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TENSILE AND FLEXURAL STRENGTH OF CEMENT SILICA FUME CONCRETE

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ABSTRACT

Silica fume is a concrete modifier used to enhance its strength up to some extent.. This study was conducted for better understanding of influence of silica fume on tensile and flexural strengths of concrete. 168 cylinders and 56 beams were cast with 0% to 9% cement silica fume replacement and water binder ratios of 0.4, 0.45, 0.5 and 0.55. Spitting tensile and flexural strengths were obtained on 7th and 28th day curing. The results indicate significant improvement in tensile and flexural strengths of concrete. The cement silica fume concrete showed 26% higher splitting tensile strength and 22% higher flexural strength than that of cement concrete when 6 to 7.5% of cement was replaced with silica fume and concrete was cured for 7 days. While for 28 days strength, cement silica fume concrete showed 20% higher splitting tensile strength and flexural strength than that of cement concrete at 6% cement replacement with silica fume.

Key words: Silica Fume, Splitting Tensile Strength, Flexural Strength, Concrete cylinders, Flexure Beams, W/B ratio.

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1. INTRODUCTION

Concrete is an artificial stone made from a mixture of Portland cement, water, fine and coarse aggregates. It is the most widely used construction material in the world. Concrete is the only major building material that can be delivered to the job site in a plastic state. This unique quality makes concrete desirable as a building material because it can be moulded to virtually any form or shape. Concrete provides a wide latitude in surface textures and colours and can be used to construct a wide variety of structures. Other desirable qualities of concrete as a building material include its strength, economy and durability depending on the mixture of material used.

The two major components of concrete are cement paste (25% by volume) and aggregates (75% by volume). The first one consists of cement and water while the next is usually composed of fine and coarse aggregate. Aggregates are usually viewed as an inert and inexpensive material dispersed throughout the cement paste. In properly mixed concrete, each particle of the fine and coarse aggregates is completely surrounded and coated by cement paste, and all spaces between the particles are filled with it. As the cement paste sets and hardens, it binds the aggregates into a solid mass so called concrete.

If talking about the strength of concrete, only its compressive strength is considered as the index to assess its quality. Depending upon the ingredients proportion and usage of additives as its strength enhancing materials, it is capable of supporting 10,000 or more lbs/in^2 in compression, while it is quite weak in tensile as well as flexural strengths. Researchers have concluded through experimental works that the tensile strength of concrete is only about 10% of the compressive strength of cement concrete cylinders. While the flexural strength, which is the major indicator of deflection and cracking behaviour of concrete structure [1], is only about 15% of compressive strength of plain cement concrete.

There is always a search for concrete with higher strength and durability. In this regards, the researchers, to suit the current requirements of construction, introduced blended cement concrete. Thus, pozzolanas as blending materials in addition to Portland cement are being used in concrete in order to cut down the fuel cost and CO_2 emission in the manufacturing process of cement [2-3]. The mostly used pozzolanic materials in the concrete are fly ash, ground granulated ballast furnace slag, silica fume and natural pozzolanas such as calcined shale, calcined clay or met kaolin.

Fly ash can replace up to 50% of the Ordinary Portland Cement which enhances final strength of the concrete and increases chemical resistance and durability. Ground Granulated Ballast Furnace Slag, also known as Slag Cement, is made up from iron ballast furnace. It was first developed in Germany in 1853 [1]. Since the beginning of 1900s, it has been used as cementitious material in concrete. For general purpose concrete, it commonly constitutes between 30% and 45% of cementing material in the mix. Some concretes have a slag component of 70% or more of the cementitious material.

Silica Fume is a highly efficient new born pozzolanic material having greater fineness and surface area than that of cement [1]. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 mm. It was first used in 1969 in Norway, but only began to be systematically employed in North America and Europe in the early 1980s. This material facilitates the adoption of lower water - cement material ratio and better hydration of cement particles including strong bonding among the particles due to which it is necessarily required in the production of not only high strength but also low or medium strength concrete [4]. The use of Silica Fume (SF) in short period of time had one of the most dramatic impacts on the industry’s ability to routinely and commercially produce SF modified concrete of flowable nature but yet remain cohesive, which in turn would develop both high early and high later-age strengths including resistant to aggressive environments [4].

2. LITERATURE REVIEW

The literature has also reported that silica fume made concrete has improved its compressive, tensile and flexural strengths with certain percentages. However, the ratios of tensile to compressive strength are decreasing with increasing silica fume content [5].

Investigations on the performance of silica fume in concrete started from the Scandinavian countries, such as Iceland, Norway and Sweden. Perhaps, Bernhadt (1952) seems be the first who discriminated his research through publishing a paper on the real work of silica fume. Later on, Fiskaa et al. (1971), Traettiberg (1977) and Jahr (1981) published their work in reputed Journal; hence Norwegian standard permitted the use of silica fume enriched with cement. Two years later the direct addition of silica fume into concrete was permitted in Norway Standard. First ever benefit of silica fume in concrete making was realized in 1980 when silica fume was used in cable-stayed bridge of New Tjorn of Sweden.

Chakraborty [1] carried out a detailed experimental study on flexural strength of high-strength M-40 grade concrete at 7 days and 28 days characteristic strength with different replacement levels of 3%, 6%, 9%, 12% and 15% of cement with silica fume. Standard prisms of 100mm*100mm*50mm were considered for investigation and it was revealed that the use of silica fume improved the flexural strength characteristics of high strength concrete at the age of 28-days & reached a maximum value of 12% replacement level for M40 concrete. Research was also carried out by Mohamed [6] on effect of silica fume and fly ash (FA) on compressive strength of self-compacting concrete (SCC) under different curing conditions and it was found that SCC mixes with 15% SF as cement content replacement gave higher compressive strength than that with 30% FA by about 12% and 10% for 550 kg/m^3 and 450 kg/m^3 cement content respectively.

Study on the prediction of Flexural strength of concrete containing silica fume and Styrene Butadiene Rubber (SPR) with an empirical model was also made by Shafieyzadeh (2015) and it was observed that the cement replacement with silica fume up to 7.5% maximizes/optimizes flexural strength and this percent with adding SBR doesn't change [7].

Bhikshma et al, (2009) carried out experimental investigation on compressive, flexural and splitting tensile strength, and stress strain characteristics of high-strength concrete of grades M40 and M50, at 28 days characteristic strength with different replacement levels of cement with silica fume or micro silica of grade 920-D at 3% increment up to 15% using standard cubes, cylinders and prisms and revealed that cement replacement up to 12% with silica fume leads to increase in compressive, splitting tensile and flexural strength, for both M40 and M50 grades which further decreases beyond 12% for 28 days curing period. The compressive strength, splitting tensile strength and flexural strength was increased by 16.37%, 36.06% and 16.40% respectively, for M40 grade concrete and 20.20%, 20.63% and 15.61% respectively for M 50 grade concrete under controlled conditions [8].

Another study on cement silica fume replacement for M20 grade concrete, with designed mix proportion of 1:1.485:3.143, using 53 grade ordinary Portland cement, Zone II sand, 12.5 mm and 20 mm down-graded aggregate, commercial Silica Fume Grade 920-D, was carried by Roy et al (2012) and it was found that at 10% silica fume replacement, maximum compressive strength (both cube and cylinder) was obtained and the values were 19.6% and 16.82% higher than those of the normal concrete cubes and cylinders respectively. Whereas, splitting tensile strength and flexural strength of the SF concrete (3.61N/mm^2 and 4.93N/mm^2 respectively) were increased by about 38.58% and 21.13% respectively over those (2.6 N/mm^2 and 4.07 N/mm^2 respectively) of the normal concrete [4].

Cakir et al (2014), also carried out a research on the incorporation of silica fume in concrete mix design to improve the quality of recycled aggregates in concrete with 0%, 5% and 10%

cement silica fume replacement [9] and found that 10% replacement of SF with cement enhanced the mechanical and physical properties of concrete with 4/12 mm fraction recycled aggregates.

Another concrete category, Crumb Rubber aggregate concrete, was also tested for changes in its mechanical and durability properties on silica fume (SF) incorporation of 5%, 10% and 15% respectively at constant (0.50) water binder ratio by Sivakumar et al (2016) and the optimum value for SF as cement replacement for enhancing its mechanical properties (Compressive strength, splitting tensile strength and flexural strength) was found to be 10% [10].

Kumar et al, (2010) demonstrated that the splitting tensile strength of concrete can be improved with addition of silica fume [11]. Khaskheli et al, (2010) observed the positive effect of silica fume on flexural strength of concrete [12].

Technical advantages are being explored and recognized now all over the world with different configuration and aspects. Though the benefits are no more secrete now, still the utilization of silica fume is limited as a mineral admixture in concrete making [2]. Thus, the main aim of this research is not only to determine the influence of silica fume on tensile and flexural strength of concrete but also to obtain the optimum percentage of silica fume to be added in concrete for 7^{th} and 28^{th} day strengths of concrete.

3. MATERIALS

The ingredients of plain concrete required under this research work were cement, aggregates, water and silica fume. The detail of each ingredient used is given below.

3.1. Cement

The cement used in this research was Ordinary Portland Cement. Tests were conducted for various physical properties of the product and the results (Table.1) were found to be remained in compliance with ASTM and BS Code [13-14].

Table 1 Physical Properties of Cement

S. No.	Properties	Results	Ranges by Codes
1	Consistency	0.31	0.26 - 0.32
2	Initial Setting Time	105 Minutes	45 - 120 Minutes
3	Final Setting Time	3 Hours & 36 Minutes	2 - 10 Hours
4	Fineness	95%	Min: 95% Passing #100 & #200 Sieves

3.2. Silica Fume

On the basis of observations made in laboratory, the physical properties of silica fume are shown below:

Table 2 Physical Properties of Silica Fume

S. No.	Properties	Results
1	Colour	Standard Grey/Purple
2	Fineness	Extremely Dusty
3	Texture	Amorphous/Softy

3.3. Aggregates

The amount of Aggregate in concrete is sum of fine and coarse aggregates. Flexural strength of concrete is greater when angular crushed aggregate is used instead rounded natural gravel because the improved bond of crushed aggregate holds the material together but is ineffective in direct or indirect tension and also, the ratio of flexural strength to compressive strength is greater for angular crushed aggregates, especially at higher compressive strengths [15]. The physical properties of aggregates utilized in this study are shown in table 3 and table 4.The coarse aggregates were obtained from Parker quarry and the fine aggregate from Bholari field, both located in Sindh province. Various researchers [16-18] have worked on these aggregates and found that the basic physical properties like specific gravity and water absorption of these aggregates are within the prescribed range as recommended for civil engineering works (Table.3,Table.4). Further, the FA and CA utilized in this study confirmed the Zone II and 20 mm size (Table.5, Table.6) respectively of BS-882 [19].

Table 3 Physical Properties of Fine Aggregates

S. No.	Properties	Results
1	Absolute Specific Gravity	2.62
2	Water Absorption	0.81%

Table 4 Physical Properties of Coarse Aggregates

S. No.	Properties	Results
1	Absolute Specific Gravity	2.65
2	Water Absorption	0.50%

Table 5 Gradation for Fine Aggregates

Sieves	Weight Retained	Percentage Weight Retained	Cumulative Percentage Weight Retained	Percentage Passing	Zone II	
					Lower Limit	Upper Limit
9.5 mm	0	0	0	100	100	
4.75 mm	543	5.85	5.85	94.15	90	100
2.36 mm	803	8.65	14.50	85.50	75	100
1.18 mm	1373	14.79	29.29	70.71	55	90
600 µm	3110	33.51	62.80	37.20	35	59
300 µm	2500	26.93	89.73	10.27	8	30
150 µm	664	7.15	96.89	3.11	0	10
< 150 µm	289	-	-	-	-	-
Total Cumulative Percentage Weight Retained			299.06			
Fineness Modulus			2.99			

Table 6 Gradation for Coarse Aggregates

Sieves	Weight Retained	Percentage Weight Retained	Cumulative Percentage Weight Retained	Percentage Passing	Lower Limit	Upper Limit
37.5 mm	0	0	0	100	100	
19.5 mm	50	5.00	5.00	95.00	90	100
9.5 mm	500	50.00	55.00	45.00	75	100
4.75 mm	450	45.00	100.00	0.00	55	90
< 4.75 mm	0	-	-	-	-	-

4. EXPERIMENTAL DETAILS/METHODOLOGY

The methodology adopted to determine the influence of silica fume on tensile and flexural strength of concrete is based on stepwise procedure. The ratio for concrete was decided as 1:2:4 by mass. The concrete manufacturing was done as per BS- 1881 (1992). The casting was done for two types of specimens. First of all, 168 standard cylinders were cast, with 0%, 1.5%, 3%, 4.5%, 6%, 7.5% and 9% cement silica fume replacement at 0.40, 0.45, 0.50 and 0.55 w/b ratios for splitting tensile strength test of concrete. After this, the other specimens, 56 flexure beams, were cast for modulus of rupture or flexural strength test of the concrete with 0%, 1.5%, 3%, 4.5%, 6%, 7.5% and 9% cement replaced with silica fume at 0.40, 0.45, 0.50 and 0.55 w/b ratios. After casting these specimens with proper identification mark showing the date of casting and batch number, they were cured in the water tank at room temperature till their testing on 7th day and 28th day.

Direct tensile test is not standardized and is rarely used because of problem in gripping the specimen properly and also because of no eccentricity of the applied load [13]. Thus, as per ASTM code (C496/C496M - 17) [20], the cylinders were tested for the splitting tensile test in the UTM (Universal Testing Machine) on their maturity period of 7th day and 28th day. The tests were conducted by applying the uniformly distributed load on the longitudinally laid cylinders. Eq. 1 was used for the calculation of splitting tensile strength of specimens.

$$\mathbf{T = 2P/\pi DL} \quad (1)$$

Where, T = Splitting tensile strength, P = Applied Load, D = Diameter of the cylinder and L = Length of the cylinder.

For the purpose of flexural strength, the beams were also tested in the UTM on 7th and 28th day curing. These tests were conducted by applying the two point loading at L/3 from both sides to overcome the bending problem as per codes instructions. The flexural strength was calculated using Eq 2,

$$\boldsymbol{\sigma} = \mathbf{2PL/BD^2} \quad (2)$$

Where, σ = Flexural strength, P = Applied Load, L = Length of the beam, B = Width of the beam and D = Depth of the beam.

After testing, the neck to neck comparison of the results of cylinders and beams of different combinations were performed to evaluate the influence of silica fume on tensile and flexural strengths of concrete.

5. RESULTS AND DISCUSSIONS

5.1. Splitting Tensile Strength

Figures 1, 2, 3 and 4 are showing combined comparison of effect of silica fume and w/b ratios on 7th and 28th day splitting tensile strengths of concrete. It has been noticed that the concrete gains its strength with increasing silica fume content up to 6% to 7.5% for all w/b ratios. Beyond that, further cement replacement with silica fume decreases the concrete strength. The 7th day strength is maximum at around 7.5% cement silica fume replacement for all w/b ratios except 0.55 where it is maximum at 6.0% cement silica fume content (Fig.1, Fig.2). Whereas, the 28th day strength is maximum at around 6.0% cement silica fume replacement for all w/b ratios except 0.50 where it is maximum at 7.5% cement silica fume content (Fig.3, Fig.4). The behaviour of both 7th and 28th day strength loss in virgin as well as silica fumed concrete against w/b ratios is almost linear.

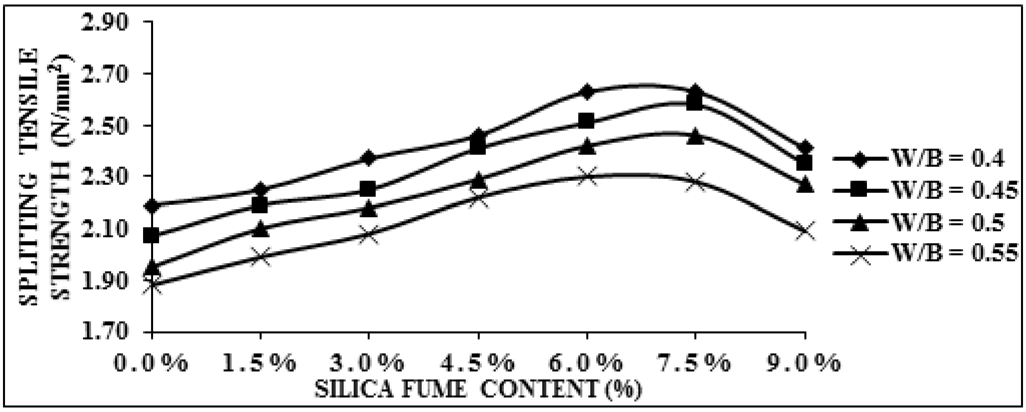

Figure 1 Effect of Silica Fume on 7th Day Splitting Tensile Strength of Concrete at Various W/B Ratios

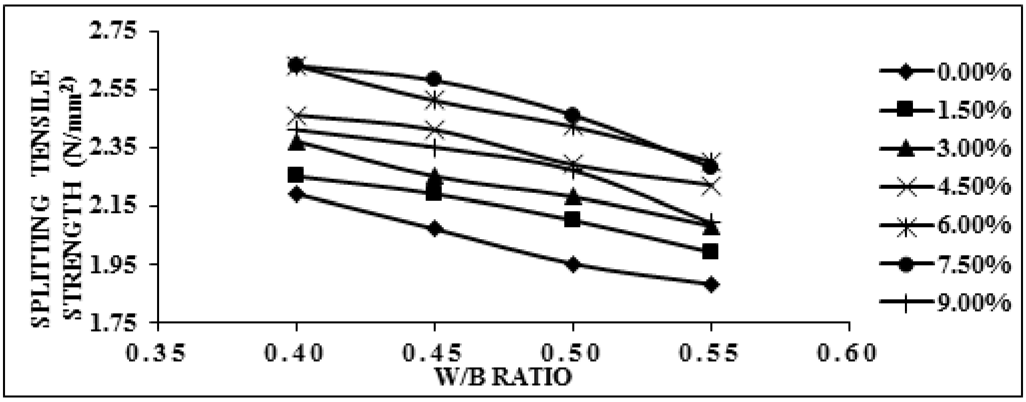

Figure 2 Effect of W/B Ratios on 7th Day Splitting Tensile Strength of Concrete at Various Percentages of Cement Silica Fume Replacement

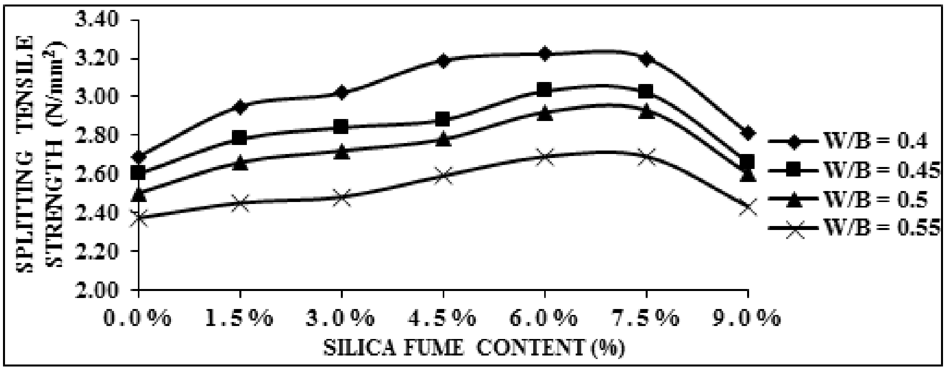

Figure 3 Effect of Silica Fume on 28th Day Splitting Tensile Strength of Concrete at Various W/B Ratios

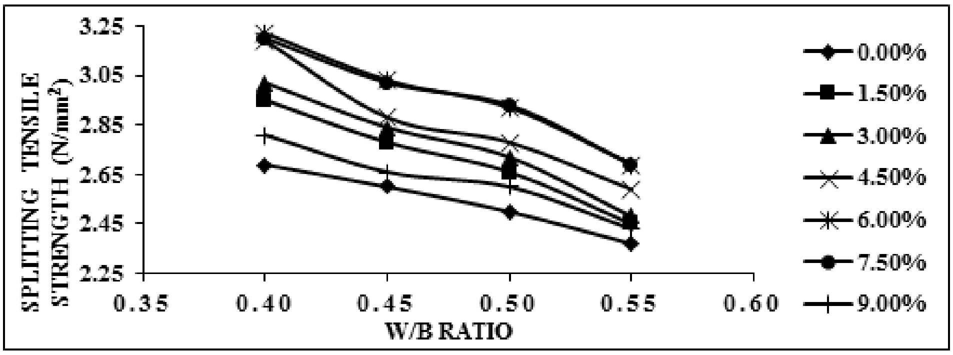

Figure 4 Effect of W/B Ratios on 28th Day Splitting Tensile Strength of Concrete at Various Percentages of Cement Silica Fume Replacement

5.2. Lexural Strength

Combined effect of silica fume and w/b ratios on 7th and 28th day flexural strengths of concrete can be seen in figures 5, 6, 7 and 8. In general, it is observed that the flexural strength of virgin as well as silica fume made concrete decreases with increasing w/b ratios at all silica fume contents on 7th as well as 28th day test results. The 7th day strength is maximized at around 7.5% cement silica fume replacement for 0.40 and 0.45 w/b ratios, whereas for 0.50 and 0.55 w/b ratios, it is maximum at 6.0% silica fume content (Fig.5, Fig.6). On the other hand, the 28th day strength is maximum at 6.0% cement silica fume replacement for all w/b ratios (Fig.7, Fig.8). The general behaviour of figures shows that the gain or loss in flexural strength on 7th as well as 28th day is almost constant with respect to silica fume contents for different w/b ratios.

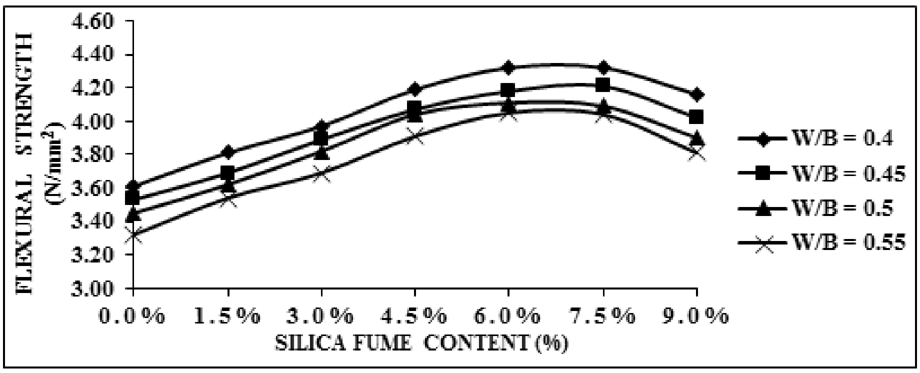

Figure 5 Effect of Silica Fume on 7th Day Flexural Strength of Concrete at Various W/B Ratios

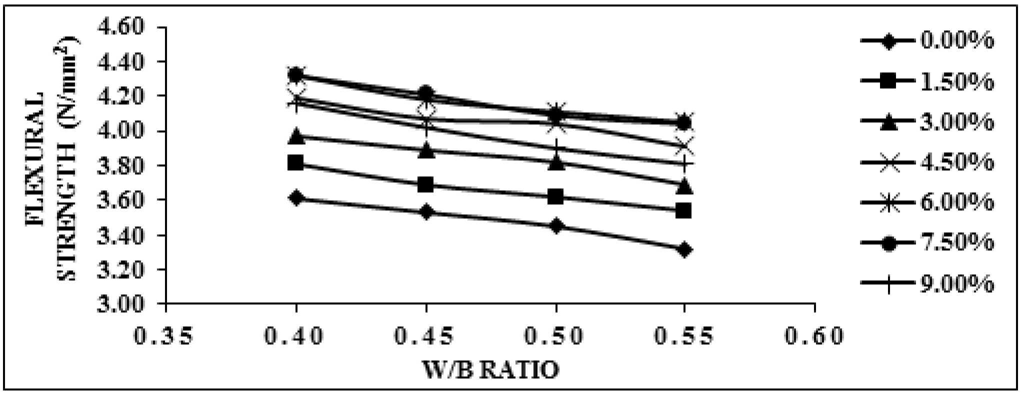

Figure 6 Effect of W/B Ratios on 7th Day Flexural Strength of Concrete at Various Percentages of Cement Silica Fume Replacement

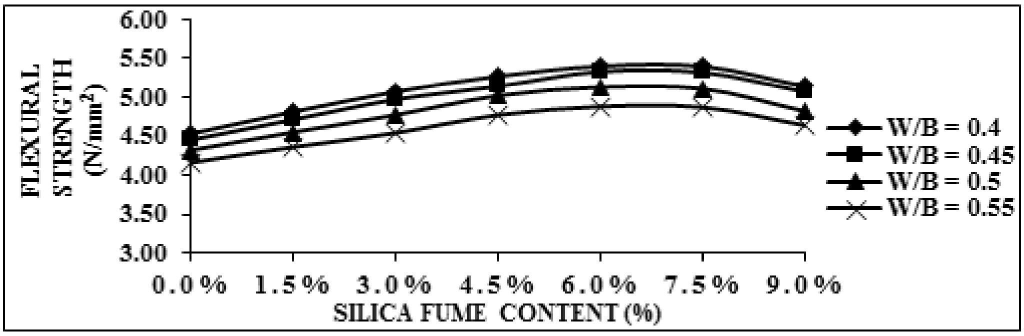

Figure 7 Effect of Silica Fume on 28th Day Flexural Strength of Concrete at Various W/B Ratios

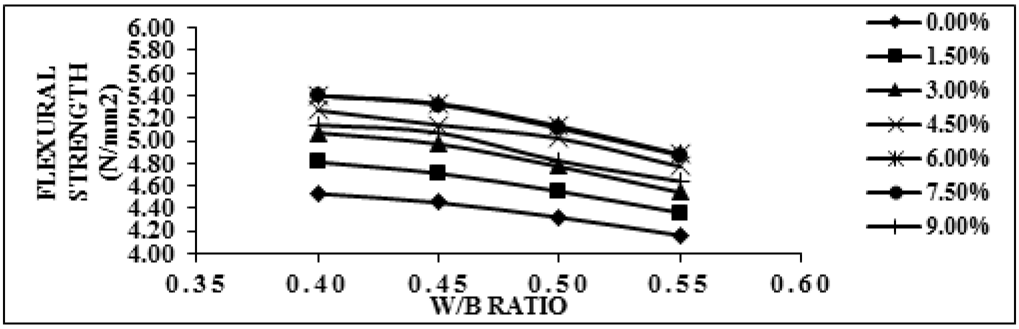

Figure 8 Effect of W/B Ratios on 28th Day Flexural Strength of Concrete at Various Percentages of Cement Silica Fume Replacement

5.3. Results for Percentage Increase in 7th and 28th Day Splitting Tensile and Flexural Strengths at Optimum Cement Silica Fume Replacement:

In this section, the results for percentage increase in 7th and 28th day tensile and flexural strengths for concrete at different w/b ratios have been compared (Table. 7-10; Fig 9-12) by applying the formula,

$$\%\,\boldsymbol{Increase} = \frac{(\textit{Silica Fumed Concrete Strength} - \textit{Normal Cement Concrete Strength})}{\textit{Normal Cement Concrete Strength}} * \mathbf{100} \qquad \textbf{(3)}$$

Table 7 Percentage Increase in 7th day Splitting Tensile Strength at Optimum Cement Silica Fume Replacement

Increase in 7th Day Splitting Tensile Strength (%)					
W/B Ratio	Silica Fume Content			Increase in Strength at 6% Replacement (%)	Increase in Strength at 7.50% Replacement (%)
	0%	6.00%	7.50%		
0.40	2.19	2.63	2.63	20.09%	20.09%
0.45	2.07	2.51	2.58	21.26%	24.64%
0.50	1.95	2.42	2.46	24.10%	26.15%
0.55	1.88	2.30	2.28	22.34%	21.28%

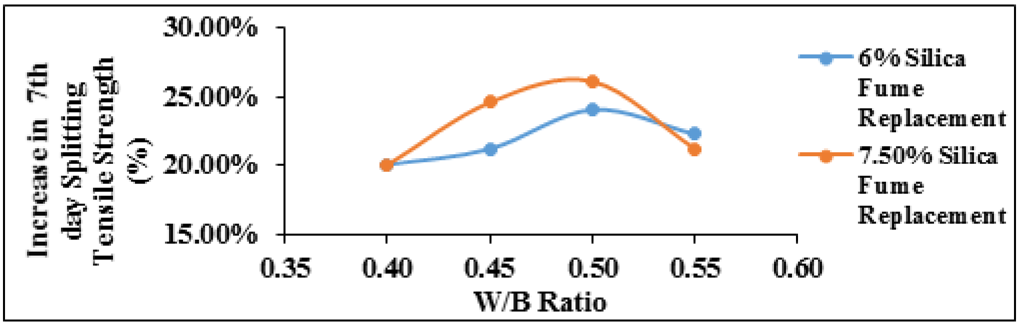

Figure 9 Percentage Increase in 7th day Splitting Tensile Strength at Optimum Cement Silica Fume Replacement

Table 8 Percentage Increase in 28th day Splitting Tensile Strength at Optimum Cement Silica Fume Replacement

Increase in 28th Day Splitting Tensile Strength (%)					
W/B Ratio	Silica Fume Content			Increase in Strength at 6% Replacement (%)	Increase in Strength at 7.50% Replacement (%)
	0%	6.00%	7.50%		
0.40	2.69	3.22	3.20	19.70%	18.96%
0.45	2.60	3.03	3.02	16.54%	16.15%
0.50	2.50	2.92	2.93	16.80%	17.20%
0.55	2.37	2.69	2.69	13.50%	13.50%

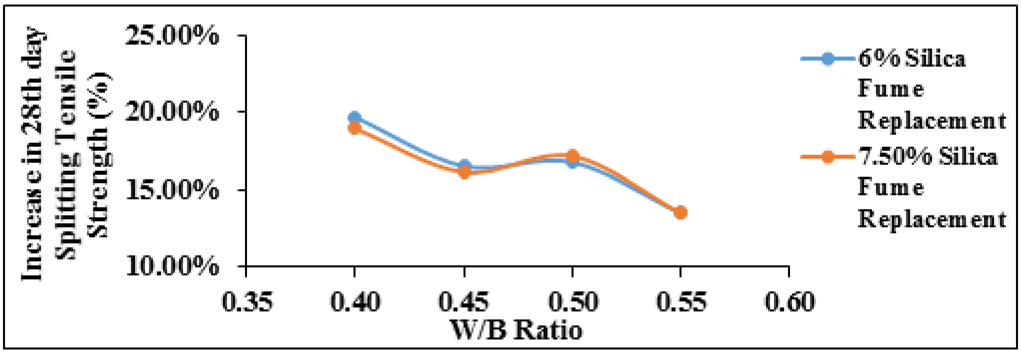

Figure 10 Percentage Increase in 28th day Splitting Tensile Strength at Optimum Cement Silica Fume Replacement

It can be seen that the maximum increase in 7th day splitting tensile strength can occur up to 26% by 7.5% of cement silica fume replacement at 0.50 W/B Ratio (Table. 7, Fig. 9).

Whereas, maximum increase in 28th day splitting tensile strength can be about 20% by 6% cement silica fume replacement at 0.40 W/B ratio (Table.8, Fig. 10).

Table 9 Percentage Increase in 7th day Flexural Strength at Optimum Cement Silica Fume Replacement

Increase in 7th Day Flexural Strength (%)					
W/B Ratio	Silica Fume Content			Increase in Strength at 6% Replacement (%)	Increase in Strength at 7.50% Replacement (%)
	0%	6.00%	7.50%		
0.40	3.61	4.32	4.32	19.67%	19.67%
0.45	3.53	4.18	4.21	18.41%	19.26%
0.50	3.45	4.11	4.09	19.13%	18.55%
0.55	3.32	4.05	4.04	21.99%	21.69%

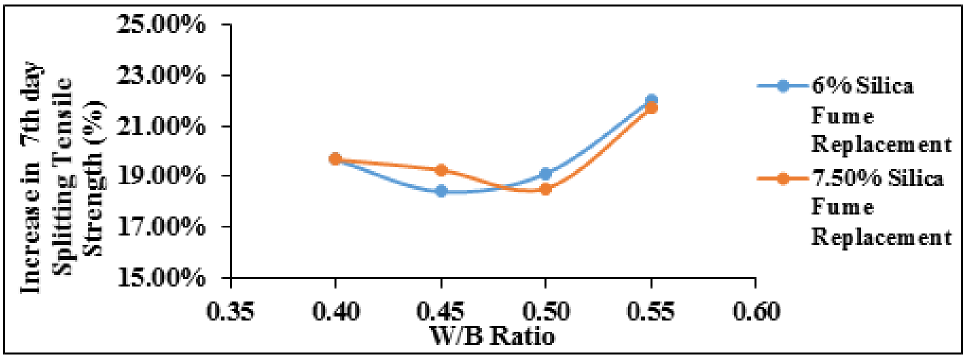

Figure 11 Percentage Increase in 7th day Flexural Strength at Optimum Cement Silica Fume Replacement

Table 10 Percentage Increase in 28th day Flexural Strength at Optimum Cement Silica Fume Replacement

Increase in 28th Day Flexural Strength (%)					
W/B Ratio	Silica Fume Content			Increase in Strength at 6% Replacement (%)	Increase in Strength at 7.50% Replacement (%)
	0%	6.00%	7.50%		
0.40	4.53	5.40	5.40	19.21%	19.21%
0.45	4.45	5.33	5.32	19.78%	19.55%
0.50	4.32	5.13	5.11	18.75%	18.29%
0.55	4.16	4.88	4.87	17.31%	17.07%

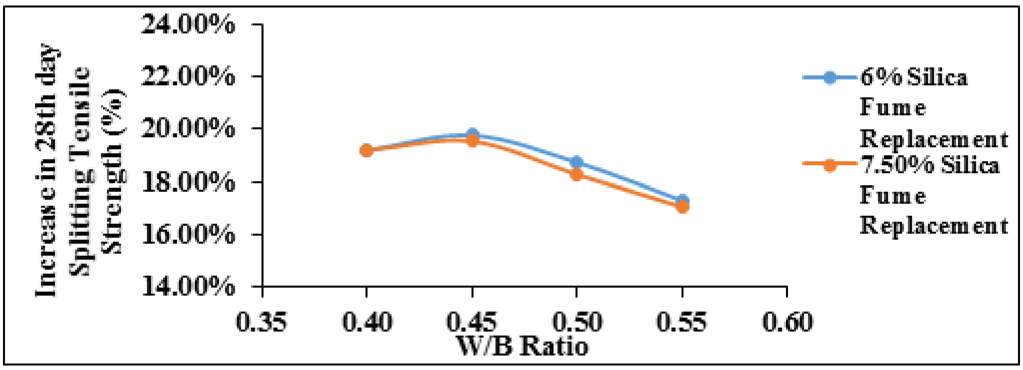

Figure 12 Percentage Increase in 28th day Flexural Strength at Optimum Cement Silica Fume Replacement

From the calculations, it is observed that the maximum increase in 7th day Flexural strength occurs up to 22% by 6.0% of cement silica fume replacement at 0.55 W/B Ratio (Table. 9, Fig. 11). Whereas, maximum increase in 28th day Flexural strength is about 20% by 6.0% cement silica fume replacement at 0.45 W/B ratio (Table.10, Fig. 12).

6. CONCLUSIONS

From the results of the research, following conclusions have been drawn,

- The optimum silica fume content for 7th day splitting tensile strength of concrete is around 7.5% for all w/b ratios except 0.55 where it is 6.0%.
- The optimum silica fume content for 28th day splitting tensile strength of concrete is about 6.0% for all w/b ratios except 0.50 where it is 7.50%.
- The optimum silica fume content for 7th day Flexural strength of concrete is around 7.50% for 0.40 and 0.45 w/b ratios whereas for 0.50 and 0.55 w/b ratios, it is 6.0%.
- The optimum silica fume content for 28th day Flexural strength of concrete is about 6.0% for all w/b ratios.
- The silica fume is more effective for 7th day tensile and flexural strengths of the concrete as compared to that of 28th day strengths.
- The maximum increase in 7th and 28th day splitting tensile strength of concrete can be up to 26% and 20% respectively of the normal cement concrete strength at optimum cement silica fume replacement. Whereas for 7th and 28th day flexural strength, maximum increase can be up to 22% and 20% respectively.

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