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STUDIES ON RELATIONSHIP BETWEEN COMPRESSIVE AND SPLITTING TENSILE STRENGTH OF HIGH PERFORMANCE CONCRETE

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ABSTRACT

This experimental study is intended to identify the relationship between compressive strength and splitting tensile strength of high performance concrete. For this purpose the applicability of existing relationship between the Compressive strength and Splitting tensile strength of Concrete was examined. The commonly accepted 0.5 power relationship as per IS 456-2000 was investigated and then a similar kind of relationship developed for High performance Concrete. M60 grade HPC mixes incorporating different percentages of high reactivity metakaolin and silica fume by weight of cement along with some suitable super plasticizer. The results of the study indicate that the strength properties of HPC mixes improved by incorporating metakoalin and silica fume up to a desirable content of 15% and 5% respectively by weight of cement. It was analyzed from the test result that the Compressive strength and splitting tensile Strength were related together and the 0.5 power relationship was found to be inaccurate. Thus the alternative relations were proposed for the High performance Concrete with the support of results and figures.

Key words: high performance concrete, fly ash, metakaolin, tensile strength, compressive strength, silica fume.

1. INTRODUCTION

The global warming is caused by emission of green house gases such as carbon dioxide, carbon monoxide into the atmosphere (Elahi. A, *et al* 2010). In terms of global warming the High performance technology could significantly reduce the carbon dioxide emission into the atmosphere caused by cement industries. The IS 456-2000 code represents the relationship between the concrete flexural tensile strength (f_t) and the Compressive strength (f_{ck}) by $f_t = 0.7(f_{ck})^{0.5}$. The American concrete Institute code ACI 318-95[4] defines the relationship between modulus of rupture (f_r) and the Compressive strength (f_{ck}) by $f_r = 0.56(f_{ck})^{0.5}$ and also recommends the relationship between the modulus of rupture f_r and the Compressive strength (f_{ck}) by $f_r = 0.62(f_{ck})^{0.5}$. The Canadian code 1994 defines only one value for the modulus of rupture up to the concrete strength of 80Mpa, namely, $f_r = 0.6(f_{ck})^{0.5}$. It has been accepted by the Concrete researchers as well as the ACI that the 0.5 power relationship exists between the tensile strength and Compressive strength of Concrete. Investigations have also conducted for finding the applicability of this 0.5 power relationship to High performance Concrete. In order to predict several relations for calculating tensile strength from the compressive strength, it has not been clearly established for the various grades of High performance Concrete. Oluokun, *et al*., 1991 suggested that the Splitting tensile strength is not necessarily proportional to the 0.5 power of Compressive strength and predicted that the tensile strength is proportional to 0.79 power of cylinder Compressive strength.

2. EXPERIMENTAL PROGRAMME

2.1 Materials used

The materials used for making high performance concrete specimens are low calcium fly ash as the source material, River sand, coarse aggregate as the filler, and water and super plasticizer as workability measure. In this investigation, class F type of fly ash is obtained from Metur power plant with fineness modulus and specific gravity were 7.86 and 2.21, respectively.

The fineness modulus and specific gravity of river sand were 3.12 and 2.64.

2.2 Metakaolin

Sabir B.B, *et al*., 2001 suggested that Metakaolin is compatible with most concrete admixtures, such as super plasticizers, retarders, accelerators, etc. Based on previous experience, replacing 10-15% of the cement with Metakaolin gives us an optimal performance.

2.3 Silica fume

Silica Fume is a very reactive and effective pozzolanic material due to its fine particle size and high purity of SiO_2 (99.5%) content. It enhances the

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mechanical properties, durability and constructability in concrete. It is used in the production of High strength and High performance concrete. The recommended dosage is 7-10% of the cement weight added to the concrete. Silica fume is the most commonly used mineral admixture in high strength concrete. It is used in the construction of high performance concrete structures like bridges where the strength and durability properties of the concrete is required.

2.4 Superplasticizer

The superplasticizer used in this study is CONPLAST SP430. To produce high workability concrete without loss of strength and to promote high early and ultimate strengths by taking advantage of water reduction whilst maintaining workability. It produces high quality concrete of improved durability and impermeability.

3. PREPARATION OF HIGH PERFORMANCE CONCRETE

In this project, a number of supplementary cementitious materials are being used. A total of 6 cases are present. For each case, a total of 12 cubes were cast. Totally 72 cubes has been cast for this work. The cubes are tested for 7 days, 14 days, 28 days, and 56 days. For each day test, 3 cubes were cast .The cement is kept constant at 30 % for the third, fourth, fifth and sixth cases respectively. Fly ash is kept constant for all the cases. 50 % fly ash is used. The term high volume fly ash can be used only when optimum fly ash content is 50 % shown in Table-1.

4. TESTING THE CONCRETE SPECIMENS

Twenty five 150X150mm cubes and 150mm diameter 300m high were cast out of which three cubes each were used to determine the compressive strength and three cylinders each were used to determine the split tensile strength of High performance Concrete. Mix ratios were shown in Table-1. Table-2 shows the detail of cube casting mix ratio. Table-3 shows the Detail of Cylinder Casting mix ratio. All High performance concrete was made with mix design procedure using Trial and error method. IS 516:1959 code represents Flow test (workability) was carried out by slump cone test as described for cement concrete. After the flow test, fresh concrete were placed in respected mould as described in the IS 516.-1959. The fresh concrete was cast and compacted by the usual methods used in the case of Portland cement concrete. The specimens were left standing for 1 day and then cured. After the curing period the specimens left at the room temperature for about an hour and ready for testing. Thus the compressive strengths and tensile strength of concrete were tested at the same day in accordance with IS 516.-1959. The reported strengths were the average of the three specimens.

Table-1. Mix ratios.

S. No.	**Case 1** (in %)	**Case 2** (in %)	**Case3** (in %)	**Case4** (in %)	**Case5** (in %)	**Case6** (in %)
Cement	100	30	30	30	30	30
Fly ash	0	50	50	50	50	50
Silica fume	0	0	5	10	15	20
Metakaolin	0	20	15	10	5	0

Table-2. Detail of cube casting.

Case	**No. of cubes**	**Required material in kg**					**Metakaolin** (kg)
		Cement (kg)	**Sand** (kg)	**Aggregate** (kg)	**Fly ash** (kg)	**Silica fume** (kg)	
1	12	20.420	27.67	44.879	0	0	0
2	12	6.126	27.67	44.879	10.21	0	4.084
3	12	6.126	27.67	44.879	10.21	1.021	3.063
4	12	6.126	27.67	44.879	10.21	2.3483	2.3483
5	12	6.126	27.67	44.879	10.21	3.063	1.021
6	12	6.126	27.67	44.879	10.21	4.084	0

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Table-3. Detail of cylinder casting mix ratio.

Case	No. of cylinders	Required material in kg					Metakaolin (kg)
		Cement (kg)	Sand (kg)	Coarse aggregate (kg)	Fly ash (kg)	Silica fume (kg)	
1	12	32.06	43.45	70.47	0	0	0
4	12	9.618	43.45	70.47	16.03	3.206	3.206
5	12	9.618	43.45	70.47	16.03	4.809	1.603
6	12	9.618	43.45	70.47	16.03	6.412	0

5. RESULTS AND DISCUSSIONS

Table-4. Cube compressive strength of concrete at different ages.

Standard	7 Days (N/mm^2)	14 Days (N/mm^2)	28 Days (N/mm^2)	56 Days (N/mm^2)
Case 1	44.29	53.82	63.33	65.86
Case 2	25.480	33.39	38.66	45.69
Case 3	18.45	25.92	42.34	48.93
Case 4	23.26	29.37	47.15	55.80
Case 5	21.79	27.03	50.22	61.75
Case 6	20.41	27.53	44.32	56.49

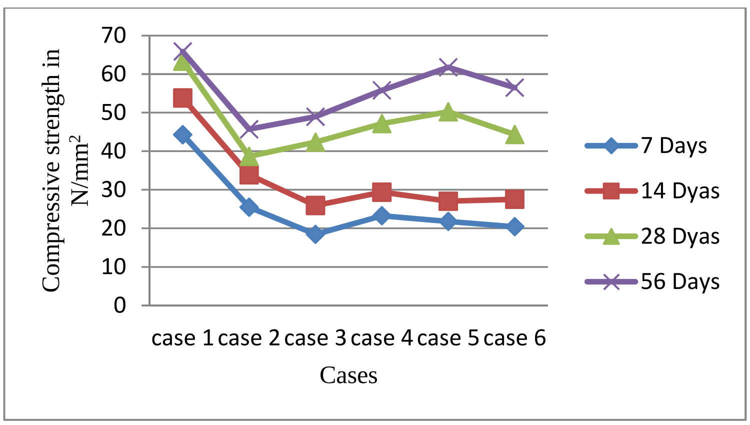

Figure-1. Variation in compressive strength of different cases.

As per above results, shown in Table-4 and Figure-1 the normal conventional concrete for M60 mix is achieved according to standards. But, the concrete containing admixtures explicit slower strength gain at 7 days, when compared to M60 concrete with 100% cement mix.

At 28 days, the mix containing 15%SF, 5% MK, 50%FA, 30 % C showed a better strength gain compared to the other mixes containing admixtures. At 56 days, the mix containing 15 % SF, 5% MK, 50% FA, 30% C has attained the desired grade proving that there is an increase in the later strength gain in the concrete containing admixtures as per Eva Vejmelkova, *et al* 2012. Case 2 and case 3 shows very less strength gain at 56 days due to the inherent properties of the concrete mix itself. Due to that, we have omitted case 2 and case 3 for split tensile strength tests results shown in Table-5 and Figure-2.

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Table-5. Split tensile strength of cylinder at different age of loading:

Standard	7 Days	14 Days	28 Days	56 Days
Case 1	2.91	3.04	3.61	3.70
Case 4	2.28	2.43	3.01	3.41
Case 5	2.24	2.34	3.24	3.72
Case 6	2.037	2.24	3.04	3.37

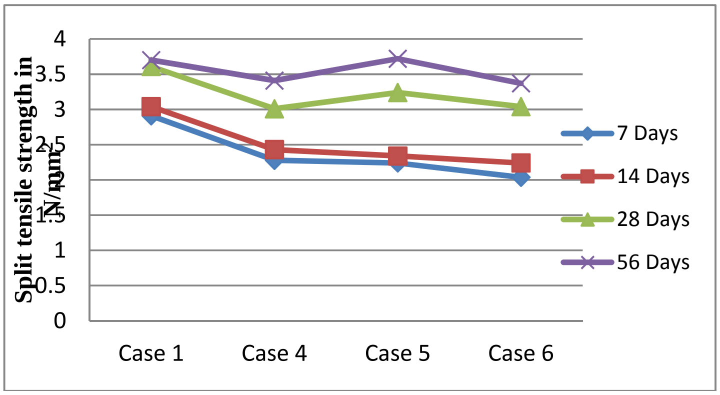

Figure-2. Variation in split tensile strength for different cases.

The split tensile results show that the concrete containing admixtures 15 %SF, 5%MK, 50%FA, 30% C, has better split tensile strength compared to the normal conventional concrete and also other concrete mixes containing admixtures. It is noticed that the strength gain happens only in later stages in case of admixture concrete unlike normal concrete. The other mixes too have achieved a considerable strength, but it is less when compared to Case 5.

6. RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND SPLITTING TENSILE STRENGTH OF HIGH PERFORMANCE CONCRETE

This experimental investigation was intended to investigate the applicability of existing relationship between the Compressive strength and Splitting Tensile Strength of High performance Concrete.

The Non linear relationship between the Compressive strength and splitting tensile strength of High performance concrete is shown in Figure-3. The slopes (S) and the intercepts (K) represent the values of the constants in the general equation $f_t = K\left(f_{ck}\right)^S$. The properties of other regression lines are shown in Table-6. From the constants of the regression equations it was shown that the 0.5 power law between splitting tensile strength and Compressive strength does not give very accurate relationship for control concrete. The same trends were observed High performance Concrete. Therefore the commonly accepted 0.5 power relationship as per IS: 456-2000 and ACI code was investigated and new relationship developed for the ternary blended concrete.

Based on this experimental investigation, the relationship between the compressive strength and Splitting tensile strength of High performance concrete for 28 days was found to be $f_t = 0.689\ (f_{ck})^{0.401}$ and the same relationship for 56 days found to be $f_t = 1.049\ (f_{ck})^{0.314}$.

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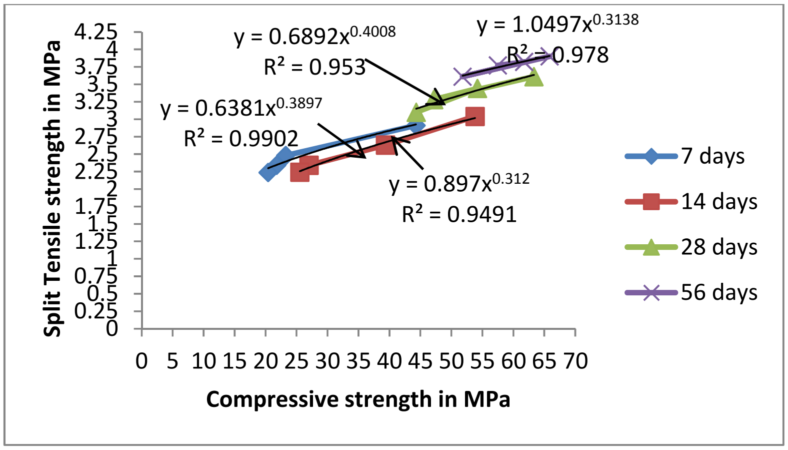

Figure-3. Relationship between compressive strength and tensile strength of high performance concrete.

Table-6. Properties of regression lines

Days	Slope, S	Intercept, K	Regression equations
7days	0.312	0.897	$f_t = 0.897\ (f_{ck})^{0.312}$
14 days	0.389	0.638	$f_t = 0.638\ (f_{ck})^{0.389}$
28 days	0.401	0.689	$f_t = 0.689\ (f_{ck})^{0.401}$
56 days	0.314	1.049	$f_t = 1.049\ (f_{ck})^{0.314}$

7. CONCLUSIONS

- The concrete mixes containing supplementary cementitious materials did not achieve the desired strength in 28 days. This may be due to the high volume of fly ash being used.
- Since high volume of fly ash is being used, the strength gain can be seen only at later ages i.e. 56 days.
- The concrete mix containing 15%SF, 5%MK, 50%FA, 30%C has shown best results when compared to other concrete mixes containing admixtures. This shows that this can be used in real time applications in places where high strength is required but at later ages is sufficient.
- The slope of the regression line for all the mixes in High performance Concrete was slightly higher than the code recommendation.
- The Splitting Tensile strength of High performance Concrete is not proportional to the 0.5 power of Compressive strength.
- The 0.401 power relationship for sand and 0.314 power relationship for 28 days and 56 days High performance Concrete were found to be more realistic relationship between Compressive strength and Tensile strength.
- The relationship between the compressive strength and Splitting tensile strength of High performance concrete for 28 days was found to be $f_t = 0.689\ (f_{ck})^{0.401}$ and the same relationship for 56 days found to be $f_t = 1.049\ (f_{ck})^{0.314}$.

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