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DETERMINATION OF A NON-DIMENSIONAL STRENGTH-BINDER RELATIONSHIP FOR PORTLAND SLAG CEMENT CONCRETE

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ABSTRACT

Hydration characteristics as well as the associated strength-durability properties of a slag modified concrete differ largely with that of an ordinary cement concrete. The properties of the supplementary additives have their influences on the behaviour of the concrete, both in fresh and hardened state. Strength-cementitious material-water relationship for Portland Slag Cement (PSC) concrete incorporating the characteristics of slag and their effects on hydration mechanism is expected to be a convenient tool for proportioning such blended concrete. This paper deals with the development and suitability study of such relationship on the basis of experimental findings for proportioning slag based concrete involving strength ratio or the ratio of compressive strength of concrete mix (f_c) to that of the standard mortar mixture (f_m) and water-cementitious material ratio (w/f_c).

KEYWORDS: Slag cement, Strength ratio, Water-cementitious material ratio.

I. INTRODUCTION

Hydration of glass granulated blast furnace slag (GGBS) in the presence of Portland cement depends largely upon the breakdown and dissolution of the glassy slag structure by hydroxyl ions released during the hydration of the Portland cement. At normal temperatures, it shows a two-stage reaction. In the first stage, the predominant reaction is with alkali hydroxide, while in the second stage, it is with calcium hydroxide [1]. Generally, the strength development in PSC improves with high fineness, alkali content and Tri-Calcium Aluminate (C_3A) content [2].

The primary factors that influence the effectiveness of GGBS in concrete and mortar are:

(1) Chemical composition of both GGBS and Portland cement; (2) Alkali-ion concentration in the reacting system; (3) Glass content of the GGBS; (4) Fineness of both GGBS and Portland cement; (5) Temperature during the early phases of the hydration process.

The progressive release of alkali by the granulated slag, together with the formation of calcium hydroxide by Portland cement, results in a continuous reaction and a long-term gain in strength [3]. Hence slag modified concrete mixes gain considerable strength even after 28 days. In practical cases, the structure is not subjected to the design load in early stages; hence to take advantage of the strength characteristics of such blended concrete, some specifications have revised the design-purpose strength criteria from 28 days to later ages.

II. LITERATURE REVIEW

ACI 211.4R [4] provides an insight to the relation between strength at 28 and 56 days and water-cementitious material ratio for proportioning high strength concrete using slag cement. However, any $\left(\frac{f_c}{f_m}\right) - \frac{w}{C_m}$ relationship, specific to slag cement, is not mentioned in this guideline. Similarly, IS 10262:2009 [5] does not provide such provisions for slag cement based concrete, one of the probable reasons for such absence may be the difficulty to incorporate the effects of variation in the characteristics and quantities of cement, mineral admixture and water.

Aitcin (1998) [6] developed a $f_c - \frac{w}{C_m}$ relation for mixture proportion methodology for high performance concrete with mineral admixtures.

Babu and Rao [7] proposed two efficiency factors, one being 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, while second factor is a percentage replacement parameter to take into account the effect of the quantity of fly ash in the binder, the value ranging between 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.

Chowdhury and Basu [8] developed a relationship for fly ash based concrete with non dimensional parameters $\left(\frac{f_c}{f_m}\right)$ and $\left(\frac{w}{C_m}\right)$, taking into account the influence of qualities and the relative quantities of fly ash and cement. Similar method can be applied to any group of mineral admixtures. This logic leads to the development of such relation for slag modified cement.

III. STRENGTH RELATIONS

Duff Abrams suggested his famous water-cement rule that could be applicable for proportioning Ordinary Portland Cement concrete [9], which can be mathematically expressed as in Equation (1) but such relation is not suitable for mixes with other supplementary cementitious materials.

$$f_c = K_1/K_2^{w/c} \quad (1)$$

where K_1 and K_2 are empirical constants.

In Equation (1), the relationship between f_c and w/c is exponential in nature. When supplementary additives are introduced into the concrete, the relationship can be written as in Equation (2), which could be further modified in Equation (3) following the approaches of Chowdhury and Basu, considering that $\left(\frac{f_c}{f_m}\right)$ is inverse-exponentially related to $\left(\frac{w}{C_m}\right)$.

$$f_c = ae^{-b\left(\frac{w}{c_m}\right)} \quad (2)$$

$$\frac{f_c}{f_m} = \alpha e^{-\beta\left(\frac{w}{c_m}\right)} \quad (3)$$

where (a, b) and (α, β) in Equations (2) and (3) respectively, are empirical constants. These constants are evaluated using the data generated from PSC based concrete mixes.

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 Slag Cement (PSC) conforming to IS 455:1989 [10] from single source is used in the present work. Physical properties of the cement have been tested in accordance to IS 4031:1988 [11].

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 [12] have been chosen for experimentation. Grain size distributions of coarse and fine aggregates are shown in Fig 1. 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 [13] has been used for mix design.

Admixture: Polycarboxylic ether based high range water reducing admixture conforming to IS 9103:1999 [14] has been used in the laboratory.

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

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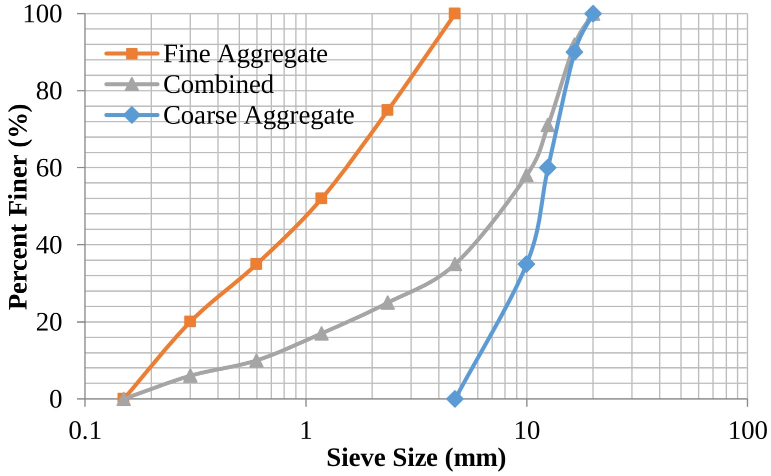

Fig 1: Particle Size Distribution of Coarse and Fine Aggregates

V. EXPERIMENTAL PROGRAM

A total of 35 mix designs have been considered for our study in which PSC content varied from 350 kg/m^3 to 550 kg/m^3 and water-cementitious material ratio ranged from 0.3 to 0.45. Compressive strength ratios are computed from the strength data for concrete (f_c) and a similar standard mortar (f_m) that have been tested in accordance with IS 516:1959 [15]. 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.

VI. RESULTS & DISCUSSIONS

Trend curves developed from 35 strength data $\left(\frac{fc}{fm}\right)$ and corresponding $\left(\frac{w}{Cm}\right)$ are presented in Fig. 2 to Fig. 4.

The upper and lower bound curves are one standard deviation shift on either sides of the mean. Empirical constants α and β for the three curves, average and the two boundary curves are given in Equations (4) to (9).

For 28 days,

Upper-bound: $$\left(\frac{fc}{fm}\right) = 2.7659e^{-2.8353\left(\frac{w}{cm}\right)} \quad (4)$$

Average: $$\left(\frac{fc}{fm}\right) = 2.7082e^{-3.8656\left(\frac{w}{cm}\right)} \quad (5)$$

Lower-bound: $$\left(\frac{fc}{fm}\right) = 2.6506e^{-3.8799\left(\frac{w}{cm}\right)} \quad (6)$$

For 56 days,

Upper-bound: $$\left(\frac{fc}{fm}\right) = 2.1504e^{-2.1797\left(\frac{w}{cm}\right)} \quad (7)$$

Average: $$\left(\frac{fc}{fm}\right) = 2.1877e^{-2.2947\left(\frac{w}{cm}\right)} \quad (8)$$

Lower-bound: $$\left(\frac{fc}{fm}\right) = 2.2290e^{-2.4156\left(\frac{w}{cm}\right)} \quad (9)$$

The R^2 values varied around 0.95 and 0.98 for 28 and 56 days strength relationships respectively, indicating the curve fitting is good.

The compressive strength of PSC based concrete increases considerably beyond 28 days. For optimal use of such concrete mixes, target strength at 56 days may be considered for mixture proportioning.

In view of the above, relation between $\left(\frac{fc}{fm}\right)_{28}$ and $\left(\frac{fc}{fm}\right)_{56}$ for slag modified concrete is developed. The data fits into a linear model as shown in Equation (10),

$$\left(\frac{fc}{fm}\right)_{56} = 0.7846\left(\frac{fc}{fm}\right)_{28} + 0.1983 \quad (10)$$

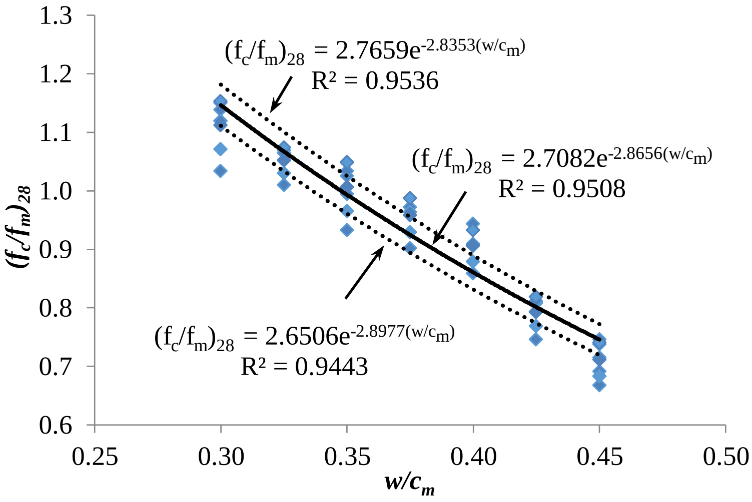

Fig 2: Relation between $\left(\frac{f_c}{f_m}\right)$ ***and*** $\left(\frac{w}{c_m}\right)$ ***at 28 days***

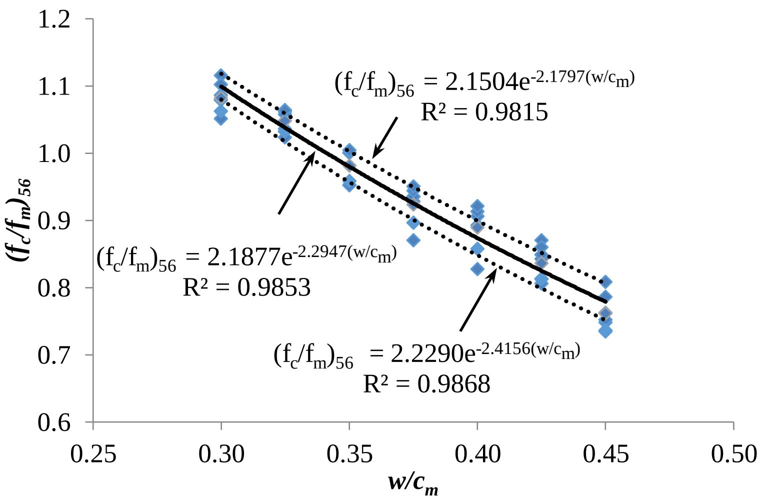

Fig 3: Relation between $\left(\frac{f_c}{f_m}\right)$ ***and*** $\left(\frac{w}{c_m}\right)$ ***at 56 days***

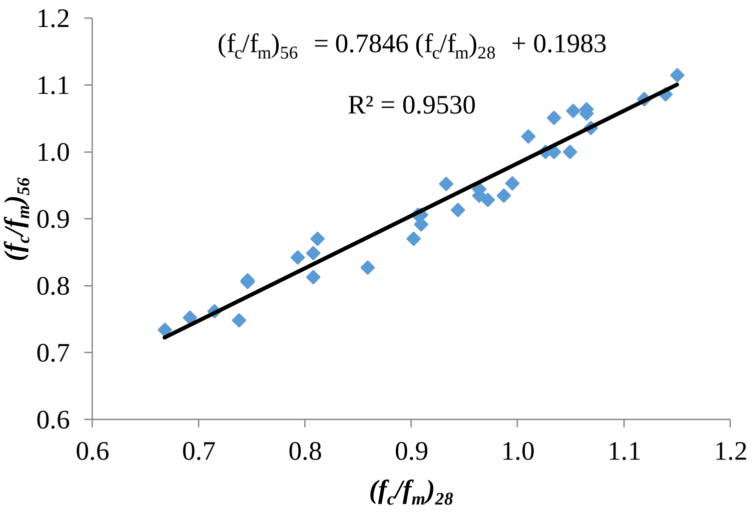

Fig 4: Relation between $\left(\frac{fc}{fm}\right)_{28}$ ***and*** $\left(\frac{fc}{fm}\right)_{56}$

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To evaluate the performance of the new relation, PSC based concrete mixtures for 28 day target strengths of 50MPa and 55MPa are proportioned using the proposed relationship. Similarly, the corresponding 56 day relationship is used for proportioning mixtures for the target strengths of 60MPa and 65MPa. The 28 day and 56 day cube compressive strengths, as obtained from test results, are 4.8% and 3.6%, and 2.8% and 1.4% above the specified target strengths respectively. Hence, the experimental results are within 5% variation of target strength. Refer Table 2 for the strength values.

Table 2. Compressive Strength of PSC based mix at 28 and 56 days

Target Strength (MPa)			Cube Compressive Strength (MPa)	Strength Ratio
Days	28	50	52.4	1.048
		55	57.0	1.036
	56	60	61.7	1.028
		65	65.9	1.014

VII. CONCLUSIONS

The set of relations derived for strength ratio and water-cementitious material content provide guidelines for proportioning PSC concrete based on the performance at 28 days and 56 days. Utilizing the relation between strength ratio at 28 days and 56 days, the performance of the mix designed for 56 days target strength can be assessed at 28 days. This relation may be accepted as a reference for the mixture proportioning of such modified concrete based on 56 days compressive strength, as in practical situations, structures are not subjected to the entire design load within 56 days from casting.

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