Evaluation of Relation between Split Tensile and Compressive Strength of OPC Concrete

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Abstract

Present study was carried out to determine the compressive strength characteristics of concrete (M40) containing flyash and silica fume with superplasticizer. The objectives were to study the effect of combined use of flyash and silica fume with superplasticizer on compressive and split tensile strength of concrete. The water cement ratios in all mixes were kept 0.32. After curing, the specimens were tested after 3, 7, and 28 days for getting the value of compressive and split tensile strength. The relation between compressive and split tensile strength has been developed and the value of R^2 is 0.938. The derived relationship of current study was compared with the relationship developed from four other authors. It is found that derived relationship of current study is in good agreement with the relationship derived by Oluokun et al. i.e. $f_{sts}= 0.294f_c^{0.69}$.
Key Words: Flyash, Silica Fume, Compressive strength, Split tensile strength

1. INTRODUCTION

Building industry, a fast growing sector, is one of the key areas of infrastructure development. To cater the requirements of building materials, we depend heavily on natural resources. As there is a limit upto which natural resources can be exploited, so it becomes imperative to find alternate substitute materials because there is a limit up to which natural resources can be exploited?

Use of industrial wastes, not only conserved natural resources but also solution to safe disposal of industrial waste is obtained. Fly ash and silica fume are the promising industrial wastes which can be easily used in construction. With the increase in the number of coal-based thermal power plants in India, generation of fly ash has reached enormous proportions. Fly ash is an industrial by-product resulting from the combustion of pulverized coal. In India, about 100 million tonnes of fly ash is accumulated every year which is generated as waste from thermal plants. This is causing enough concern as its disposal involves design and installation of ash ponds covering large areas at each plant site. In spite of concerted efforts at national scale, only a very small fraction (around 6%) of the fly ash is put to use in India. Fly ash has many applications in the building industry. It is a better solution as a partial replacement of cement in concrete.

Silica fume is also a waste by-product from the silicon metal and ferrosilicon alloy industries. The chief problems in using this material are associated with its extreme fineness and high water requirement when mixed with Portland cement. However, the availability of super plasticizers has opened up new possibilities for its use. Though use of super plasticizers is very common in developed countries, but their use is not so common in developing countries like India. It is in this context that effort has been made to study the effect of addition of super plasticizer in addition to fly ash and silica fume on compressive strength of concrete.

In general, use of silica fume or other mineral admixture causes pore as well as grain refinement that leads to reduced permeability. Performance of silica fume in concrete depends greatly upon its physical, chemical and mineralogical properties. The combined use of fly ash and silica fume is new for the present era in concrete technology. The fly ash-silica fume concrete with optimum percentage of fly ash and silica fume has higher ultimate strength than OPC concrete. It has been established that the waste materials like fly ash and silica fume can be converted into meaningful wealth as new construction materials having considerable cementitious properties which result in major saving of raw material of cement. Hence, fly ash-silica fume concrete may be an alternative material for construction industry in the next few decades. The usage of industrial waste materials such as fly ash and silica fume in construction sector is very important in term of limiting the environmental pollution, cost reduction and slowing down the use of natural resources in the world.

A properly designed concrete mix should have minimum possible cement content without sacrificing the concrete quality in order to make it an economical mix. In general, a fresh concrete must be workable and a hardened concrete must be durable and have the desired strength and appearance. If fresh concrete is not properly workable, it will not be possible to achieve compaction; with the result the strength and durability of the hardened concrete will be significantly hampered. Water-cement ratio is the most critical factor in concrete mix design. To study the effect of fly ash and silica fume with super plasticizer on compressive strength of concrete.

2. MATERIAL AND METHODS

The present chapter deals with the results of tests conducted on concrete cube using fly ash, silica fume & super plasticizer to determine the effect of fly ash and silica fume on compressive and split tensile strength of concrete. The experimental program consist of casting, curing and testing of silica fume and fly ash concrete specimens at different ages. The compressive and split tensile strength was investigated at the ages of 3, 7 & 28 days. Workability of various mixes was kept medium.

2.1 PROPERTIES OF MATERIAL USED

The aim of studying various properties of the material used is to check the conformance with codal requirements and to enable an engineer to design a concrete mix for a particular strength. The following materials were used in the present study.

2.1.1 Portland cement

Ordinary Portland cement (OPC) of 43 grade (Ultratech) confirming to BIS: 8112:1989[1] was used for making concrete. It was fresh and without any lumps The relevant cement properties experimentally obtained are given in Table 1.

Table 1: Properties of OPC 43 grade cement

S. No.	Characteristics	Value obtained experimentally	Value specified by IS:8112:1989
1.	Specific gravity	2.975	-
2.	Standard consistency	32%	-
3.	Initial setting time	123 min	30 min (minimum)
4.	Final setting time	266 min	600 min (maximum)
5.	Compressive strength 3 Days 7 Days	 29.18 N/mm^2 33.78 N/mm^2	 23 N/mm^2 33 N/mm^2

	28 Days	47.36 N/mm^2	43 N/mm^2

The values obtained conform to specifications given in code

2.1.2 Aggregates

Coarse Aggregate

The coarse aggregate used were a mixture of two locally available crushed stone of 10 mm and 20 mm size in 50:50 proportion and confirming to BIS: 383:1970[2]. Specific gravity and other properties of coarse aggregate are given in Table 2. Sieve analysis of coarse aggregate was done. Proportioning of coarse aggregate was done and Fineness Modulus was obtained as given in Table 3 and Table 4 respectively.

Table 2: Properties of coarse aggregates

Characteristics	**Value**
Colour	Grey
Shape	Angular
Maximum size	20 mm
Specific gravity	2.63

Table 3: Proportioning of coarse aggregate

IS-Sieve designation	**Cumulative percentage passing of 10 mm Agg.**	**Cumulative percentage passing of 20 mm Agg.**	**Proportion 50:50 (10 mm : 20mm)**	**IS 383-1970 requirements**
80 mm	100.00	100.00	100.00	100
40 mm	100.00	100.00	100.00	100
20 mm	100.00	94.6	97.3	95-100
10 mm	56.2	0.4	28.3	25-55
4.75 mm	0.6	0	0.3	0-10

Table 4: Fineness modules of proportioned coarse aggregate

IS Sieve designation	**weight retained on sieve in gms (10 mm aggregates)**	**Weight retained on sieve in gms (20 mm aggregates)**	**Average weight retained (gm)**	**Cumulative weight retained (gm)**	**Cumulative @age weight retained (gm)**	**%age passing**
80 mm	0.00	0.00	0.00	0.00	0.00	100.00
40 mm	0.00	0.00	0.00	0.00	0.00	100.00
20 mm	0.00	270	135	135	2.7	97.3
10 mm	2190	4710	3450	3585	71.7	28.3
4.75 mm	2780	20	1400	4985	99.7	0.30
2.36	30	0	15	5000	100	0

Cumulative percentage weight retained = 674.1

Fitness Modules (F.M.) = $\frac{674.1}{100} = 6.741$ Say 6.74

It lies within desirable range 5.5-8.0

Fine Aggregates

Fine aggregates were collected from Chaki River Pathankot. It was coarse sand brown in color. Specific gravity of fine aggregates was experimentally determined as 2.62. Fineness Modulus of the fine aggregates was found by sieve analysis and results are given in Table 5.

Table 5: Fineness Modulus of the fine aggregates

Sieve no.	Retained on each sieve weight (gm)	Retained on each sieve (%age)	Cumulative %age retained	%age Passing	%age passing for zone-II as per IS-383-1970
10mm	0	0	0	0	100
4.75 mm	80 gm	4	4	96	90-100
2.36 mm	200 gm	10	14	86	75-100
1.18 mm	500 gm	25.0	39	61	55-90
600 Micron	510 gm	25.5	64.5	35.5	35-59
300 Micron	240 gm	12.0	76.5	23.5	8-30
150 Micron	360 gm	18.0	94.5	5.5	0-10
Pan	110 gm	5.50			
Total wt. of sample	2000 gm	100	292.5		

Fineness modulus = 2.925

Fly Ash

Fly ash used in present work was obtained from Guru Hargobind Thermal Plant Lehra Mohabbat, Distt. Bathinda. The fly ash, which was used, falls under class F category. The physical and chemical properties of flyash are given in
Table 6.

Table 6: Physical and Chemical properties of fly ash

S. No.	Characteristics	Values
1	Colour	Light brown
2.	Specific gravity	2.09
3.	Class	F
4.	Chemical composition SiO_2 AL_2O_3 Fe_2O_3	 57.41 26.92 5.21

	CaO MgO SO_3 LoI IR Lime reactivity	2.05 0.71 0.085 1.18 93.12 59.50
5.	Sieve analysis	
	Sieve no.	%age of weight retained
	100 140 200 270 Pan	0.00 31.35 26.51 24.72 17.42

Silica Fume

The silica fume used was obtained from Orkla India (Pvt) Ltd(Brand name : Elkem Microsilica 920-D), Navi Mumbai. Its chemical composition and other properties are given in Table 7.

Table 7: Physical and Chemical properties of silica fume

S. No.	Characteristics	Values
1	Specific gravity	2.26
2.	Colour	Grey
3.	Surface area	20500 m^2/kg
4.	Bulk density	610 kg/m^3
	Chemical composition SiO_2 Al_2O_3 Fe_2O_3 CaO MgO K_2O Na_2O C S Cl Loi	 93.800 0.206 0.096 0.426 0.222 0.337 0.107 3.000 0.240 0.006 2.900

Super plasticizer

The super plasticizer used in the study was Rheobuild SPI obtained from Basf construction chemicals (India) Pvt. Ltd., Navi Mumbai. It is based on Naphthalene formaldehyde polymer. The physical and chemical properties of super plasticizer, which was obtained from the company, conform to BIS-9103-1979[3] and are given in Table 8

Table 8: Physical and Chemical Properties of superplasticizer Rheobuild-SP1

S. No.	Parameter	Specifications (As per IS 9103)	Properties of Rheobuild SPI
1.	Physical state	Dark brown free flowing liquid	Dark brown free flowing liquid
2.	Chemical name of active ingredient	Naphthalene formaldehyde polymers	Naphthalene formaldehyde polymers
3.	Relative density at 25^0C	1.15 ± 0.02	1.151
4.	pH	Min 6	7.34
5.	Chloride ion content (%)	Max 0.2	0.0010
6.	Dry material content	32 ± 5 (%)	32.04
7.	Ash content	8 ± 5 (%)	8.01

2.2 EXPERIMENTAL PROGRAME

2.2.1 Mix Design by Indian Standard Recommendations:-

Present investigation includes design of concrete mix (non-air entrained) for medium strength concrete. The guidelines given in BIS: 10262-1982[4] has been adopted for mix design of concrete.

For the present investigation, it is required to have characteristic compressive strength 40 N /mm^2. The compaction factor for the design mix is taken as 0.9. The maximum size of aggregate is 20 mm (angular). Type of exposure moderate and degree of quality control as very good. The target mean strength for the specified characteristic strength is 40 + 5.6 x 1.65 = 49.24 N/mm^2

The quantities determined by IS design method are given in Table 9.

Table 9 Proportion of different materials

Water	Cement	Fine aggregate	Coarse aggregate
185.4 liters	579.375 kg	467.58 kg	1108.52 kg
0.32	1	0.81	1.91

2.2.2 Preparation of Specimen for strength test

Firstly, the coarse aggregates, which were saturated surface dry, were placed in the mixer. The binder (cement only in case of control mixes and cement & silica fume for other mixes already thoroughly manually mixed) and fine aggregates were added and mixed for about a minute. Subsequently 70% of total water is mixed for nearly 3 minutes. After the initial mixing is complete remaining 30% of water, which was premixed with the pre-calculated superplasticizer dosage (from requirements of workability) and nano silica in two equal parts, was added and mixing was done for another one and a half to two minutes. The compaction factor test was conducted to check the workability, and then finally, the fresh concrete was poured into the well-oiled cubical moulds of size 150mm x 150mm x 150mm.

After pouring the concrete, an external vibrator was used to facilitate the compaction and decrease the amount of air bubbles.

2.2.3 Test of Strength

The compressive and split tensile strength tests were performed in accordance with BIS: 516[5] and BIS: 5816[6]. The cube moulds having size 150 ×150×150 mm were used for both compressive and split tensile strength. For all the designated mixes and for each of the testing ages, 3 samples were cast and the average value of results is given in Table 3.

2.2.4 Curing conditions for specimens

All the specimens were demoulded after 24 h and then put in water tank for curing at a temperature of 27±2°C.

3. Results and Discussion

3.1 Compressive strength:

The compressive strength of all the mixes was determined at the ages of 3, 7 and 28 days for the various replacement levels of flyash and silica fume. The results are reported in Table 10. Table 10 shows the variation of compressive strength of concrete with the different percentages of flyash and silica fume. The compressive strength of reference mix is 27.14 N/mm^2, 34.85 N/mm^2 & 54.71 N/mm^2 for 3, 7 & 28 days respectively. With the addition of various percentages of silica fume (4 %, 8 % & 12 %) to the 0 % level of flyash, the maximum values compressive strength of 3,7 & 28 days are 45.33 N/mm^2 ,54.22 N/mm^2 & 69.57 N/mm^2 respectively whereas , the minimum values compressive strength of 3 ,7 & 28 days are 40.74 N/mm^2, 50.47 N/mm^2 & 67.19 N/mm^2 respectively. It is observed that addition of silica fume to concrete, results in increase in compressive strength of concrete as compared to the compressive strength of control mix at all ages. It is pertinent to mention that the compressive strength of concrete have increased by 50.11 % - 67.17 %, 44.82% - 55.58 % & 22.81%-27.16 % for 3, 7 & 28 days respectively.

The maximum / minimum value of compressive strength of concrete with the addition of 10 percentages of fly ash to the various percentages of silica fume (i.e. 4 %, 8 % & 12 %) for 28 days were 76.83 N/mm^2 / 63.75 N/mm^2 as compared with compressive strength control mix 54.71 N/mm^2. It shows there is increase of 16.52 % to 40.43 % of compressive strength.

The increasing trends are due to the use of silica fume, which helps in filling concrete pores resulting in improved impermeability of concrete, lesser moisture diffusion and increased strength may be attributed to the increased concrete density. Also secondary reaction takes place between silica and a byproduct of cement hydration that is calcium hydroxide to produce a cementitious agent, calcium silicate hydrates. This additional cementitious agent i.e. calcium silicate hydrates adds strength to concrete in addition to increasing its density. The superfine size and high pozzolanic reactivity makes silica fume a basic ingredient for concrete requiring high strength. The decreasing trends are due to Alumina of flyash, which in the presence of lime forms gehlinite (C_2ASH_8) – an inert material. The low strength of flyash – lime mix inspite of high reactivity of flyash is due to the formation of gehlinite. Further, the rate of growth of these pozzolanic products is small and their influence on strength of the system is seen only after long periods of curing.

The optimum value of compressive strength is achieved with addition of
10 % of flyash & 4% of silica fume. But as the percentage of silica fume increases more than the optimum value for the same % age of flyash, compressive strength of concrete probably starts decreasing due to the excessive heat of hydration.
Similarly, the if percentage of dosage of flyash increases more than the optimum value for the same %age of silica fume, compressive strength of concrete starts decreasing due to the formation of gehlinite. It is recommended to use 10 % flysh and 4% of silica fume as replacement of cement for getting economical and better compressive strength.

Table 10: Test result of Compressive and Split tensile strength with different level of replacement.

Sample	%age of Replacement (Flyash+Silica fume)	Compressive strength (MPa)			Split Tensile Strength (MPa)		
		3 days (MPa)	7 days (MPa)	28 days (MPa)	3 days (MPa)	7 days (MPa)	28 days (MPa)
N_0	0+0	27.14	34.85	54.71	2.71	3.14	4.6
N_1	0+4	45.33	54.22	67.19	4.10	4.40	5.18
N_2	0+8	40.94	50.47	67.52	3.80	4.34	5.00
N_3	0+12	40.74	51.78	69.57	3.51	4.44	5.78
N_4	10+4	35.60	50.29	76.83	3.85	4.42	6.1
N_5	10+8	27.59	40.77	63.75	3.10	3.77	4.55
N_6	10+12	26.18	38.24	66.61	2.58	3.68	5.02

3.2 Split tensile strength:

The split tensile strength of all the mixes was determined at the ages of 3, 7 and 28 days for the various replacement levels of fly ash and silica fume. The results are reported in Table 10. Table 3 shows the variation of compressive strength of concrete with the different percentages of fly ash and silica fume. The split tensile strength of reference mix is 2.71 N/mm^2, 3.14 N/mm^2 & 4.6 N/mm^2 for 3, 7 & 28 days respectively. With the addition of various percentages of silica fume (4 %, 8 % & 12 %) to the 0 % level of fly ash, the maximum values split tensile strength of 3, 7 & 28 days are 4.10 N/mm^2, 4.40 N/mm^2 & 5.18 N/mm^2 respectively whereas, the minimum values split tensile strength of 3, 7 & 28 days are 3.80 N/mm^2, 4.34 N/mm^2 & 5.00 N/mm^2 respectively.
The maximum / minimum value of split tensile strength of concrete with the addition of 10 percentages of fly ash to the various percentages of silica fume (i.e. 4 %, 8 % & 12 %) for 28 days were 6.1 N/mm^2 / 4.55 N/mm^2 as compared with split tensile strength control mix 4.6 N/mm^2.
The increasing trends are due to the use of silica fume, which helps in filling concrete pores resulting in improved impermeability of concrete, lesser moisture diffusion and increased strength may be attributed to the increased concrete density. Also secondary reaction takes place between silica and a byproduct of cement hydration that is calcium hydroxide to produce a cementitious agent, calcium silicate hydrates. This additional cementitious agent i.e. calcium silicate hydrates adds strength to concrete in addition to increasing its density. The superfine size and high pozzolanic reactivity makes silica fume a basic ingredient for concrete requiring high

strength. The decreasing trends are due to Alumina of fly ash, which in the presence of lime forms gehlinite (C_2ASH_8) – an inert material. The low strength of flyash – lime mix inspite of high reactivity of flyash is due to the formation of gehlinite. Further, the rate of growth of these pozzolanic products is small and their influence on strength of the system is seen only after long periods of curing.

The optimum value of split tensile strength is achieved with addition of 10 % of flyash & 4% of silica fume. But as the percentage of silica fume increases more than the optimum value for the same % age of flyash, split tensile strength of concrete probably starts decreasing due to the excessive heat of hydration.

Similarly, the if percentage of dosage of flyash increases more than the optimum value for the same %age of silica fume, split tensile strength of concrete starts decreasing due to the formation of gehlinite. It is recommended to use 10 % flysh and 4% of silica fume as replacement of cement for getting economical and better split tensile strength.

3.4 Correlation between split tensile and compressive strength:

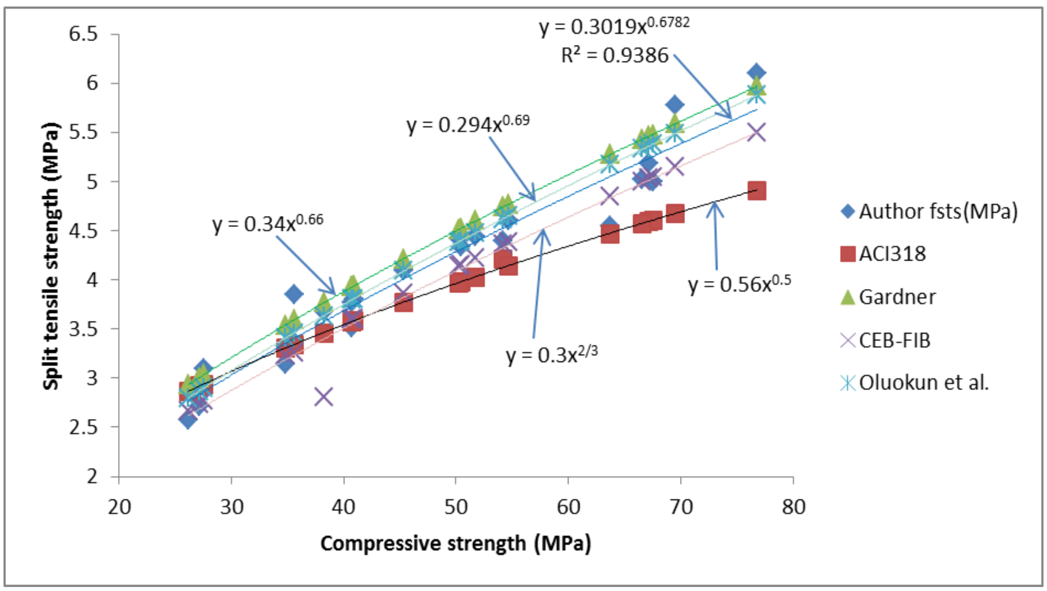

Fig.1. Relationship between compressive strength and splite tensile strength

$F_{sts}(y)= 0.3019f_c^{0.6782}$, $R^2= 0.9386$

The relation derived from this current study is compared with those proposed by Gardner [7], given in ACI-318-99[8], given in CEB-FIB [9] and by Oluokun et al. [10]. Fig.1 demonstrates the relation between split tensile and compressive strength of normal concrete and nano silica concrete. Based on the Fig. 1, the empirical expression obtained from this study and form other authors are listed below.

$f_{sts} = 0.3019f_c^{0.6782}$	Current Study (Author)
Gardner, $f_{sts} =0.34f_c^{0.66}$	Eq. 1
ACI318R-99, $f_{sts} =0.56f_c^{0.5}$	Eq. 2
CEB-FIB, $f_{sts} =0.3f_c^{2/3}$	Eq. 3
Oluokun et al., $f_{sts} =0.294f_c^{0.69}$	Eq. 4

f_{sts}= Split tensile strength and f_c= compressive strength

The relationship derived from the test results of the current study is very close to relationship derived by Oluokun et al. i.e. y (f_{sts}) =0.294$f_c^{0.69}$. The value of coefficient of determination (R^2=0.9386) attains good correlation between split tensile and compressive strength of concrete and the relationship between these two is significant.

4. CONCLUSIONS

From the experimental investigation, the following conclusions can be drawn:

i) There was a significant increase in early age strength of concrete containing silica fume only after 3 days of curing, but it started decreasing with the addition of 10 % flyash.

ii) There was an increase in compressive strength of concrete containing flyash and silica fume after 7 days of curing. From this, it can be concluded that the effect of flyash on the early age strength has decreased considerably after 7 days.

iii) The partial replacement of cement with flyash and silica fume is capable of producing a medium strength concrete. The optimum replacement levels of flyash and silica fume are 10 % and 4%. This optimum level of combination gave 28 days compressive strength of 76.83 MPa.

vi) As silica fume is costly and its use without flyash may not be economical in producing medium strength concrete. Flyash is an industrial waste and was used to produce medium strength concrete economically. So when flyash and silica fume are used in combination, it gives high as well as early age strength to concrete economically.

vii) A low water cement ratios like 0.32 can be tried for producing a concrete for commercial purposes but appropriate superplasticizer compatible with the materials are required to be used.

viii) The relationship derived between compressive and split tensile strength from the test results of the current study is very close to relationship derived by Oluokun et al. i.e. y (f_{sts}) =0.294$f_c^{0.69}$. The value of coefficient of determination (R^2=0.9386) attains good correlation between split tensile and compressive strength of concrete and the relationship between these two is significant.

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