and this tendency can be explained by the fact that it offers better bond strength and dense microstructure. These results demonstrate that approaches that focus on material optimization and performance indicators provide significant improvements on mechanical performance at improvement over compressive strength.

4. Discussion

Comparative analysis of all three approaches reveals the level of important performance dissimilarity:

IS Method: attained target strength though needed more cement and was only moderate in workability and durability.

ACI Method: Even strength and workability were significantly better, however, durability was not much higher than with IS.

DOE Method: This has repeatedly been weak, unworkable, and less durable than desired which indicates it would not be used in high-rate strength applications without drastic changes.

The discussion highlights that the traditional approaches such as IS method is feasible and used but more efficient methods such as ACI design are the best with the contemporary demands wherein strength and sustainability are as well valuable.

5. Conclusions

The current research evaluated and compared 3 techniques of High Strength Concrete (HSC) mix proportioning: IS 10262:2019, ACI 211.4R-08, DOE Method. The fresh and hard concrete trial mixes were prepared and tested in terms of workability, compressive strength, tensile and flexural strength. The findings demonstrate the strengths and weaknesses of all approaches, which are highly informative to the concerned practitioners and researchers in concrete technology.

6.1 Key Conclusions

Workability:

The ACI approach gave out the highest workability at 96 mm. Workability of the DOE mixes was poor and, the IS and particle packing techniques only gave moderate performances.

Strength Development:

ACI techniques had given a satisfactory level of strength whereas IS and DOE techniques, though satisfying minimum requirements demonstrated need of more cement or further modifications.

Comparative Suitability:

ACI Method: Useful and trusted when there is need of a balance of strength and workability in projects.

IS Method: Sufficient in the field practicability of India but optimality towards sustainability.

DOE Method: This was the least appropriate to work with HSC, unless so altered, because it performed poorly in both workability and tenacity.

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