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VALIDATION OF NON-DIMENSIONAL STRENGTH-CEMENTITIOUS MATERIAL-WATER RELATIONSHIP WITH FLY ASH CEMENT CONCRETE

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ABSTRACT

Admixture modified concrete shows deviation both in physical and chemical properties, compared to that of an ordinary cement concrete. The properties of these supplementary additives influence the characteristics of concrete to a great extent. Many researchers have proposed strength relationships incorporating the properties of the mineral admixtures and their influence on hydration mechanism for effective proportioning of such mixes. The present study aims to exhibit the suitability of a non-dimensional strength-cementitious material-water relationship as proposed by Chowdhury and Basu for fly ash based concrete, on commercially available PPC. Results obtained in case of commercial PPC are found to be within tolerance limits of ±4 % and ±1% of that derived using the lower bound relations of fly ash concrete for 28 and 56 days respectively. Test results also indicate that better utilization of material strength is possible if 56 days strength is considered while proportioning concrete mixture with PPC.

KEYWORDS: Fly ash, Pozzolana cement, Strength ratio, water-cementitious material ratio.

I. INTRODUCTION

Modifications in the strength-durability characteristics of concrete can be brought by suitable choice of admixtures. For a binder material consisting of cement and mineral admixture, hydration process depends on the characteristics of the cementitious material, water to cementitious material ratio, ambient temperature and addition of admixtures which bring changes in concrete enthalpy, microstructure, rheology and mechanical characteristics [1, 2]. However, the water to cementitious material ratio is the most fundamental guiding factor affecting the strength of a fully compacted concrete. Attempts to incorporate hydration characteristics increase the number of variables for concrete proportioning.

II. LITERATURE REVIEW

The absence of proper guidelines in this regard has prompted researchers to attempt analysis of mineral admixture based concrete. Two efficiency factors have been suggested by Babu and Rao [3], by virtue of which a given strength-water-cementitious material relation could be used to proportion a fly ash based concrete mixture. The first one is the general efficiency factor to incorporate the difference in hydration characteristics between cement and fly ash, the value of which was estimated to be 0.5 for all percentage replacements of fly ash in concrete. The second factor is the percentage replacement parameter to take into account the effect of the quantity of fly ash in the cementitious material. The authors suggested its value as 0.75 to -0.15 for cement replacement level varying from 10 to 75 percent. However, one of the major shortcomings is that this approach does not consider the influence of the different characteristics of cement and fly ash.

Larrad [4] developed a model for 28 days compressive strength of concrete taking into consideration the strength of the cement, cement concentration, and maximum paste thickness with OPC. The water- cementitious material ratio has been replaced by a ratio of the volume of cement to the total volume of cement, water and air which is termed as ‘cement concentration’. In the case of pozzolana based concrete, the volumetric ratio is converted to a mass ratio and mass of cement being replaced by the equivalent cement mass accounting for the contribution of mineral admixture. The empirical ‘activity coefficient’ suggested by the author is independent of the interaction of fly ash with cement.

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III. MODIFIED STRENGTH - CEMENTITIOUS MATERIAL - WATER RELATION

Chowdhury and Basu [5] have suggested a strength-cementitious material-water relation in a generic format incorporating the non-dimensional parameters, the strength ratio $\left(\frac{f_c}{f_m}\right)$ and water-binder ratio $\left(\frac{w}{c_m}\right)$ for fly ash based concrete. The strength ratio represents the ratio of the target compressive strength of the concrete mix (f_c) and that of the standard mortar(f_m), the mortar being a mixture of the identical cement, fly ash and fine aggregates that would be used in the concrete with water-binder ratio of 0.4. Again, the proportion of cement and fly ash is similar to that in the concrete. Cementitious material to fine aggregate in a standard mortar bears a ratio of 1:3.

The relationships based on test results of 138 concrete mixes are as follows,

For 28 days,

Upper-bound: $$\left(\frac{f_c}{f_m}\right) = 5.9659e^{-3.8055\left(\frac{w}{c_m}\right)} \quad (1)$$

Average: $$\left(\frac{f_c}{f_m}\right) = 5.3315e^{-3.8607\left(\frac{w}{c_m}\right)} \quad (2)$$

Lower-bound: $$\left(\frac{f_c}{f_m}\right) = 4.7322e^{-3.9598\left(\frac{w}{c_m}\right)} \quad (3)$$

For 56 days,

Upper-bound: $$\left(\frac{f_c}{f_m}\right) = 5.4717e^{-3.6163\left(\frac{w}{c_m}\right)} \quad (4)$$

Average: $$\left(\frac{f_c}{f_m}\right) = 4.9741e^{-3.6623\left(\frac{w}{c_m}\right)} \quad (5)$$

Lower-bound: $$\left(\frac{f_c}{f_m}\right) = 4.4652e^{-3.7165\left(\frac{w}{c_m}\right)} \quad (6)$$

The above relations are developed with an attempt to incorporate the impact of individual characteristics of different fly ash, their interaction with given cement and hydration characteristics of cementitious materials in mix proportioning. Fig 1 depicts the graphical representation of the one of the above set of strength relations for 28 days.

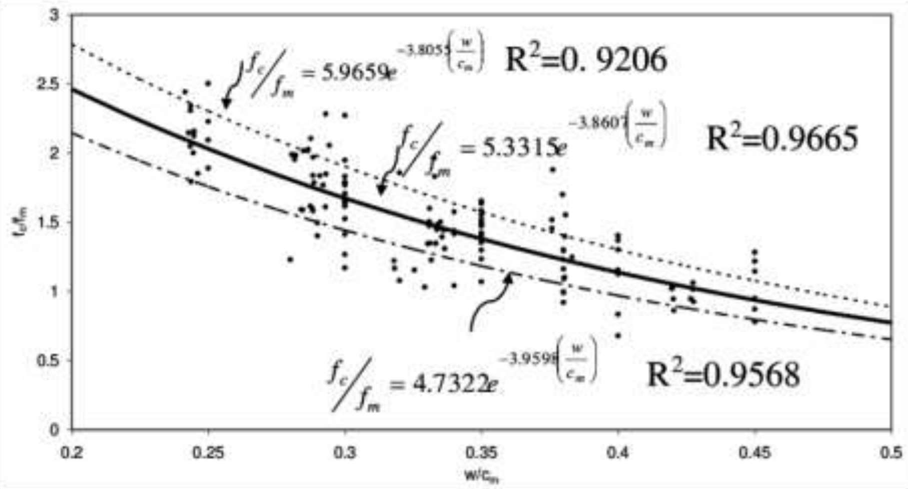

Fig 1: Strength ratio vs water-cementitious material ratio for 28 days (Chowdhury and Basu,2010)

IV. MATERIAL CHARACTERISATION

Material characteristics of each and every component have its influence on the properties of concrete, both in fresh and hardened state. Due to this reason, all the materials used in the present study have been characterized using Indian Standard Specifications as far as possible.

Cement **:** Commercially available Portland Pozzolana Cement (PPC) conforming to IS 1489 (Part-I): 1991[6] from single source is used in the present work. Physical properties of the cement have been tested in accordance to IS 4031:1988 [7]. The fly ash content in the cement is equal to 26 percent, which implies OPC and gypsum content of this cement is about 74%.

Aggregates: Locally available crushed coarse aggregate of nominal size 20mm and river sand as fine aggregate having a fineness modulus of 2.9, conforming to IS 383:1970 [8] have been chosen for experimentation. Grain

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size distributions of coarse and fine aggregates are shown in Fig 2. The physical properties of the aggregates are presented in Table 1.

Water: Deleterious material in water has detrimental effects on concrete. Hence, portable water satisfying the requirements of IS 456:2000 [9] has been used for mix design.

Admixture: Polycarboxylate based superplasticizer conforming to IS 9103:1999 has been used in the laboratory [10].

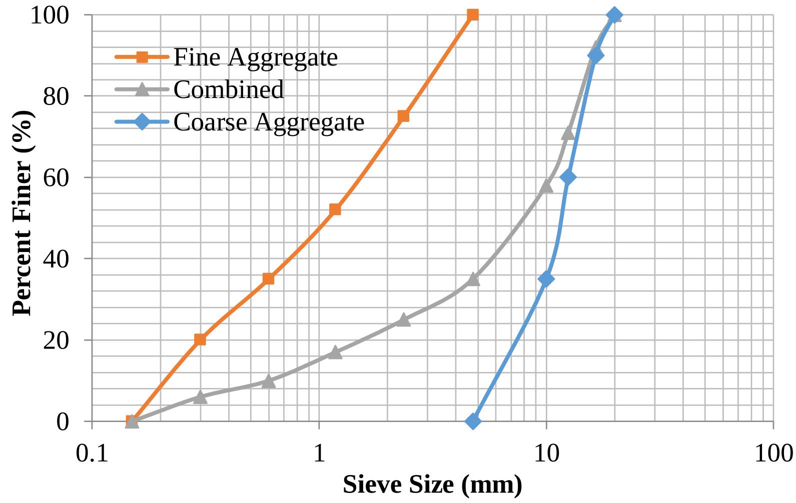

Fig 2: Particle Size Distribution of Coarse and Fine Aggregates

Table 1. Physical Properties of Coarse and Fine Aggregates

Sl. No	Properties	Test Results		Acceptance Criteria
		Coarse Aggregate	Fine Aggregate	
1	Fineness modulus	7.2	2.9	-
2	Elongation index (%)	7.0	-	20% Max
	Flakiness Index (%)	10.0	-	
3	Specific gravity	2.89	2.66	-
4	Water absorption (%)	1.0	1.2	-
5	Crushing value	14.4	-	30.0
6	Impact value	11.2	-	30.0

V. EXPERIMENTAL PROGRAM

Based on the target strength of the mixes, strength ratio is determined utilizing the compressive strength data of standard mortar f_m. From the $\left(\frac{f_c}{f_m}\right) - \frac{w}{C_m}$ relation as proposed, water-binder ratios for all mixes are determined. In each of the cases, unit water content has been considered. Quantities for different ingredients are finalized following absolute volume method. Coarse to total aggregate ratio is taken as 63%. Similar procedures have been followed for preparation of the standard mortar mixture. The compressive strength of the standard mortar f_m and that of the concrete mixture f_c are tested in accordance with IS 516:1959 [11].

VI. RESULTS & DISCUSSION

Three sets of concrete mix proportions, corresponding to target strengths of 45, 55 and 60 MPa are finalized utilizing the proposed $\left(\frac{f_c}{f_m}\right) - \frac{w}{C_m}$ lower bound relation (Equation 3) corresponding to 28 days and similar sets corresponding to target strengths of 50, 60 and 70 MPa are finalized utilizing the lower bound relation (Equation 6) corresponding to 56 days. The above six set of mixes have been denoted as Mix 1,2,3,4,5 and 6 respectively.
The mix proportions are presented in Fig 3. The mortar strength has been found out to be equal to 57.0 MPa and 60.9 MPa at the curing age of 28 days and 56 days respectively. The compressive strength ratios achieved at

laboratory (denoted by 28 and 56 days PPC) have been plotted in Fig 4 and compared to that derived from the relation as proposed by the authors (denoted by 28 and 56 days FA).

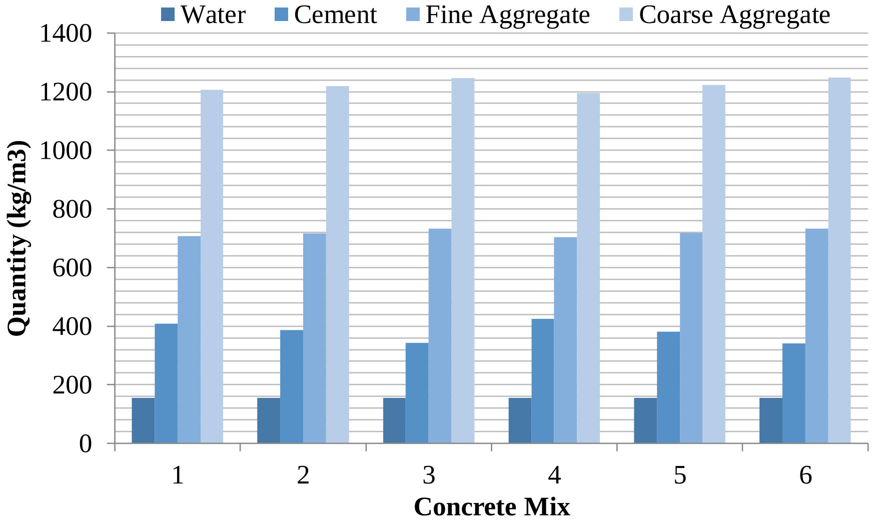

Fig 3: Quantity of water, cement and aggregates in different mixes

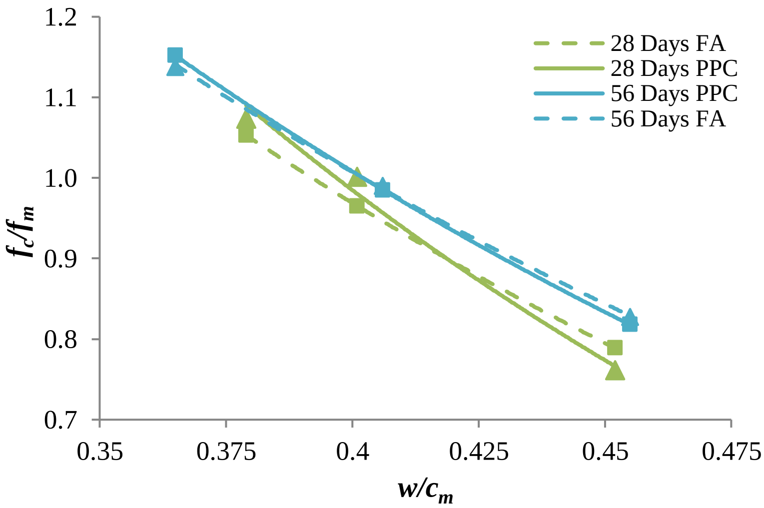

Fig 4: Strength ratio vs water-cementitious material ratio

As it is evident from the error plot in Fig 5, the 28 day cube compressive strength is found to be within ± 4% of the target strength while in case of 56 days the strength lies within ±1% of the target strength. The results obtained during the present study with PPC falls within the range of target compressive strength reported by the authors for 30% concrete replacement level with fly ash. The results indicate satisfactory effectiveness of the proposed $\left(\frac{f_c}{f_m}\right) - \frac{w}{C_m}$ relation in proportioning PPC based concrete with materials from different sources also.

For target strength of 60 MPa at the age of 28 days, $\frac{w}{C_m}$ and cement content are found to be 0.379 and 409 kg/m3 respectively. In comparison, for target strength of 60 MPa at the age of 56 days, $\frac{w}{C_m}$ and cement content are found to be 0.406 and 382 kg/m3 respectively. Hence PPC based concrete mix can be proportioned with lesser cementitious material content and relatively higher water cementitious material ratio considering 56 day strength.

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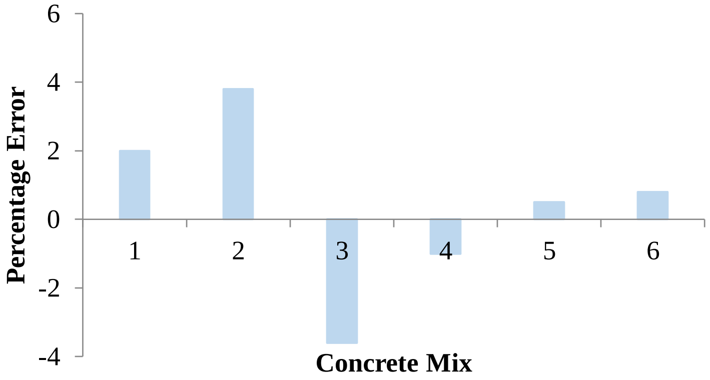

Fig 5: Error plot of compressive strengths for different concrete mixes

VII. CONCLUSIONS

The $\left(\frac{f_c}{f_m}\right) - \frac{w}{C_m}$ relationship proposed by Chowdhury and Basu for fly ash based concrete is validated with commercially available PPC. Both 28 and 56 days cube compressive strength of PPC based concrete is found to be within tolerable limits of the target strength. Hence, test results indicate commercially available PPC based concrete mixtures can be proportioned using the proposed relation. Test results also indicate that better utilization of material strength is possible if 56 days strength is considered while proportioning concrete mixture with PPC.

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