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Study on the Effect of Silica Fume on the Properties of Brick Aggregate Concrete

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***Abstract*-The objective of the study is to evaluate the effect of using silica fume on the properties of fresh and hardened concrete made with crushed bricks through experimental investigation. The effect of using silica fume on the workability of concrete due to addition of silica fume was measured by taking the slump of the concrete produced with and without silica fume. The strengths and stiffness were experimentally determined for the hardened concrete. For the hardened concrete, cylinders and prisms of standard dimensions were cast for a particular mix ratio at constant water cement (W/C) ratio with and without adding silica fume. The casted specimens were tested for determining the tensile, compressive and flexural strength of concrete made with crushed bricks as coarse aggregate. From the investigation, it has been found that the workability, strength and modulus of elasticity of concrete increases with the addition of silica fume. It has also been found from the investigation that the enhancement effect using silica fume increases with the age of concrete.**

Keywords-*silica fume; brick aggregate; compressive strength; tensile strength; flexural strength; modulus of elasticity and slump.*

I. INTRODUCTION

Concrete is one of the most versatile and widely used construction materials. Engineers are continually pushing to improve its performance with the help of innovative chemical admixture and supplementary cementitious materials (SCMs).In recent years significant attention has been given to the use of the pazzolanic silica fume, a mineral additive, which enhances the properties and applications of concrete and has been assessed as a partial replacement for Portland cement. Silica fume has also been referred to as silica dust, condensed silica fume or Micro-silica.

The terms of micro-silica, condensed silica fume or silica fume are often used to describe by-products extracted from the exhaust gases of ferrosilicon, silicon and other metal alloy smelting furnaces. However, the terms silica fume and micro-silica are used for referring high quality condensed silica fumes which are used in the concrete industry [3].

Silica fume was first discovered in Norway in 1947, when the environmental controls started the filtering of the exhaust gases from furnaces. The main portion of these fumes is a finely composed of a high percentage of silicon dioxide. As the pazzolanic reactivity for silicon dioxide was well known, many studies have been done on it [14].

Hence, publications are available about silica fume and silica fume concrete. Conforming to AASHTO M 307 or ASTM C 1240, silica fume can be utilized as a material for supplementary cementations to increase the strength and durability [13]. According to the published literatures [2, 3, 4], the quantity of cement replacement with silica fume should be between 7% and 9% by mass of cementation materials.

Silica fume consists of the fine particles with specific surface about six times the cement because its particles are much finer than cement particles. Hence, it has been found that when silica fume mixes with concrete the minute pore spaces decreases. Silica fume is pazzolanic, because it is reactive, like volcanic ash. Its effects are related to different properties of cement such as strength modulus, ductility, air void content, shrinkage, permeability [2].

Silica fume, also called micro silica composed of at least 85% silicon dioxide particle. It is extremely fine, approximately 1/50th the size of an average Portland cement particle and minimum specific surface area 15000 m^2/kg. The specific gravity of silica fume is 2.20 and bulk density varies 200-250 kg/m^3. Advantages of using silica fume are reduction in bleeding and segregation of fresh concrete and improvement in the strength and durability of hardened concrete. It is explained through two mechanisms: pazzolanic reaction and the micro filler effects. Like other pazzolans, silica fume does not have any binding property. When water is added to cement, hydration occurs forming two primary products. The first product is calcium-silicate-hydrate (C-S-H) gel, which is cementations and binds the aggregates together in.

Silica fume can increase workability, because of its very loose bulk density and fine particles [7]. However, it causes other problem such as stickiness, bridging in storage silos, and clogging of the pneumatic transport equipment.

Fig. 1. Package of silica fume in factory

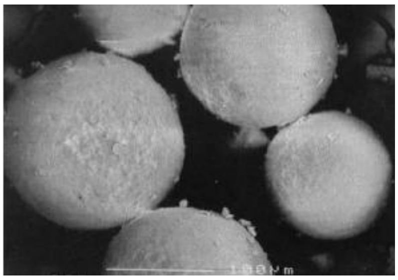

Fig. 2. Scanning electron microscopy of condensed silica fume

Fig. .3. Silica fume colors (Premium-White)

Fig. 4. Silica fume colors (Standard-Grey)

In Bangladesh scarcity and high cost of natural aggregate has led to the use of brick aggregate as substitutes for concrete making. So, it is necessary to investigate the properties of concrete cast with brick chips as coarse aggregate. The effect of using silica fume on the compressive strength of concrete has not yet been addressed. It has not yet verified that whether additional strength can be achieved by adding silica fume. Financial feasibility of using silica fume in the concrete has not yet been judged. The influences of using silica fume on the mechanical properties other than compressive strength, for example tensile strength, flexural strength, modulus of elasticity has not yet to be worked out.

The present study aims primarily at generating information on the physical characteristics and also the compressive, tensile and flexural strengths, including the complete stress-strain response of crushed bricks as coarse aggregate by using silica fume.

II. FACTORS INFLUENCING THE STRENGTH OF CONCRETE

A. Properties of Ingredients in Concrete

The strength of concrete is greatly influenced by the properties of ingredients. The following ingredients are generally used in concrete:

a) Natural Aggregates
b) Cement
c) Silica fume
d) Water
e) Chemical admixture

B. Natural Aggregates

In ordinary structural concrete the aggregate occupy about 70% to 75% of the volume of the hardened mass. Aggregate is important that the aggregate have good strength, durability and weather resistance, that is surface be free from impurities such as loam, silt and organic matter which may weaken the cement past, and that no unfavorable chemical reaction taken place. Natural aggregates are generally classified as:

a) Coarse aggregate
b) Fine aggregate

C. Coarse aggregate

The aggregate most of which are retained on the 4.75 mm IS sieve and contain only that much of fine material which is permitted by the specifications are termed as coarse aggregate. Brick chips had been used as coarse aggregate of maximum size 12 mm in concrete mixes and with grading satisfying ASTM standard requirements of the specifications C136.

D. Fine aggregate

The aggregate most of which passes through a 4.75mm IS sieve and contain only that much coarser material which is permitted by the specifications are termed as fine aggregate. It should be clean and free from organic substances size should be uniformly distributed. Sylhet sand has been used as a fine aggregate which, satisfying the ASTM standard requirements of specifications C136.

*1) Organic content test of fine aggregate***:** This is an approximate method for estimating organic compound contents in the natural sand, and verifies whether it is within the permissible limit. The sand from the natural source is tested as delivered and without drying. A 350 ml graduated clear glass bottle is filled to the 75 ml mark with 3percent solution of sodium hydroxide in water. The sand is added gradually until the volume measured by the sand layer is 125ml. The volume is then made up to 200ml by adding more solution. The bottle is then stopper and shaken vigorously. Roding also may be permitted to dislodge any organic matter adhering to the natural sand by using glass rod. The liquid is then allowed to stand for 24 hours. The color of this liquid after 24 hours is compared with a standard solution.

2) Salinity content test of fine aggregate: Sand won from seashore or from a river estuary contains salt, which can be removed by washing in fresh water. Special care is required with sand deposits just above the high water mark because they contain large quantities of salt .This can be acceding dangerous in reinforced concrete where corrosion steel may result. However, in general, sand from the sea bed which has been washed, even in sea water, does not contain harmful quantities of salts.

E. Cement

Cement is a binding material in concrete mixture. In this project Ordinary (ASTM Type I) Portland Cement (OPC) has been used in making concrete. Specific gravity of OPC ranges from 3.12 to 3.16 and weight 1208 kg/m^3.Its measured fineness by particle size ranges from 10 micron to 50 micron. The normal consistency value of cement had been found between 22 to 30 percent by weight of dry cement. The initial setting time and final setting time had been found34 minutes and 250 minutes respectively. These test method conforms to the ASTM standard requirements of specification C187 and C 191 for normal consistency and setting times respectively.

1) Compressive strength of cement: It is recommended to conduct the strength of cement to be used for the investigation. Among different strength compressive strength of cement is the most important one. To determine the compressive strength, sand cement mortar was prepared for a mix ratio of 1:3 and the quantity of water expressed as water/cement ratio, corresponds to 0.30 by weight. A standard procedure, prescribed by BS 455: part 3: section 3.4 1978, is flowed in mixing, and 70.7mm (2.78 in)cubes are made using a vibrating table with a frequency of 200 Hz applied for two minutes. The cubes are remolded after 24 hours and further cured in water until tested in a wet-surface condition.

2) Tensile strength of cement: The tension test exists in some countries as permitted test for one-day strength of rapid hardened Portland cement, and the details of the test as prescribed in the 1971 edition of BS 12 may be of interest. In this test, a 1:3 cement-sand mortar with a water content of 8% of the weight of the total solids is mixed and molded into a briquette shape. The locally available Sylhet sand was standardized as equivalent to Ottawa sand. The sand consists of pure siliceous material and is practically all of one size; all particles are nearly spherical and smaller than an 850 µm (No. 20 ASTM) sieve and at least 90% of the sand is retained on a 600 µm (No 30 ASTM) sieve.

F. Silica Fume

Silica fume is defined as "very fine non-crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon''. It is usually a gray colored powder, somewhat similar to Portland cement or some fly ashes. It is very high amorphous silicon dioxide content; silica fume is a very reactive pazzolanic material in concrete. As the Portland cement in concrete begins to react chemically, it releases calcium hydroxide. The silica fume react with this calcium hydroxide to form additional binder material called calcium silicate hydrate, which very similar to the calcium silicate hydrate formed from the Portland cement. It is largely this additional binder that gives silica-fume concrete its improved hardened properties.

Chemical properties of silica fume:

- Amorphous
- Silicon dioxide>85%
- Trace elements depending upon type of fume

Physical properties of silica fume:

- Particle size (typical) < 1µm
- Bulk density:
  (as produced): 130 to 430 kg/m^3
  (densified): 480 to 720 kg/m^3
- Specific gravity: 2.2
- Specific surface: 15,000 to 30,000 m^2/kg

G. Water

Water is an important ingredient of concrete as it activity participates in the chemical reaction with cement, to wet the aggregate and to lubricate the mixture for easy workability, since it helps to form the strength giving cement gel. The quantity and quality of water is required to be looked in to very carefully. Water having harmful ingredients, contamination, salt, oil sugar or chemical is destructive to the setting properties of the cement. It can disrupt the affinity between the aggregate and cement paste and adversely affect the workability of mixture. In this study drinking water was used in mixing of concrete.

H. Chemical Admixture

Admixture are the materials other than the basic ingredients of concrete; cement water and aggregate; added to the concrete mix immediately before or during mixing to modified are that ratio on the specific properties of concrete in the fresh or hardened state. The properties commonly modified are that ratio of hydration or setting time, workability, dispersion and air-entertainment. Some important purpose for which the admixtures could be used for:

- To accelerate the initial set of concrete
- To increase the strength of concrete
- To improve the workability
- To reduce the heat of hydration
- To increase the durability of concrete

Admixture are widely used in the production of high strength concrete .These materials includes air entraining agent chemical and mineral admixtures. We used DARACEM-100 Super Plasticizer as admixture in the study. High range water reducing admixture (HAWR) is sometimes called super plasticizer. The optimum admixture percentage should be determined on trial and adjustment Basis as they can reduce the water demand by almost 30 to 35% with a corresponding increase in compressive strength. A slump of 2 inches is considered adequate. If however, no HRWR admixtures are used, the slump should increase 2 to 4 inches.

III. WATER CEMENT RATIO AND ITS EFFECTS ON CONCRETE PROPERTIES

The proportion between the amount of water and cement used in concrete in a concrete mix is termed as water cement ratio. The water in the concrete does primarily three following functions:

- To wet the surface of the aggregate
- To improve workability
- To combine chemically with cement

Water is needed wetting of the aggregate, as the water is added to the fluidity of the mix increases consequently causing larger volume of void created by the free water. To reduce the free water while retaining the workability, admixture must be added. Therefore the water cement ratio is the chief factor, which controls the strength of concrete.

A. Workability of Concrete

Where structures are heavily reinforced consequently concrete had to be workable enough to be placed and compacted through dense reinforcement. Such cases are mat by high strength concrete. Therefore it needs high workability.

According to research laboratory, U.K workability of concrete is defined as the property of the concrete, which determine the amount of usual internal work necessary to produced full compaction. The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are given below:

a) Water cement ratio
b) Size of aggregate
c) Surface texture of aggregate
d) Use of admixture
e) Mix proportion
f) Shape of aggregate
g) Grading of aggregate
h) Slump test

1) Slump test: Silica fume concrete is very cohesive and behaves somewhat differently than conventional concrete. A given slump will not be same workability for concrete with and without silica fume. In case of silica fume, slump increase about 40 mm to 50 mm to achieve the same workability. A good rule of thumb for silica fume concrete is to place it at as high a slump as possible for the placement. Using a higher slump will make closing the surface and achieving the desired finish much easier. Frequently, for bridge decks or parking structure flatwork, the slump will be determined by the slope of the structure.

IV. EXPERIMENTAL INVESTIGATION

In the experimental program, volumetric batching had been used for measuring the materials. It is recommended that silica fume should not be provided before any other ingredients. To fully utilize the effects of silica fume is to ensure that the silica fume is uniformly dispersed throughout the concrete. In this study concrete mixing had been done by tilting type mixture. Speed of the mixture was about of 15 to 20 revolutions per minute. Mixing time was 5to 6 minutes and Silica fume concrete had been successfully placed cast in situ. Also hand compaction had been done according to ACI code. If silica fume concrete mixtures are given seven days of continuous wet curing, there is no association between silica fume content and cracking. Structural design is generally based on the 28 days strength, about 70 percent of which is reached at the end of the first week after placing concrete. Test specimens were immersed in curing tank for 28 days. For each mix, the following specimens were made: (4 X 8) inch cylinders for both compressive strength and splitting tensile strength determination and (6 X 6 X 18) inch beams for flexural strength determination.

V. TEST RESULTS AND DISCUSSIONS

Testing of concrete plays an important role in controlling and confirming the quality of cement concrete work. To perform the study a total of 36 cylindrical specimens, 18 prisms specimens were casted. Among 36 standard size cylinders, 18 cylinders were tested to determine the compressive strength and modulus of elasticity of concrete and 18 cylinders were tested to determine the split tensile strength. 18 prisms were tested to find out the flexural strength of concrete. Curing periods for test specimens were 7, 28, 60 days with normal water.

A. Properties of Concrete without and with Silica Fume

A variation of different properties of concrete strength was observed with the presence of silica fume for hardened concrete. For freshly mix concrete there is also a deviation in slump size was detected between concrete without silica fume and concrete with silica fume. The following table shows the variation of Slump and concrete strength as obtained from experimental investigation.

TABLE I. SLUMP OF FRESH CONCRETE

Weight of silica fume per bag cement (kg)	Slump (mm)
0	54.61
5	58.42

TABLE II: SUMMARY OF THE PROPERTIES OF THE CONCRETE MADE WITH AND WITHOUT SILICA FUME

Age of concrete (Days)	Compressive Strength (MPa)		Modulus of elasticity (MPa)		Tensile Strength (MPa)		Flexural Strength (MPa)	
	(with silica fume)	(without silica fume)	(with silica fume)	(without silica fume)	(with silica fume)	(without silica fume)	(with silica fume)	(without silica fume)
7	28	25	25.53	17.62	1.98	1.9	8.57	8.18
28	40	33	45.84	40.5	2.57	2.356	9.15	8.30
60	43	35	77	74	3.1	2.58	9.54	8.57

B. Effect of silica fume on stress-strain relationship of concrete

Fig.5. represents the variation of stress-strain diagrams of concrete with and without silica fume. From the figure, it is seen that with the increase of strain stress increases for both the cases up to a certain limit of strain and a distinct peak can be seen for both the concrete. However, the concrete with silica fume shows larger stress at any level of strain. It means that use of silica fume has a positive impact on the stiffness of concrete. Hence, the modulus of elasticity of concrete at 7 days has found to increase at 7 days. Similar trend can also be seen from Fig. 6. and Fig. 7.

Fig.8. demonstrates the improvement in the compressive strength of concrete at different ages with and without silica fume. It is observed that the compressive strength of concrete is increasing moderately up to 28 days and after 28 days it is found that the variation of stress is raising gradually for both with and without silica fume.

The results of flexural strength of concrete with and without silica fume represents in fig. 9. The test was carried out conforming to obtain the flexural strength of concrete with and without silica fume at 7, 28 and 60 days. It is seen that from the figure the value of stress corresponding to the strain is higher with silica fume than that of without silica fume.

The splitting tensile strength test results of various mixes concrete with and without silica fume at 7, 28 and 60 days are given in fig. 10. From the figure, there is an increase in splitting tensile strength with the increase in silica fume contents; however, the maximum increase in split tensile strength is obtained at 28 days. The trend in splitting tensile strength with silica fume content is similar to that in the case of compressive strength.

From Fig.11, it has been observed that the modulus of elasticity increases with the age of concrete linearly for both the concrete with and without silica fume. This is a fact because, the modulus is directly related to compressive strength of concrete, and it has been found that the compressive strength increases with age of concrete.

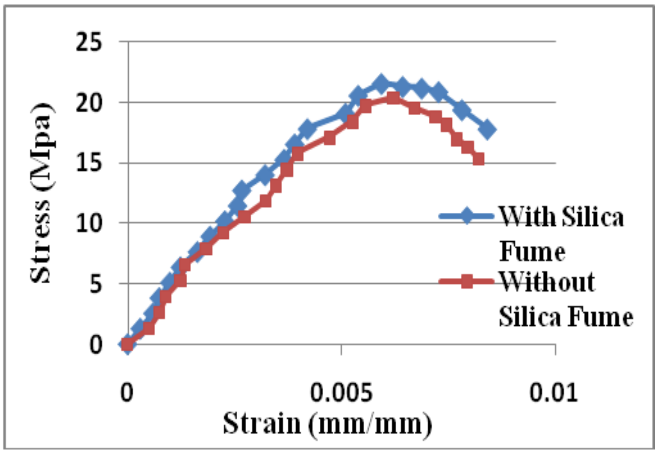

Fig. 5. Stress-Strain curve of concrete at 7 days

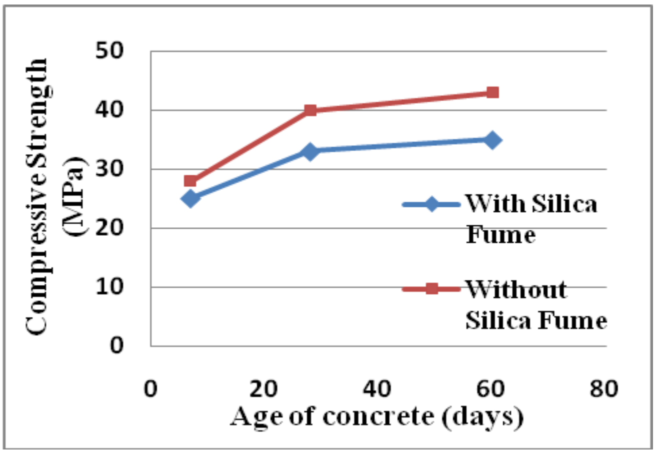

Fig. 8. Effect of Silica Fume on Compressive Strength of concrete

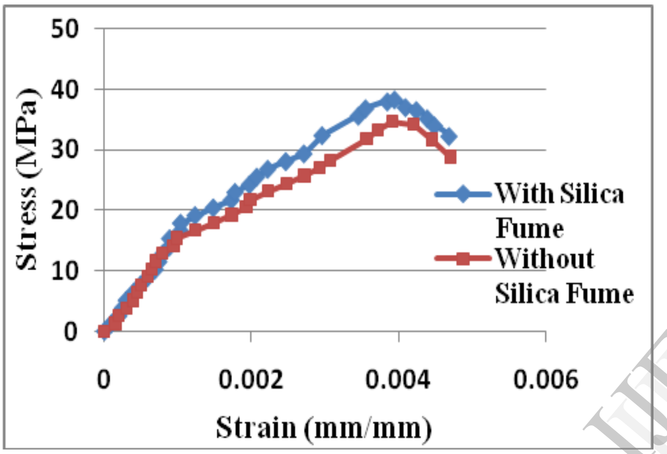

Fig. 6. Stress-Strain curve of concrete at 28 days

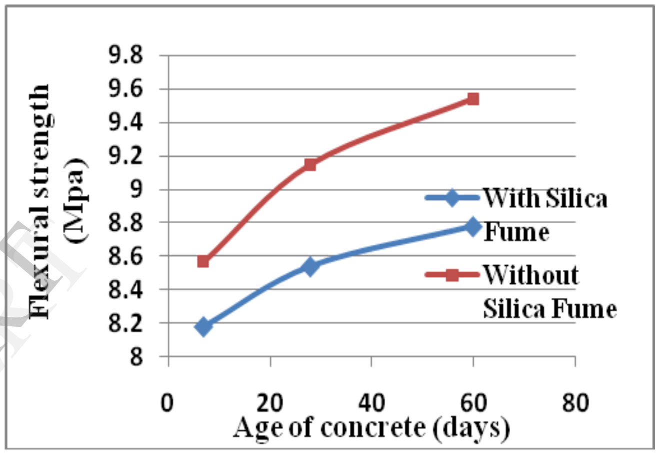

Fig. 9. Effect of Silica Fume on Flexural Strength of concrete

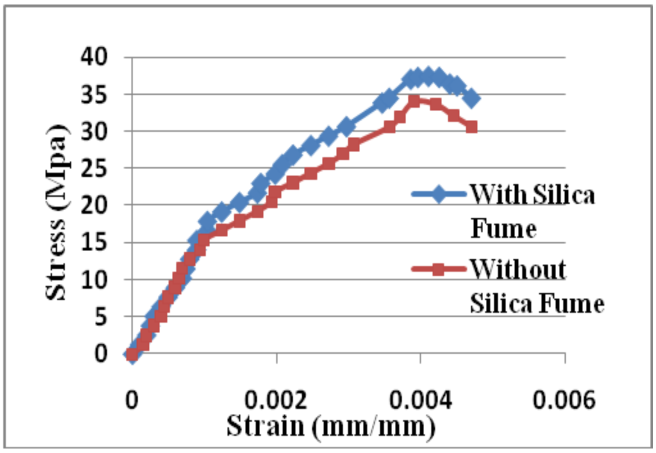

Fig. 7. Stress-Strain curve of concrete at 60 days

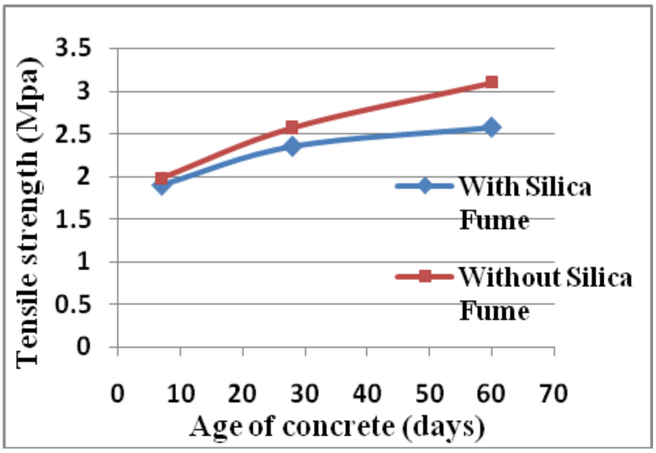

Fig. 10. Effect of Silica Fume on Tensile Strength of concrete

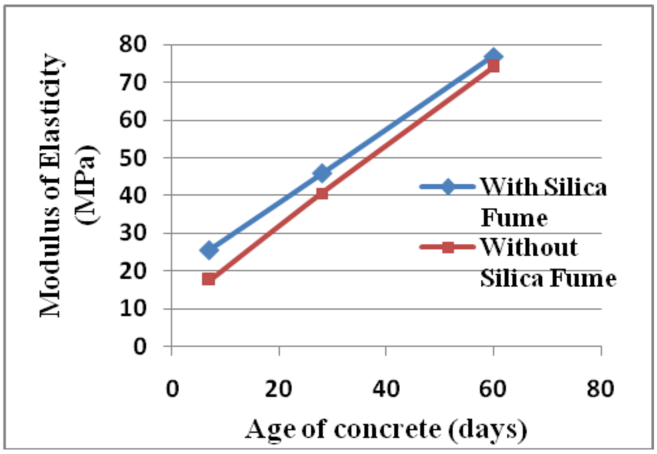

Fig. 11. Effect of Silica Fume on Modulus of Elasticity of concrete

VI. CONCLUSION

The following conclusions may be drawn from the study:

(1) The slump of concrete with silica fume was increased by 7% from the same concrete without silica fume.

(2) Due to addition of silica fume, an amplified compressive strength was observed at 7days, 28 days and 60 days by 12%, 21.2% and 22.9% respectively than that of the concrete without silica fume.

(3) An increased value of modulus of elasticity has been found at 7 days, 28 days and 60 days. The increment was 8.6%, 9.1% and 14.3% respectively with silica fume than that of the concrete without silica fume.

(4) The split tensile strength has been increased at 7 days, 28 days and 60 days by 4.2%, 9.1% and 8.8% respectively with silica fume than that of the concrete without silica fume.

(5) It has been found that flexural strength has increased at 7days, 28 days and 60 days by 4.7%, 10.6% and 11.3% respectively with silica fume than that of the concrete without silica fume.

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