EFFECT OF SILICA FUME ON THE COMPRESSIVE STRENGTH OF CEMENT-SILICA FUME MORTARS

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ABSTRACT

This paper reviews the recent developments and present state of the application of silica fume (Cement-silica) and nano-silica for sustainable development of concrete industry. This would save not only the natural resources and energy but also protect the environment with the reduction of waste material. Limited work is done on use of cement-silica and micro silica in paste, mortar and concrete and whatever work is available is highly contradictory about their influence on mechanical strength development and durability properties. Various literatures have been reviewed to understand the influence of micro and nano-silica on fresh, hardened and micro structural properties of paste, cement mortar and concrete. Taking advantage of nanostructure and microstructure characterization tools and materials, the simultaneous and also separate optimal use of cement-silica and nano-silica will create a new concrete mixture that will result in long lasting concrete structures in the future.

Key words: Cement, Silica, compressive strength, mortar, Pozzolana

1. INTRODUCTION

Silica fume is a new pozzolanic material that has received a great amount of attention recently. In recent years , a number of organizations have become increasingly involved in research aimed at energy conservation in the cement and concrete industry . This in part, is being accomplished by encouraging the use of cementitious materials such as fly ash, slag and pozzolans. Lately, some attention has been given to the use of silica fume, as a possible partial replacement for Portland cement. This interest is due to the availability of this material in various countries, and to the strict enforcement of pollution control measures to stop dispersing the material into the atmosphere. Further more , the availability of high range water-reducing admixtures(super plasticizers) has opened up new possibilities for the use of silica fume as a part of the cementing material in concrete and mortars to produce very high-strength concrete mortar or high durable concrete and mortars. Unlike natural pozzolans and fly ash, the silica reaction involving silica fume is rapid and therefore, a long curing period is not necessary. Investigations on the performance of silica fume in concrete and mortars have been conducted in Scandinavian Countries, particularly in Iceland, Norway, and Sweden, where the material has been in use on limited scale since 1976. In North America some data on the use of silica fume has been classified as a pozzolan by the American Concrete Institute (ACI) Committee 226 on cementitious materials (ACI 1987). ASTME 618 recognizes three classes of pozzolan: N, F, and C.Silica fume is somewhat closer to the N Class.

Silica fume is a by product resulting from the reduction of high purity quartz with coal, in electric arc furnaces in the production of silicon and ferro-silicon alloys. The material, which contains more than 80% of silica in non crystalline state in the form of extremely fine particles, is highly pozzolanic .It is also collected as a by product in the production of other silicon alloys such as ferro chromium, ferro magnesium and Calcium Silicon. In 1981, the world production of silica fume was estimated to be 10 million metric tons, with Norway and United States as leading producers accounting for 1,

20,000 tons each. In 1983, the United States, Norway, France, Switzerland, and West Germany produced 140, 113, 75, 50, and 42 thousand metric tons of silica fume respectively .Due to the rapidly changing status of steel industry in many countries of the world the production rates in the future are likely to increase significantly. Silica fume which contains more than 80 to 85% Sio_2 in the amorphous form is suitable for use in the cement and concrete industries. The average size of the spheroidal particles is of the order of 0.1 micron metre, which is about two orders of magnitude finer than particles of ordinary Portland cement. Being composed of essentially non-crystalline Sio_2 in a finely divided State. Silica fume exhibits excellent pozzolanic characteristics.

Depending on the type of silicon alloy produced and the design of furnace the physico-chemical properties of the silica fume may vary. The chemical composition of silica fume is related to the prinicipal product made by the furnace. Generally, a furnace equipped with heat recovery system produces silica fume with lower carbon content. The carbon content generally varies from 0.5 to 1.5%, unlike other by-product pozzolans; silica fume from a single source has little or no variation in chemical composition from one day to another. The specific gravity of silica fume from silicon meta or ferro silicon alloy industries is close to that of amorphous silica , that is approximately 2.2.Many researchers observing through electron microscope, reported that the material is composed mostly of spherical particles of 0.001 to 0.3µm.Generally, the particles exist in the form of agglomerated structure are responsible for difficulty in handling the material and for the high water requirement to make slurry with a workable consistency.

2. LITERATURE REVIEW

Pozzolans are siliceous and aluminous materials, which in the presence of moisture and at ordinary temperature , can react with $Ca(OH)_2$ or (CH*) to form strength contributing cementations products, such as calcium silicate hydrates(C-S-H),Calcium aluminate hydrates(C-A-H),and Calcium sulphoaluminate hydrates(C-S-A-H).The CH is one of the products of hydration of Portland cement and constitutes about 20 percent of the volume of the hydration products. Materials such as colloidal silicas (0.5µm to 0.0005µm in size) behave like pozzolans and their pozzolans and their pozzolanic nature is now well established usually, the percentage of CH consumed by silica fume has been used as an index of the pozzolanic activity of silica fume. Contradictory data have been obtained with respect to the percentage in a Portland cement paste with 10 percent silica fume liberated CH was consumed by the silica fume. In Contrast, Buck and Burkes have reported high pozzolanic activity in Portland cement silica fume pastes in which all the CH liberated was consumed by silica fume at 28 days. Sellevoid and Co-workers have studied paste of cement with silica fume by X-ray diffraction quantitative analysis (QXRD).Thermo gravimetric analysis (TGA), mercury porosimetry and other methods. They have reported a very reactive pozzolanic reaction; an addition of 24 percent of silica fume by weight of cements being enough to consume all the CH.

Nelson and Young have studied the pozzolanic activity of colloidal silica added to C_3S and Portland cement (ASTM 1) pastes. The colloidal silica had a 99.8 percent content of amorphous Sio_2 while their surface areas ranged from $174m^2/g$ to $430m^2$ /g. The addition of amorphous silica to the C_3S pastes varied from 25 percent to 75 percent of the theoretical amount required to convert all the CH to C-S-H according to the following two equations.

$$2C_2S + 6H \rightarrow C_3S_2H_3 + 3CH$$
$$3CH+2S \rightarrow C_3S_2H_3$$

By TGA the amount of CH, expressed as a percentage of the weight of the original C_3S, was determined at different ages. A 14 percent reduction in CH content was found at 3 days with the 25 percent addition of amorphous silica, while for 75 percent addition the reduction was 73 percent. Even greater reductions in the content of CH were found with Portland cement pastes. For example, with a 25 percent addition of amorphous silica a 65 percent reduction in CH content with respect to the control paste was found at one day of curing. Based on the above experimental results, Nelson and Young have concluded that amorphous silica of colloidal dimensions act as very reactive pozzolans and the pozzolanic reaction may be evident as early as the first day of curing. The paper represented by cheng-yi and Feldman, it was shown that

hydration reaction in Portland cement is accelerated in the presence of silica fume particles because of their reaction Ca^{2+} ions and their ability to act as nucleation sites for CH. This reaction occurs within minutes after contact with water and the reduced Ca^{2+} ions affects the nature of the hydration products, pozzolanic reaction in this study occurred as early as 8 hours.

The addition of silica fume to Portland cement pastes, mortars, or concretes improves the strength development of the Portland cement mixes. It is on this basis of strength improvement, that silica fume has been claimed to be highly pozzolanic. There are three mechanisms suggested to explain the strength enhancement capability of silica fume due to pozzolanic reaction process and they are discussed in the following sections strength enhancement by non-pozzolanic activities have also been suggested and will be discussed as well.

Strength enhancement by pore-size refinement and matrix densification: Mehta studied the strength development characteristics of Portland-pozzolan cement pastes. Volcanic ash (Santorin Earth) was used as the pozzolanic material .This material resembles silica fume (65 percent content of Sio_2, $15m^2/g$ surface area). Three Portland pozzolanic cements were made with the pozzolan replacing 10, 20, & 30 percent by weight of cement, respectively. The water/cement ratio of the pastes was 0.50, compressive strength tests were made according to ASTMC-109.Also a pore-size distribution analysis was carried out by mercury penetration technique. The compressive strength tests showed that the paste containing 10 percent pozzolan exhibited the higher strength (6 percent over the control) 28 days. In one year, the paste with 20% pozzolan content had the higher strength, a 10 percent increase over the controlled Portland cement paste. These strength characteristics could be explained in terms of the pore-size distribution of the hydrated pastes. The higher strength achieved by the paste containing 10 percent pozzolan, at 28 days, was attributed to the low volume of large pored(>0.1μm) present in the paste at 28 days. Also, the higher strength achieved by the paste with 20 percent pozzolan after 1 year was attributed to the absence of large pored and the large volume of small pores (<0.05μm).

Based on these results, it was concluded that the volume of large pored, not the total porosity, adversely affect the strength of the hydrated cement pastes. More-over, the transformation of large pores into finer pores – pore refinement, as a result of the pozzolanic reaction, played an important role in enhancing the strength of Portland pozzolanic cements.

The contribution to strength increase by the pozzolanic reaction mechanism has been viewed differently by Scrivener and Co-workers. CH crystals in Portland cement pastes are a source of weakness because cracks can easily propagate through or within these crystals without any significant resistance. In the presence of pozzolanic reaction, the reduction in the content of CH leads to an increase in strength. Thus, strength increase is not due to increase in C-S-H gel formation or reduction of pores but simply to reduction in CH content. In concrete the characteristic of the transition zone between the aggregate particles and the cement paste plays a very significant role in the cement-aggregate bond. Even though the effect of this bond on concrete performance is a subject of controversy, its significance on the mechanical properties and durability had been established. Not all investigators agree that pozzolanic reaction activity is the source of strength enhancement. Chatterji and Co-workers have examined the hydration characteristics of Portland cement – silica pastes and concretes by X-ray diffraction (XRD). The silica fume content varied from 16 to 30 percent by weight of cement and the water/cement ratio ranged from 0.40 to 1.0. The XRD results showed that CH was present in the pastes for at least up to 4 months and up to 2 years in the concrete mix. It was noticed that 30 percent silica fume could not consume the CH liberated by 70 percent Portland cement even though the curing temperature was 50ºC. The absence of CH from one of the pastes after 5 days of curing was attributed by the investigators to the lack of water due to low water/cement ratio. As a result, chatterji and co-workers have concluded that the strength improvement achieved by silica fume to mortars or concretes must be due to the physical nature of the product and not to its pozzolanic activity.

3. EXPERIMENTAL INVESTIGATIONS

The experimental programme is designed to study the behaviour of cement mortar and cement-pozzolana composite mortar of various proportions with respect to certain variables namely mix proportion, percentage of pozzolana (silica fume), water content and age. The details of test specimens are furnished in the following articles.

Selection of mixes:

The mix proportions chosen are 1:6, 1:8 and 1:10. These mortars are used for masonry works like stone masonry, brick work and foundations.

Cement –Sand Mortars:

For the purpose of comparison of strength of cement-silica fume-sand cubes with that of cement-sand mortar cubes, a total of 36 numbers of cement mortar cubes were casted and tested at 7, 14, 21 and 28 days. The specimens were made with three different mix proportions like 1:6, 1:8 and 1:10, the water content is used for 1:6 mix is 16% for 1:8 mix water content is 18% and for 1:10 mix the water content is 19%. The above water contents are obtained by constructing small brick masonry walls in the laboratory. For each mix proportion the water content is increased from the water content (12%) obtained from consistency of cement paste to a water content that will give workable mortar for constructing brick masonry wall.

Cement- silica fume-sand mortars:

144 Nos. of cement-silica fume sand cubes were made with three mix proportions of 1:6, 1:8 and 1:10 it is 16%, 1;8. The cement is replaced in pozzolana (Silica fume) is increase from 0%, 5%, 10%, 15% and 20% by weight for each mix. The water content is used for 1:6 it is 16%, 1:8 it is 18% and 1:10 it is 19%. There is no change in the water content due to the replacement of cement by silica fume. The mortar is workable and no extra water is added.

Materials used:

Cement:

The cement used in the experimental work was procured in a single consignment and properly stored. The type of cement was ordinary Portland cement (confirming to IS 650-1966) with 43 grade.

Sand:

Locally available sand was sieved by using different sieve and the particles of different sizes were mixed in the required proportion.

Silica fume:

Silica fume which contains more than 80 to 85 % Sio_2 in amorphous form is suitable for use in cement and concrete industries. The material consists of extremely fine spheroidal particles with an average size of 0.1 μm which is about two orders of magnitude fine than particles of ordinary Portland cement. Silica fume, because of its extreme fineness and high silica content is a highly effective pozzolanic material.

The properties of the silica used are as follows:

Property	Value
Specific gravity Fineness by wet	1.84
Sieving on 45 μ sieve	5.04
Lime reactivity	2.34 Mpa
Compressive strength	14.35 Mpa (7 days)
Initial setting time	40 minutes
Final setting time	143 minutes
Loss of ignition	10%
Soundness	11.4%

The tests to determine the above properties were conducted in accordance with IS: 1727 – 1967

Water:

Potable water was used for mixing and curing purposes.

Test for determination of compressive strength:

Preparation of Test Specimens:

Size of specimens – the test specimens shall be in the form of cubes having area of face equal to 50 Sq.cm.

Cube Moulds: Moulds, for the cube specimens of 50 Sq.cm.face areas, shall be metal not attacked by cement mortar, and there shall be sufficient material in the sides of the mould to prevent spreading and warping. The moulds shall be rigidly constructed in such a manner as to facilitate the removal of the moulded specimen without damage. The moulds shall be machined

so that when assembled ready for use, the dimensions and internal faces shall be accurate to the following limits. The height of the moulds and the distance between the opposite faces shall be 70.60 mm +0.15/-0.10 mm. The angle between adjacent interior faces and between interior faces of the moulds shall be plane surfaces with a permissible variation of 0.15mm. Each mould shall be provided with a base plate having a plane surface machined to tolerance 0.15mm and made of non absorbent material, preferably metal not attacked by cement mortar. The base plate shall be of such dimensions as to support the mould during the filling without leakage.

The weight of the cube mould shall be such that the total weight of the machine and cube does not vary from the total approximate weight of 30 Kg. The parts of the mould when assembled shall be positively held together. And suitable methods of ensuring this, both during the filling and on a subsequent removal of the filled mould from the vibration machine, shall be provided in order to prevent the mould specimen from damage.

Mix Proportions and Mixing:

Clean appliances shall be used for mixing and the temperature of the water and that of the test room at the time when the above operations are being performed shall be 27+-2 degrees centigrade. Place on a nonporous plate a mixture of cement and standard sand in the required proportion by weight. Mix it dry with a trowel for one minute and then add water until the mixture is of uniform colour. The time of mixture shall in any event be not less than 3 min and should the time taken to obtain a uniform colour exceed 4 min, the mixture shall be rejected and the operation repeated with a fresh quantity of cement, sand and water.

Moulding Specimens:

In assembling the moulds ready for use, cover the joints between the halves of the mould with a thin film of mould oil jelly and apply a similar coating of mould oil jelly between the contact surface of the bottom of the mould and its base plate in order to ensure that no water escapes during vibration. Treat the interior faces of the mould with a thin coating of mould oil.

Place the assembled mould on the table of the vibration machine and firmly hold it in position by means of a suitable clamp, securely attach a hopper of suitable size and shape at the top of the mould to facilitate filling and this hopper shall not be removed until completion of the vibration period. Immediately after mixing the mortar, place the mortar in the cube mould. The mortar shall be prodded 20 times in about 8 sec to ensure elimination of entrained air and honey Combing. Place the remaining quantity of mortar in the hopper of the cube mould and prod again as specified for the first layer and then compact the mortar by vibration. The period of vibration shall be two minutes at the specified speed of 12000+-400 vibrations per minute. At the end of vibration remove the mould together with the base plate from the machine and finish the top surface of the cube in the mould by smoothening the surface with the blade of trowel.

Curing of specimens:

Keep the filled moulds at a temperature of 27+-2 degree centigrade in an atmosphere of at least 90 percent relative humidity for 24 hrs completion of vibration. At the end of that period remove them from the moulds and immediately submerge in clean fresh water and keep these until taken out just prior to testing. The water in which the cubes are submerged shall be changed every 7 days and shall be maintained at a temperature of 27+-2 degree centigrade. After they have been taken out and until they are tested the cubes shall not be allowed to become dry.

Testing:

Test three cubes at the periods mentioned, the periods being reckoned from the completion of vibration, are tested under axial compression. The compressive strength shall be the average of the strengths of the three cubes for each periods of curing. The cubes shall be tested on their sides without any packing between the cube and the steel plates of the testing machine. One of the platens shall be carried on a base and shall be self-adjusting, and the load shall be steadily and uniform applied, starting from zero at a rate of 350 Kg/Cm^2/min.

4. RESULTS AND DISCUSSIONS

The increase in compressive strength is due to mainly of two phenomena, one physical and one chemical. The physical phenomenon acts immediately, at early ages when the chemical phenomenon is still latent. According to some researchers (Detwiler & Mehata 1989) this physical phenomenon is due to the silica's fineness its large specific surface and to the fact

that its particles fill the existing spaces between the various granules of cement, and hose between the cement paste and the aggregate which are rich in exuded water and calcium hydrate (Monteria 1985). Later, the chemical reaction between the silica fume and the calcium hydrate also comes into action, producing hydrated calcium silicate which occupies a large space to that of the two reagents, so reducing the porosity of the mortar. The test result are given in graphs for three different mixes 1:6 with 16 percent water content, 1:8 mix with 18 percent water content and 1:10 mix with 19 percent water content. In each mix five different percentages of replacement of cement with silica fume by weight (0, 5, 10, 15 and 20) are considered and presented in figure 1, 2 and 3. In each percentage of replacement of cement by silica fume 3 cubes are tested at four different ages i.e. at 7 days, 14 days, 21 days and 28 days.

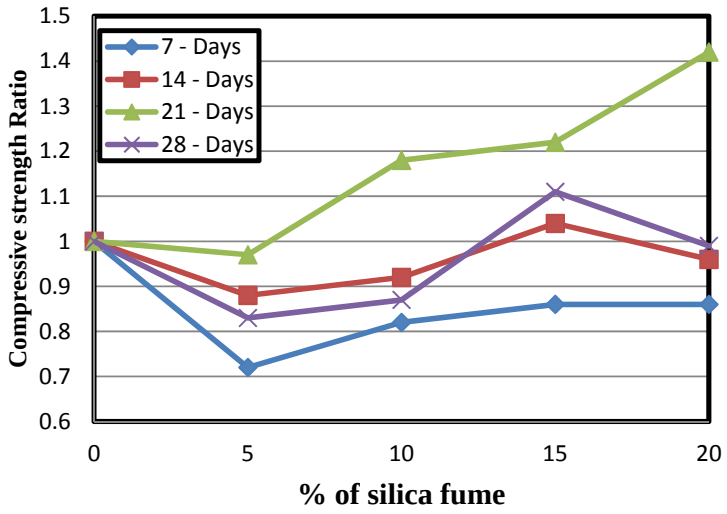

Figure.1. Compressive strength ratio vs percentage replacement of cement by silica fume for 1:6 mix

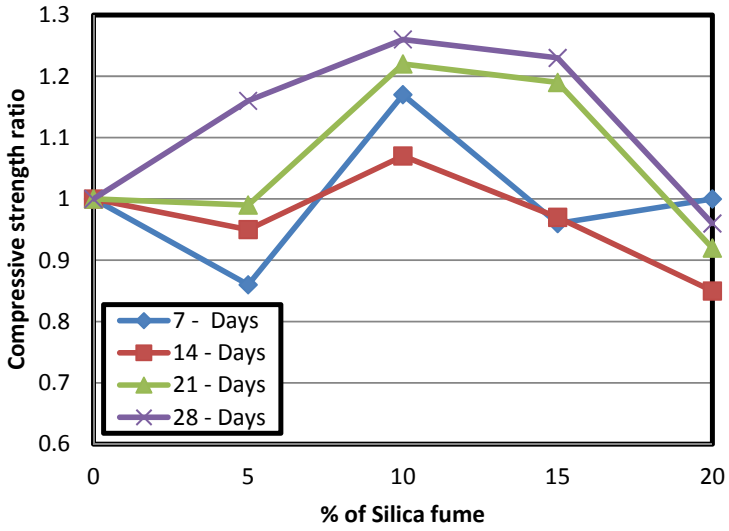

Figure.2. Compressive strength ratio vs percentage replacement of cement by silica fume for 1:8 mix

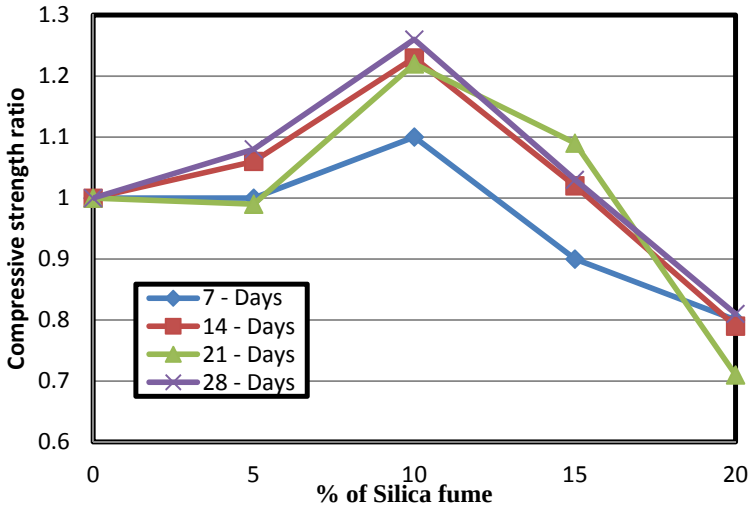

Figure.3. Compressive strength ratio vs percentage replacement of cement by silica fume for 1:10 mix

The variations of compressive strength to percent replacement of cement by silica fume for the, mixes 1:6, 1:8 and 1:10 respectively. From these graphs it is found that for 1:6 mix (16 percent water content) and 1:8 mix (18 percent water content) the optimum percentage replacement of cement by silica fume is between 10 and 15, where as for 1:10 mix (19percent water content) is at 10. The variation of compressive strength ratio for the three different mixes at the age of 7 days, 14 days and 28 days for 1:6 mix for all the percentage replacements of cement by silica fume, at 21 days the compressive strength ratio is maximum whereas for 1:8 and 1:10 mixes for all most all percentage replacements of cement by silica fume the compressive strength ratio is maximum at 28 days are presented in figures 4, 5 and 6.

Compressive strength ratio = compressive strength of cement-silica fume mortar/compressive strength of cement mortar

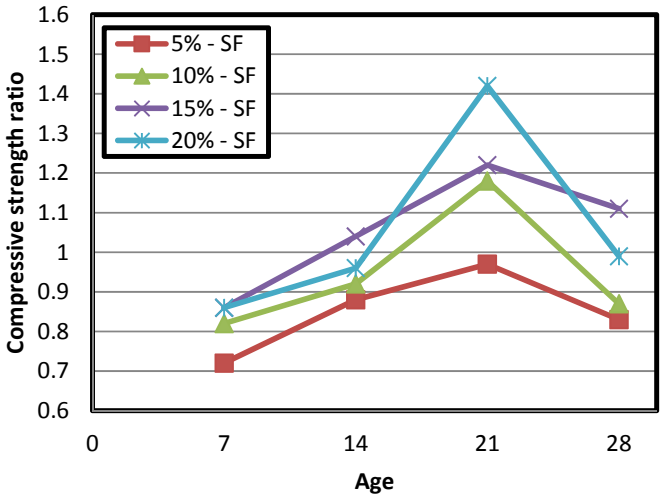

Figure.4. Compressive strength ratio vs Age for 1:6 mix

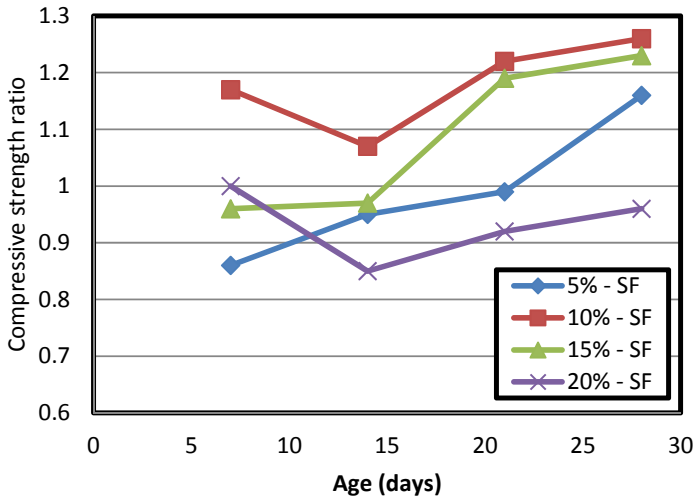

Figure.5. Compressive strength ratio vs Age for 1:8 mix

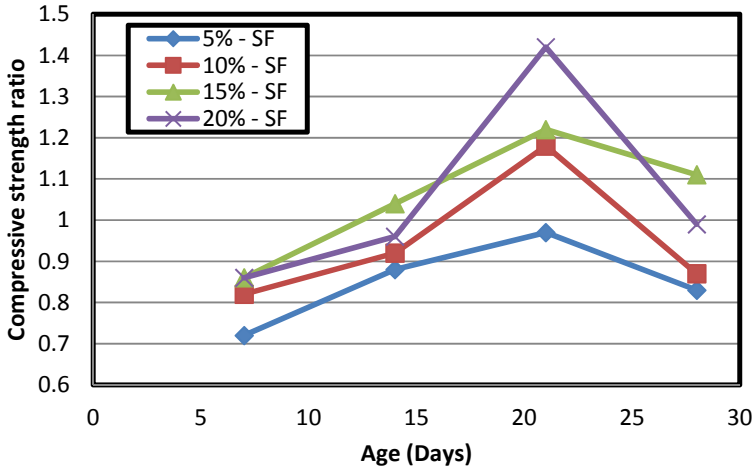

Figure 6. Compressive strength ratio vs Age for 1:10 mix

5. CONCLUSIONS

The following conclusions are drawn based on the experimental work:

- The maximum increase in the compressive strength is at 21days for 1:6 mix.
- For 1:8 and 1:10 mixes the maximum increase in the compressive strength is at 28 days.
- The increase in compressive strength of 1:6 mortar mix (16 percent water content) is maximum at 15 percent replacement of cement by silica fume.
- The increase in compressive strength of 1:8 mortar mix (18 percent water content) and 1:10 mortar mix (19 percent water content) is maximum at 10 percent replacement of cement by silica fume.

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