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STUDY O`N CONCRETE BY REPLACEMENT OF SILICA FUME

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Abstract: India's rapid population growth and infrastructure expansion have significantly increased the demand for construction materials, especially cement. However, cement production poses considerable environmental challenges, including the emission of harmful greenhouse gases. To tackle these challenges and sustainably address the rising demand, there is growing interest in using mineral admixtures as supplementary cementing materials (SCMs) in concrete. This report examines the application of Silica fume as an SCM in concrete. The research methodology includes detailed mix design, concrete sample casting, curing, and a series of tests to assess the performance of concrete with Silica fume. These tests consist of cube compressive strength tests at various curing stages, split tensile strength tests, Slump cone tests, and Flexural tests. A review of existing literature indicates that incorporating Silica fume can improve the strength and durability of concrete while lowering its environmental impact. Studies show that adding Silica fume enhances compressive strength, tensile strength, and durability. Concrete mixes of M40 grade were created with different percentages of Silica fume (0%, 2.5%, 5%, 7.5%, 10%, 12.5%, and 15%) replacing cement. The mixes were tested for compressive strength, split tensile strength, flexural strength, and slump. Results indicate that workability decreases as the percentage of Silica fume increases. The slump value dropped from 95 mm for standard OPC cement to 34 mm for the mix with 15% Silica fume. Strength improves with up to 12.5% Silica fume but starts to decline at 15% at 3, 7, and 28 days. A 12.5% replacement of cement with Silica fume increased split tensile strength to 4.24 N/mm² compared to 100% cement concrete, but further increases in Silica fume content reduced it to 4.08 N/mm². Similarly, flexural strength increased to 5.67 N/mm² with a 12.5% Silica fume replacement but decreased to 5.21 N/mm² with higher proportions. The anticipated outcomes of this study include demonstrating early strength development, enhanced overall strength, and reduced environmental impact through the use of Silica fume as an SCM in concrete. The results could lead to the creation of more sustainable concrete mixtures with optimized performance, encouraging eco-friendly construction practices and decreasing dependence on traditional cement materials.

Keywords: Silica fume; Supplementary cementing materials (SCMs); Sustainable concrete; Cement replacement; Carbon footprint reduction; Mineral admixture.

INTRODUCTION

In its most basic form, concrete is a mixture of Portland cement, sand, coarse aggregate and water. The principalcementitious material in concrete is Portland cement. To-day, most concrete mixtures contain supplementary cementitious materials that make up a portion of the cementitious component in concrete. These materials aregenerally byproducts from other processes or natural ma-trials. They may or may not be further processed for usein concrete. Some of these materials are called pozzolans,which by themselves do not have any cementitious proper-ties, but when used with Portland cement, react to form cementitious compounds. Other materials, such as slag, doexhibit cementitious properties. For use in concrete, supplementary cementitious materials,sometimes referred to as mineral admixtures, need to meetrequirements of established standards. They may be usedindividually or in combination in concrete. They may beadded to the concrete mixture as a blended cement or as aseparately batched ingredient at the ready mixed concreteplant.An SCM is defined by ASTM International as "an inorganic material that contributes to the properties of a cementitious mixture through hydraulic or pozzolanic activity, or both" (ASTM 2015). Hydraulic activity refers to a property most familiar when discussing hydraulic cement such as ordinary Portland cement (OPC). ASTM C125-15a defines hydraulic cement as "a cement that sets and hardens by chemical reaction with water and is capable of doing so under water." That is, hydraulic cements, including SCMs that have hydraulic properties, react with water to harden, and that hardening process does not require drying. In the case of OPC, the products formed by the reaction are calcium silicate hydrate (CSH) and calcium hydroxide (CH). The CSH is the desirable product and provides strength; the CH is undesirable, provides little strength, and is a key ingredient in many materials-related distress (MRD) mechanisms (Sutter 2015). Pozzolanic reactivity refers to the property of a material that needs both water and CH as reactants in order to harden. Again, in the case of OPC-based mixtures, the initial reaction of the cement forms the undesirable CH, but the pozzolan consumes that CH and produces additional CSH. This pozzolanic reaction is the underlying reason why SCMs contribute to durability and can mitigate many MRDs. The most commonly used pozzolan is Class F fly ash.

1.1 Fly Ash is a byproduct of coal-fired furnaces at power generation facilities and is the non-combustible particulatesremoved from the flue gases. Fly ash used in concrete should conform to the standard specification, ASTM C 618.The amount of fly ash in concrete can vary from 5% to 65% by mass of the cementitious materials, depending onthe source and composition of the fly ash and the performance requirements of the concrete. Characteristics of flyash can vary significantly depending on the source of thecoal being burnt. Class F fly ash is normally produced byburning anthracite or bituminous coal and generally has alow calcium content. Class C fly ash is produced when subbituminous coal is burned and typically has cementitiousand pozzolanic properties.

1.2 Ground Granulated Blast Furnace Slag (GGBFS) is anon-metallic manufactured byproduct from a blast furnacewhen iron ore is reduced to pig iron. The liquid slag is rapidly cooled to form granules, which are then ground toa fineness similar to Portland cement. Ground granulatedblast furnace slag used as a cementitious material shouldconform to the standard specification, ASTM C 989. Three grades - 80, 100, and 120 are defined in C 989, with thehigher grade contributing more to strength potential. GGBFS has cementitious properties by itself, but these are enhancedwhen it is used with Portland cement. Slag is used at 20%to 70% by mass of the cementitious materials.

1.3 Silica Fume is a highly reactive pozzolanic material and isa byproduct from the manufacture of silicon or ferro-sili-con metal. It is collected from the flue gases from electricarc furnaces. Silica fume is an extremely fine powder, withparticles about 100 times smaller than an average cementgrain. Silica fume is available as a densified powder or in awater-slurry form. The standard specification for silica fume is ASTM C 1240. It is generally used at 5 to 12% bymass of cementitious materials for concrete structures thatneed high strength or significantly reduced permeability towater. Due to its extreme fineness special procedures arewarranted when handling, placing and curing silica fumeconcrete.

1.4 Natural Pozzolans. Various naturally occurring materialspossess or can be processed to possess pozzolanic prop-erties. These materials are also covered under the standardspecification, ASTM C 618. Natural pozzolans are gener- ally derived from volcanic origins as these siliceous materi-als tend to be reactive if they are cooled rapidly. In the US,commercially available natural pozzolans include, metakaolin and calcined shale or clay. These materialsare manufactured by controlled calcining (firing) of natu-rally occurring minerals. Metakaolin is produced from rela-tively pure kaolinite clay and it is used at 5% to 15% bymass of the cementitious materials. Calcined shale or clayis used at higher percentages by mass. Other natural poz-zolans include volcanic glass, zeolitic trass or tuffs, rice husk ash and diatomaceous earth.

1.5 Silica Fume Definition

The American Concrete Institute (ACI) defines silica fume 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” (ACI 116R). It is usually a gray colored powder, somewhat similar to Portland cement or some fly ashes. Silica fume is usually categorized as a supplementary cementitious material. Th to materials that are used in concrete in addition to Portland cement.

1.6 Production

Silica fume is a by-product of producing silicon metal or ferrosilicon alloys in smelters using electric arc furnaces. These metals are used in many industrial applications to include aluminum and steel production, computer chip fabrica- tion, and production of silicones, which are widely used in lubricants and sealants. While these are very valuable materials, the by-product silica fume is of more importance to the concrete industry. SF and NS are synthesized by different chemical procedures. SF (also known as micro silica) is a by-product of the smelting process of silicon metal and ferrosilicon alloys used for steel and aluminum production (Silica Fume Association, 2005). In electric arc furnace, raw materials (quartz and coal) are smelted at high temperature. The smoke produced during the furnace operation is a fine powder known as SF. Finally, the SF is captured in filtration system of the baghouse where it is packed for commercial usage.

II TESTS

2.1 Slump test

Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. It does not measure all factors contributing to workability, nor is it always representative of the placability of the concrete.

The pattern of slump is shown in Fig. It indicates the characteristic of concrete in addition to the slump value. If the concrete slumps evenly it is called true slump. If one half of the cone slides down, it is called shear slump. In case of a shear slump, the slump value is measured as the difference in height between the height of the mould and the average value of the subsidence.

2.2 Flexure test.

This clause deals with the procedure for determining the flexural strength of moulded concrete flexure test specimens.

Theory Age at Test - Tests shall be made at recognized ages of the test specimens, the most usual being 7 and 28 days. Where it may be necessary to obtain the early strengths, tests may be made at the ages of 24 hours ± ½ hour and 72 hours ± 2 hours. The ages shall be calculated from the time of the addition of water to the dry ingredients.

Testing Machine - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load.

Beam Moulds - The beam moulds shall conform to IS: 10086-1982. The standard size shall be 15 × 15 × 70 cm. Alternatively, if the largest nominal size of the aggregate does not exceed 19 mm, specimens 10 × 10 × 50 cm may be used.

Weights and weighing device, Tools and containers for mixing, Tamper (square in cross section) etc.

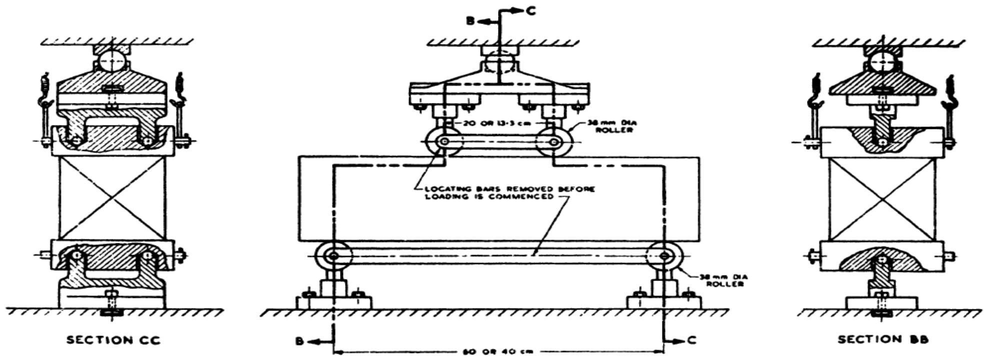


Fig 2a *Flexure test.*

2.3 Splitting Tensile Strength of Cylindrical Concrete Specimens

This method covers the determination of the splitting tensile strength of cylindrical concrete specimens.

Theory Age at Test - Tests shall be made at recognized ages of the test specimens, the most usual being 7 and 28 days. Where it may be necessary to obtain the early strengths, tests may be made at the ages of 24 hours ± ½ hour and 72 hours ± 2 hours. The ages shall be calculated from the time of the addition of water to the dry ingredients.

Apparatus

Testing Machine - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load.

Cylinders -The cylindrical mould shall be of 150 mm diameter and 300 mm height conforming to IS: 10086-1982.

Weights and weighing device, Tools and containers for mixing, Tamper (square in cross section) etc.

2.4 Compressive strength

Compressive strength refers to the ability of hardened concrete to withstand loads before experiencing failure, typically measured through a compression test. This test involves crushing cube or cylinder specimens in a compression testing machine. Cube specimens will be utilized to study the compressive strength in this research. To determine the equivalent cube strength of the concrete, the corrected cylinder strength will be multiplied by 5/4, as per IS 516 (clause 5.6.1). This calculation method helps in estimating the compressive strength of concrete based on cylinder test results.

III LITERATURE REVIEW

3.1 GENERAL

Numerous researchers have worked on the utilization of Silica fume in concrete. They have found that the large surface area and small particle size of these materials improved the characteristics of the resulting materials. A brief review of the work carried out in the subject area is presented in this section. This chapter presents an overview of literature on the various experiments conducted by many authors on the partial replacement of cement by silica fume and the results there of highlighting the significance of using the silica fume for partial replacing the cement in concrete. It includes the literature about mix design, fresh concrete properties, strength, durability aspects, microstructures, and the structural behaviors of concrete with the partial replacement of cement by silica fume. Silica fume is a by-product resulting from the reduction of high purity quartz with coal and wood chips in an electric arc furnace during the production of silica metal or ferrosilicon alloys. The silica fume, which condenses from the gases escaping from the furnaces, has a very high content of non-crystalline silicon oxide and consists of extremely fine particles. The SiO2 content of silica fume is roughly related to the manufacturing process of silicon alloys. Ferrosilicon alloys have nominal silicon content of 61% to 91%. When the silicon content is greater than 91%, the product is called silicon metal rather than ferrosilicon. The majority of published data and field use of silica fume has been from its alloys having silicon content of 75% and higher. A unique feature of silica fume procured from a single source is little or no variation in chemical composition from one day to another.

Ali Mardani-Aghabaglou et. al[1], "Comparison of fly ash, silica fume and metakaolin from mechanical properties and durability performance of mortar mixtures view point"

In this experimental work, researchers worked on the effect of cement replacement with fly ash, silica fume and metakaolin on the compressive strength, dynamic elastic modulus, chloride-ion penetration, water absorption, water sorptivity, and freeze–thaw and sulfate resistance of the mortar mixtures were comparatively investigated. In addition, micro-structural investigation was performed on some selected mortar mixtures, and regression analysis was applied on the sulfate resistance test results. Scholars observed that, the presence of the mineral admixture and its type changed the ettringite morphology. Besides, only ball-ettringite and a special type of ettringite were observed in the silica fume- and metakaolin-bearing mixtures, respectively. Scholars found that, the silica fume-bearing mortars showed the highest compressive strength values compared to those of the other mortar mixtures. It was also found that the UPV values of the control mixture and mixtures containing silica fume and metakaolin were higher than 4.5 km/s, the limit specified for strong concrete. The transport properties of the mortar mixtures were improved upon inclusion of the mineral admixtures. Relative chloride ion penetration values of silica fume-, metakaolin- and fly ash-bearing mixtures compared to that of the control mixture were 25%, 35% and 55%, respectively. The corresponding values for the relative water absorption were 42%, 67% and 74%, for silica fume metakaolin and fly ash-containing mixtures, respectively. In the mortar mixtures' containing silica fume and metakaolin, ettringite was only formed inside the pores; however, in the control and fly ash mixtures, it was formed both inside and outside of the pores.

A.M. Said et.al [2], "Properties of concrete incorporating nano-silica."

In this research work scholars investigate the effect of colloidal nano-silica on concrete incorporating single (ordinary cement) and binary (ordinary cement + Class F fly ash) binders. In addition to the mechanical properties, the experimental program included tests for adiabatic temperature, rapid chloride ion permeability, mercury intrusion porosimeter, thermogravimetry and backscattered scanning electron microscopy in order to link macro- and micro-scale trends. In the findings researchers conclude that Significant improvement was observed in mixtures incorporating nano-silica in terms of reactivity, strength development, refinement of pore structure and densification of interfacial transition zone. This improvement can be mainly attributed to the large surface area of nanosilica particles, which has pozzolanic and filler effects on the cementitious matrix. Micro-structural and thermal analyses indicated that the contribution of pozzolanic and filler effects to the pore structure refinement depended on the dosage of nano-silica.The overall performance of concrete, with or without fly ash, was significantly improved with the addition of variable dosages of nano-silica. At all curing ages, the strength generally increased with the addition of nano-silica up to 6%. In particular, at 28 days, the compressive strength was considerably improved for mixtures incorporating 30% Class F fly ash and nano-silica, which indicates that the inherently slower rate of strength development of concrete containing Class F fly ash can be controlled by the addition of small dosages of nano-silica.

Ashhad Imam et.al [3], "Review study towards effect of Silica Fume on the fresh and hardened properties of concrete"

In this review work researcher reviewed the use of Silica Fume (SF) as a mineral admixture in the concrete. Distinctive outcome from several research have been demonstrated here, particularly emphasizing on the fresh and hardened properties of concrete when blended with Silica Fume (Micro-silica or Nano-silica). The results showed a substantial enhancement in the mechanical properties of concrete when replaced with SF. The review also presented a brief idea of percentage replacement of SF in case of normal and high-strength concrete. A decreasing trend in workability (slump value) has been identified when there is a increase in percentage replacement of SF. It can be concluded that the optimize percentage of replacement with SF lies in the range of 8-10% particularly for compressive strength. However, the variation of blending goes up to 12-15% in case of split tensile and flexure strength of concrete. The study also demonstrates the effect of silica fume on durability parameters like water absorption, permeability, sulphate attack and chloride attack. Based on the review, it was quite clear that mineral admixture like Silica Fume has proved to be the most promising blending material to provide a good quality concrete. They made the following conclusions in there study.I. Silica Fume is considered as a highly reactive pozzolanic material which provides an increased cohesiveness in concrete due to its high fineness modulus which consequently results into a high amount of water requirement to maintain the desired workability.II. The workability of fresh concrete decreases with the increasing in the percentage of silica fume. III. The compressive strength of concrete increases with the increase in replacement level of Silica Fume in a range of 8-12% below which no significant change in compressive strength can be expected. Rather, a decreasing trend in compressive strength is anticipated if the replacement level is going beyond 12%. Also, It was found that the compressive strength decrease with increasing w/c ratio followed by an increase in Silica Fume replacement. IV. The split tensile strength of concrete shows an increasing tendency up to a limit of 10-15%. It can be said that the split tensile strength decreases with increasing w/c ratio followed by an increase in Silica Fume replacement. However, a similar trend is observed in case of flexure strength in a replacement range of 10-15%. V. Durability parameters like water absorption, permeability, sulphate attack and chloride penetration resistance are higher in case of concrete blended with silica fume as compared to normal OPC concrete.

Arihant S. Baid et.al [4], "Effect of Micro-Silica on Mechanical Properties of Concrete"

In this experimental work scholars investigate the effect of partial replacement of cement by silica fume (micro-silica), studies had been conducted on concrete mixes for M40 grade at 0%, 3%, 6%, 9%, 12% & 15% replacement levels of micro-silica. Properties of hardened concrete such as Compressive strength, Split Tensile strength, Flexural strength, Capillary absorption (Durability) assessed. Based on comparisons and interpretations, conclusions have been drawn. Water requirement or normal consistency of a mix increases with increment in percentage of Micro-Silica replacement. The maximum increase in characteristic strength was observed by scholars for 12% replacement. For this dose, the relative increase in compressive strength is found to be up to 14.5%.The reason for gain of strength in fly ash cement (PPC) could be fast reaction between fly ash and silica-fume particles due to fine nature.It was again that observed that up to 12% replacement of cement with silica fume the Compressive strength increases with increasing dose of silica Fume and then reduces slightly. Silica fume increases the strength of concrete largely because it increases the strength of the bond between the cement paste and the aggregate particles. They observed that the split tensile strength of concrete increases with increase in silica content up to 9% replacement of cement. Inclusion of micro-silica as a replacement of cement shows slight increase in the split tensile strength though not in a definitive manner. However, there was no loss or any significant reduction in strength was observed with increase in the micro-silica content. The maximum increase in characteristic strength is observed for 9%. For this dose the relative increase in split tensile strength is found to be up to 17%. It was observed that the flexural strength of concrete increases with increase in silica content up to 15% replacement of cement. The maximum increase in characteristic strength is observed for 15%. For this dose the relative increase in flexural strength is found to be nearly 27%. scholars found that the split tensile strength to be 8- 10% of the compressive strength for 28 days of curing. The flexural strength is found to be 12-15% of the compressive strength for 28 days of curing. It would be reasonable to say that inclusion of silica fume to the concrete actually forms denser matrices thereby improving resistance of the matrices against water ingress which is one of the most important reasons that increases the deterioration of concrete So, by using micro-silica, the concrete matrix gets a denser composition filling even the micro-voids thus enhancing the impermeability of concrete. Better impermeability may ensure better crack resistance and corrosion resistance as well as less prone to chemical attack. The properties shown by micro-silica concrete are much better than plain cement concrete.

Erhan Guneyisi et.al [5] , "Strength, permeability and shrinkage cracking of silica fume and metakaolin concretes"

In this work researcher worked investigates the effectiveness of metakaolin (MK) and silica fume (SF) on the mechanical properties, shrinkage, and permeability related to durability of high-performance concretes. Mechanical properties were evaluated by means of compressive and splitting tensile strength. Water sorptivity and gas permeability tests were carried out to find out the permeation characteristics of the concretes due to the incorporation of MK and SF. For concrete production, replacement levels of 5% and 15% of MK or SF by the weight of cement were assigned. Water-to-cementitious (w/cm) material ratios of 0.25 and 0.35 were used in production of concrete. The design strength level ranging from75 to 86 MPa was achieved. Test results revealed that replacement level of MK and SF had significant effects on the mechanical and especially durability characteristics of high-performance concretes.

Based on the findings of the experimental program presented above, the following conclusions were present by researcher SF and MK concrete had consistently higher compressive strength than the control concrete. There was a systematic increase in compressive strength with the increase in MK and SF content for both w/cm ratios. According to the test results obtained in this study, it was observed that the splitting tensile strength development of the concretes had similar tendency with compressive strength. For all replacement levels, MK and SF modified concretes exhibited lower shrinkage in comparison to the plain concretes. The lowest shrinkage strains were measured at the concrete containing 15% SF. Addition of MK and SF decreased the rate of weight loss due to the drying of the concretes. Especially, for the concretes having higher rate of replacement levels, the weight losses observed to be relatively lower than that of plain concrete.

Gaurav Chand et.al[6], "Assessment of the properties of sustainable concrete produced from quaternary blend of Portland cement, glass powder, metakaolin and silica fume"

In this research work, researchers used different cementitious materials like glass powder, metakaolin and silica fume to replace cement at different percentages by weight. After conducting mechanical properties tests, optimum replacement percentages are obtained and consequently a quaternary blend of hybrid concrete is prepared containing cement + glass powder + metakaolin + silica fume, in the ratio 60:20:05:15thier. The 28 days compressive strength, split tensile strength and flexural tensile strength of hybrid concrete are 13.42%, 10.31% and 8.29% higher than control mix, after same days of curing. In the acidic environment, for 28 days, reduction in compressive strength of hybrid concrete by 11.44% is noticed, which is comparatively lesser than control mix in which reduction of 17.92% was observed. Similarly, the reduction in weight of hybrid concrete in acidic environment is 0.73% whereas, 1.87% is noticed for control mix. The present research at macro and micro level recommends the use of OPC with different SCMs like glass powder in conjunction with metakaolin and silica fume at 60:20:05:15 ratio respectively. The novel finding of the experiment marks a 40% clear reduction in the demand of OPC which directly contributes in reducing the carbon emission. However, the obtained results restrict the replacement of OPC with SCMs at 40% and do not suggest any further replacement. In order to attain higher replacement percentages, more research is required to be conducted on pozzolanic properties of other SCMs in this regard. These practices in construction industry will promote the usage of industrial and domestic wastes more efficiently and effectively, eventually leading to sustainable development.

Hasan Biricik et.al[7], "Comparative Study of the Characteristics of Nano Silica–, Silica Fume– and Fly Ash–Incorporated Cement Mortars

In this work researchers made an attempt to study the structural characteristics of cement mortars, impregnated with nano silica (NS), silica fume (SF) and fly ash (FA), were comparatively studied using Fourier transform infrared spectrometer (FTIR), thermogravimeter-differential thermogravimeter (TG-DTG) and scanning electron microscope (SEM). The mechanical strengths of the specimens were determined at early (7th day) and standard (28th day) curing ages. The compressive strengths and flexural strengths developed in the mortar specimens containing NS particles were found considerably higher than those of the corresponding specimens of SF and FA over and above the control at both ages. FTIR, TG-DTG and SEM analyses results were consistent with the remarkable increase in the mechanical strength of the mortars with NS. These increases in the strengths of the mortars with NS are attributable to the nano sized particles and extensive surface area of NS. The nano sized particles, as nucleating agents, promoted the hydration of C3S and C2S and the formation of C–S–H phase.

In the present study researchers tried, the influence of high dosages of nano silica (NS) 5 wt% and 10 wt.%, on the mechanical and structural properties of cement mortars at early (7th day) and standard (28th day) curing ages were studied and compared with the effects of equal amounts of the commercially used pozzolanic mineral additives silica fume (SF) and fly ash (FA).

The compressive strengths developed in the mortar specimens containing NS particles were found considerably higher than those of the corresponding specimens of SF and FA over and above the control at early and standard ages. Parallel to the increase in the amount of NS from 5 wt.% to 10 wt.%, the increases in compressive strength at both ages were observed. At standard age, the compressive strength of the mortar specimen with 10 wt.% NS was 84% higher than that of the control, while the compressive strengths of the specimens with 10 wt.% SF and 10 wt% FA were only 44% and 18% higher than that of the control. The increases in the flexural strengths of the mortars with 5 wt.% and 10 wt.% NS were also noticeable compared to the mortars with SF and FA on top of the control at standard age of curing.

Hongjian Du et.al[8],, "Durability performances of concrete with nano-silica"

In this experimental work researchers investigated the durability properties of concrete containing nano-silica at dosages of 0.3% and 0.9%, respectively. They studied experimentally measured the transport properties related durability of OPC concrete with the addition of nano-silica at 0.3% and 0.9%, respectively. The following conclusions were reached:

(1) In comparison with the reference concrete, the study showed that nano-silica exhibited obvious pozzolanic reaction with the Portlandite, even at a very early stage. This was verified by the reduced Portlandite content and the increased compressive strength at 1 day. (2) The pozzolanic reaction, as well as the nano-filler effect of nano-silica, densified the paste microstructures, particularly at the ITZ. SEM observations found the paste morphology at ITZ was more homogeneous for concrete containing nanosilica. In addition, MIP results revealed that the pore size distribution became refined which reduced the ingress rate of water and chloride ions.(3) The modification mentioned above would increase the compressive strength and resistance against water and chloride ions for concrete added with nano-silica, even at a small amount of 0.3%. At this dosage, the uniform-dispersion of silica nano-particles can be readily achieved. Hence, a reduction of 45%, 28.7% and 31% was observed for water penetration depth, chloride migration coefficient and diffusion coefficient into concrete, respectively. The initial water sorptivity, water absorption and water accessible porosity was marginally changed by the nano-silica.

Rafat Siddique[20], "Utilization of silica fume in concrete: Review of hardened properties"

In this review work researcher reviewed the physical, chemical properties of silica fume, and its reaction mechanism. It deals with the effect of silica fume on the workability, porosity, compressive strength, splitting tensile strength, flexural strength, creep and shrinkage of concrete. Addition of silica fume increases the 28-day compressive strength. After studied they concluded that Silica fume does not have significant influence on the splitting tensile strength of concrete. Silica fume seemed to have a pronounced effect on flexural strength in comparison with splitting tensile strength. For flexural strengths, even very high percentages of silica fume significantly improved the strength. Also, it was found that there was a steady increase in the flexural strength with increase in the silica fume replacement percentage. Increasing the silica fume replacement level increased the secant modulus of concrete. The inclusion of silica fume at high replacement levels significantly increased the autogenous shrinkage of concrete due to the refinement of pore size distribution that leads to a further increase in capillary tension and more contraction of the cement paste. The plastic shrinkage strain increased with increasing dosage of silica fume. Silica fume reduced the strain due to creep compared with Portland cement concrete.

Rishav Garg et. al[21], "Experimental study on strength and microstructure of mortar in presence of micro and nano-silica"
In this experimental study researchers investigated the strength and microstructure of the preferentially substituted cement mortars with incorporation of micro silica (MS), nano silica (NS) and their combined use at 3, 7 and 28 days of curing. The substituent MS (5.0–20%) and NS (0.5–1.25%) have been used at a water binder ratio of 0.5. The specimens were analyzed for the fresh (consistency, setting time, flow) and hardened (compressive and split tensile strength) properties and a correlation between compressive and split tensile strength was obtained. Mortar containing NS was found to develop better strength as compared to the mortar containing MS. The optimum usage of MS with incorporation of NS was further found to increase the strength of mortar significantly. SEM-EDX was used for the analysis of the microstructure of the specimens and the correlation between Ca and Si content was used to analyze the cement matrix. The findings show that the optimized usage of micro and nano silica can give beneficial effects to improve the fresh properties as well as strength with dense microstructure. The study of effect of preferential substitution of cement by MS and/or NS on fresh as well as hardened properties & microstructure of cement mortars in comparison to control mix has been carried out. The consistency, initial and final setting time of the specimens were found to increase while the flow was found to decrease in content of MS as well as that of NS but the effect was more pronounced in case of ternary blends. An increase in compressive and split tensile strength was obtained with increasing content of MS and NS from 5.0% to 15% and from 0.5% to 1.0% respectively along with a slight reduction in strength afterwards. The results were confirmed with SEM-EDX analysis with profound decrease in Ca/Si ratio accordingly. This decrease in strength was because of the reduction in homogeneity of the cement matrix at higher content of MS while the decrease in strength at higher content of NS was attributed to the agglomeration of nano particles at higher content in the cement matrix. SEM-EDX analysis confirmed the loss of pozzolanic activity of MS and NS at higher content due to agglomeration and friction among particles.

Rishav Garg[22], "Strength and microstructural analysis of nano-silica based cement composites in presence of silica fume"
In this study researchers used to replacement of cement with pozzolanic materials has addressed numerous inquiries identified with impact of these materials on the microstructural and other properties of cement composites. In this study, the composition of silica fume (SF) was differed as 3%, 6%, 9% and 12% at a fixed composition of nano-silica (NS) as 0.5% by weight for substitution of cement. The fresh and hardened properties of cement mortars were analyzed, and microstructural analysis was performed. The specimens were found to exhibit better developed microstructure and enhanced compressive strength with inclusion of optimized dosage of SF in presence of NS. The study has confirmed that the simultaneous replacement of cement with the optimized dosage of pozzolanic materials brings improvement in the properties of the cement mortar and can be used to partially substitute cement for the beneficiary effects. The study represents the potentiality of using Silica (a waste product) in cement paste analyzed by the simultaneous influence of nano-Silica and silica fume on the microstructural and mechanical properties of cement mortar. Silica fumes (SF) was taken as Micro modifier and Nano-silica (NS) was used as Nano modifier. For analysis point of view, SF at 3%, 6%, 9% and 12% with 0.5% NS by weight replacement of cement was employed to investigate the effects on the fresh and hardened properties of cement paste at primitive and advanced ages. The study can be concluded with the following comments:

1. Partially replacing cement with SF in presence of NS increased the stiffness of the mortar leading to an increase in consistency and setting time with decrease of the flow of the mortar.
2. The compressive strength of all the specimens was found to increase with increase in curing age.
3. An overall increase of the compressive strength of all the specimens containing SF in presence of NS as compared to the controlled mix was observed. These specimens were observed to have compact microstructure due to the formation of calcium silicate hydrate gel and resulted in higher compressive strength.
4. The higher percentage of SF resulted in a comparative reduction in the compressive strength of the specimens that was assigned to the presence of agglomerates. Thus, the cement can be partially substituted with optimized dosage of SF and NS to obtain synergistic effect for improved properties of the cementitious materials.

Manthar Ali Keerio[23] et.al, "Effect of Silica Fume as Cementitious Material and Waste Glass as Fine Aggregate Replacement Constituent on Selected Properties of Concrete"
The aim of researcher's is to study the properties of concrete using silica fume as a partial replacement of cement and glass waste instead of fine aggregate. This research includes the study of workability, water absorption, compressive strength and split tensile strength. In this experimental study, 5%, 10% and 15% by weight of cement were replaced with silica fume, and fine aggregates were replaced with 10%, 20%, 30 and 40% by waste glass powder. A total of 20 mixtures in which one control mix, three mixes with addition of silica fume, four mixes with incorporating of glass powder and twelve mixtures with combined use glass powder and silica fume were prepared with 1:2:4 mix ratio at 0.5 water-binder ratios. According to the study parameters, replacing 10% cement with SF and 30% fine aggregate with glass powder is the best choice for optimum strength. Moreover, the utilization of glass powder and silica fume together significantly reduces the workability and water absorption of the composite concrete mixture. For this investigational study, SF was utilized as cementitious constituent and WGP used as sand replacement ingredient in order to progress the hardened concrete. Based on the experimental results the conclusions are drawn i. The workability of concrete is noted by 14.67%, 26.67% and 33.33% at 5%, 10% and 15% of SF as cement substitute component in concrete is lower than that of control concrete mix. Similarly, the flow of fresh concrete is measured by 10.67%, 20%, 25.33% and 29.33% while using 10%, 20%, 30% and 40% of WGP as fine aggregates in concrete is lower than that of concrete without WGP. Moreover, the slump value of concrete mix is reduced as the content of SF as cementitious ingredient and glass powder as replacement of fine aggregates increases together in concrete.ii. The water absorption was estimated by 8%, 16%and 20% at 5%, 10% and 15% of SF as cementitious component in concrete is lower than that of concrete without addition of SF in concrete after 28 days. It was stated that the water absorption is minimized with increasing in the content of SF in concrete. Similarly, the water absorption of concrete was calculated by 4%, 10%, 16% and 21% while using 10%, 20%, 30% and 40% of glass powder as fine aggregates replacement in concrete is lower than that of control mix after 28 days.Moreover, the water absorption of concrete is minimized with increasing the content of SF as cementitious ingredient and glass powder as sand replacement together at 28 days.iii. The compressive strength

of concrete was measured by 29.40 N/mm2, 32.5 N/mm2 and 27.50 N/mm2 at 5%, 10% and 15% of SF as cementitious material in concrete after 28 days. Similarly, the compressive strength is estimated by 26.60 N/mm2, 27.50 N/mm2, 28.40 N/mm2. and 27.10 N/mm2 while using 10%, 20%, 30% and 40% of glass powder as sand replacement in concrete at 28 days. Moreover, the maximum compressive strength of concrete was calculated by 34.95 N/mm2 at 10%of SF as cement substitute ingredient and 30% of glass powder as sand replacement together and minimum strength was recorded by 28.25 N/mm2 at 15% of SF as cement substitute ingredient along with 40%of glass powder as sand replacement after 28 days. iv. The splitting tensile strength was measured by 3.30 N/ mm2, 3.45N/mm2 and 3.20 N/mm2 at 5%, 10% and 15% of SF as cementitious material in concrete after 28 days. Similarly, the split tensile strength is estimated by 3.17 N/ mm2, 3.26 N/mm2, 3.35 N/mm2 and 3.25 N/mm2 while using 10%, 20%, 30% and 40% of glass powder as sand replacement in concrete at 28 days. Moreover, the maximum split tensile strength of concrete was calculated by 3.55 N/mm2 at 10%of SF as cement substitute ingredient and 30% of glass powder as sand replacement together and minimum strength was recorded by 3.29 N/mm2 at 15% of SF as cement substitute ingredient along with 40% of glass powder as sand replacement after 28 days.

M. Berra[24], "Effects of nanosilica addition on workability and compressive strength of Portland cement pastes"

In this experimental work researchers studied the effect of nano-size particles of amorphous silica (nanosilica) on the rheological behaviour and mechanical strength development of cementitious mixes. Mini-slump and rheometric tests were carried out on cement pastes made with three dose levels of nanosilica at different water/binder ratios. Cement pastes workability resulted to be significantly lower than expected for the adopted water/binder ratios, as a consequence of instantaneous interactions between nanosilica sol and the liquid phase of cement pastes, which evidenced the formation of gels characterised by a significant water retention capacity. The resulting reduction of the mix workability was avoided by suitable addition procedures of superplasticizers. No appreciable improvement in the compressive strength development of cementitious mixes by nanosilica addition was observed, in contrast with some results from literature. Thus, only a limited quote of the improvement in compressive strength of cementitious mixes can be ascribed to nanosilica addition, at least when this admixture is used in the form of a slurry (mean particle size = 10 nm; sodium hydroxide as stabilising agent) at NS dose levels up to 3.8 wt.% of blended cement.

Nayana A M et.al[25], "Strength and durability study on cement mortar with ceramic waste and micro-silica "The effect recycled materials was examined by researchers by conducting tests like compressive strength test and durability tests such as rate of water absorption, sorptivity test and sulfate attack test. In this study, mortar mixes are produced by replacing a fraction of cement by 5% and 10% with micro-silica and sand by 15%, 30% and 50% with ceramic waste. The mechanical and durability properties were evaluated for different mixes and compared it with reference mix. The compressive strength of recycled mortar increases with 15% ceramic and 10% micro-silica content by 20.78% when compared with control mix and then decreases with further addition of ceramic waste. The rate of water absorption has reduced by 1.17% for mix with 15% ceramic waste and 0% micro-silica when compared with reference mix and sorptivity has reduced by 11.96% for mix with 15% ceramic waste and 0% micro-silica when compared with reference mix. The expansion of the mortar remained lower for mix with 15% ceramic waste when compared with other mixes .

S. Jagan et.al[26], "Effect of silica fume on the hardened and durability properties of concrete"

In this research paper scholars studied the hardened and durability properties of the concrete at two different grades containing silica fume (SF) with various replacement percentages. Investigation on the performance of the SF was performed for M25 and M40 grades concrete with 0, 5, 10, and 15 % replacement levels at 7, 14, 28, and 90 days. The behavior of SF on the autogenous shrinkage of the concrete was studied for both the grades of concrete in the sealed (SC) and unsealed conditions (USC). The workability of the SF concrete was examined at various levels of replacement by the slump cone test. As Increase in the percentage of SF decreases the workability of concrete as the finer SF having higher surface area tends to absorb more water reducing the slump value of the concrete. As the percentage of SF increases, the strength of the concrete increases irrespective of the grades of the concrete. Conversely, the percentage improvement in the strength of concrete upon addition of SF was reduced due to its lesser pozzolanic reactivity at later ages. The elastic modulus of the concrete is not much dependent on the percentage of SF as no significant variation was observed.

Ye Qing et.al[27], , "Influence of nano-SiO2 addition on properties of hardened cement paste as compared with silica fume"

In this research paper scholars studied the influence of nano-SiO2 (NS) addition on properties of hardened cement paste (hcp) as compared with silica fume (SF) has been studied through measurement of compressive and bond strengths of hcp, and by XRD and SEM analysis. Results indicated that the influence of NS and SF on consistency and setting time of fresh cement paste showed different. NS made cement paste thicker and NS accelerated the cement hydration process. Compressive strengths of hcp and bond strengths of paste–aggregate interface incorporating NS were obviously higher than those incorporating SF, especially at early ages. And with increasing the NS content, the rate of bond strength increase was more than that of their compressive strength increase. With 3% NS added, NS digested calcium hydroxide (CH) crystals, decreased the orientation of CH crystals, reduced the crystal size of CH gathered at the interface and improved the interface more effectively than SF. The results suggest that with a small amount of added NS, the CH crystals at the interface between hcp and aggregate at early ages may be effectively absorbed in high performance concrete (HPC). The influence of nano-SiO2 and silica fume on consistency and setting time are different. Nano-SiO2 makes cement paste thicker and accelerates the cement hydration process. Compressive strengths of hcp increase with increasing the nano-SiO2 content, especially at early ages. However, the strengths of hcp decrease slightly with increasing the silica fume content at early ages, but increase at later ages.

2.2 Summery

After reviewing literature, it is concluded that the use of silica fume, as partial replacement of cement results in significant improvement in the strength of concrete. The results showed a substantial enhancement in the mechanical properties of concrete when replaced with silica fume. A decreasing trend in workability (slump value) has been identified when there is a increase in percentage replacement of silica fume. It can be concluded that the optimize percentage of replacement with SF lies in the range of 8-10% particularly for compressive strength. However, the variation of blending goes up to 12-15% in case of split tensile and flexure strength of concrete. At the same time the results are not consistent. There are a lot of gaps found in results reported by various researchers. Also, most of the work has been carried out to study mainly the concrete compressive strength and water permeability for mixes containing silica fume, individually as well as in combination. So, it has become the need of hour to carry out detailed research on the proposed topic as well as study all the related strength properties of concrete consisting of silica fume. Also, an optimum percentage replacement of the components envisaged to be used in the study needed to be found out.

IV METHODOLOGY

Table 4.1 *Methodology Sequence*

	Steps
1	Literature survey
2	Mix design
3	Arrangement of materials
4	Conduct trials
5	Cast samples
6	Curing of samples
7	Conduct tests
8	Result interpretation

4.1 Mix design.

In the experimental program, three basic tests for mechanical properties of concrete were conducted i.e. tests for compressive strength, flexural strength and split tensile strength. The mechanical properties of concrete were tested at the ages of 7 days, 14 days, 28 days. The compressive strength was tested on concrete cubes of 150 x 150 x 150 mm after water curing for 7 days, 28 days. The flexural strength was tested using concrete beams with dimension of 150 x 150 x 700 mm after curing in the water for 7 days, 28 days. The split tensile strength was tested using concrete cylinders with dimension φ150 mm x 300 mm after curing in the water for 7 days, 28 days. This study has investigated the influence of replacing cement with silica fume from zero to 15% at 2.5% increment level. Although IS:10262 (2019) and IS:456 (2000) were used for the designing the mix. Experimental analysis have been conducted to assess consistency of concrete with silica fume when replaced with cement up to 15%, including the concrete grades M40 microscopic studies respectively.

Cement – 53 grade OPC will be used in the mix.

Silica Fumes – SF having surface area above 2000 m2/kg is used as an SCM in the mix.

Fine aggregate – Crush sand is used as fine aggregate.

Coarse aggregate – 10mm and 20mm aggregate will be used.

Admixture – Superplasticizer

Table 4.2 *Mix Design*

Mix	M1(0%)	M2(2.5%)	M3(5%)	M4(7.5%)	M5(10%)	M5(12.5%)	M5(15%)
Cement	492.5	480.18	467.875	455.56	443.25	430.93	418.62
Silica Fume	0	12.32	24.625	36.94	49.25	61.57	73.88
Fine Aggregate	629						
Coarse Aggregate	1118						
Water	197						

4.2 Curing of samples

The curing process for the concrete samples will involve immersing them in a water tank for a minimum duration of 10 days. This prolonged immersion is crucial for ensuring proper hydration and development of the concrete's strength and durability properties.

4.3 Testing

Slump test after trials, Compressive strength (3days,7days,28days), Split tensile strength (3days,7days,28days), Flexural Test (3days,7days,28days).

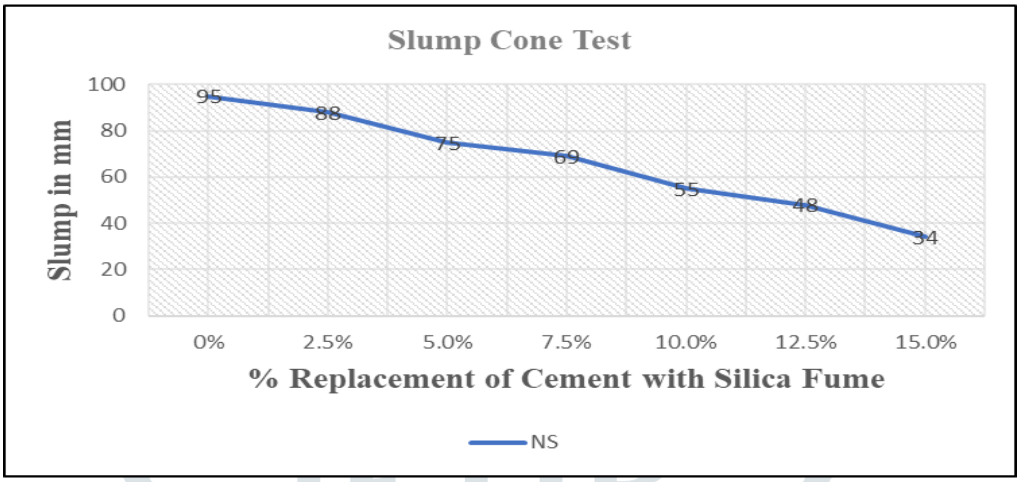
4.4 Result interpretation

Upon the culmination of all test procedures and the acquisition of relevant data, this experimental exploration has brought to its conclusion through the careful analysis and interpretation of the obtained results. The results obtained are discussed in the next chapter that is results and discussion.

V RESULTS AND DISSCUSSION

5.1 Slump Cone Test

The workability of concrete is one of the functions of the relative magnitudes of various concrete mix constituents. Slump Test is one of the tests which measure the parameters close to workability and provide useful information about it. It is the most commonly used method of measuring consistency of concrete which can be employed either in lab or at the site. From this test, slump is deduced by measuring the drop from the top of the slumped fresh concrete. Additional information on workability of concrete can be obtained by observing the shape of the slump in concrete.

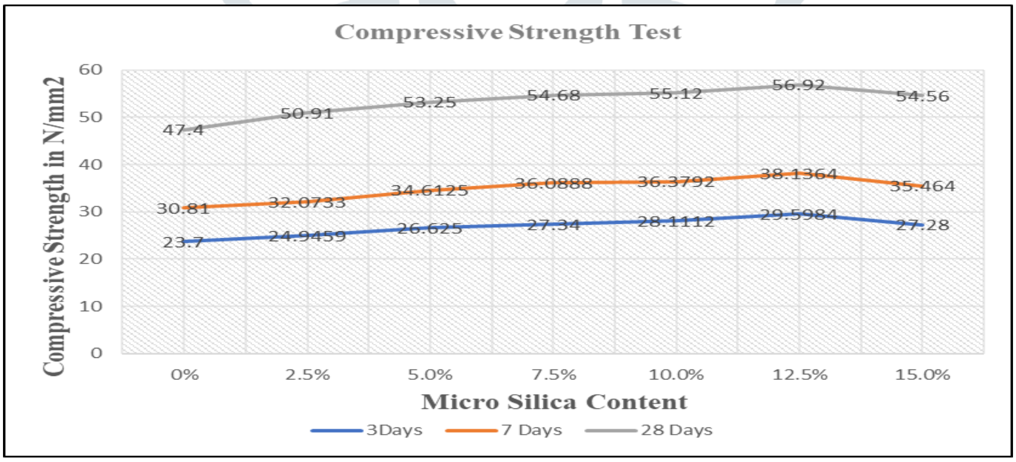


Graph No.4.1 : workability of concrete, with partial replacement of cement with silica fume

From above results it is concluded that the workability decreases with increase in the percentage of silica fume. Slump value decreased from 95 mm for normal OPC cement to 34 mm for mix with maximum 15% replacement of cement with silica fume.

- **Compressive strength**

The test method covers determination of compressive strength of cubic concrete specimens. It consists of applying a compressive axial load to moulded cubes at a rate which is within a prescribed range until failure occurs. For each mix cubes of 150mm x 150mm x 150mmin size, three cylinders of 150mm diameter and 300m height were cast using steel moulds. The caste specimens were kept in ambient temperature for 24 hours. After 24 hours they were demoulded and placed in water for curing. Cubes were used to determine the compressive strength of concrete for 7 days and 28 days. Thus, there is improvement in compressive strength because of continuous increase of silica fume sand with respect to cement. The strength increases with addition of silica fume up to 12.5%, and after that declines at 15% at 3 days, 7days and 28 days.



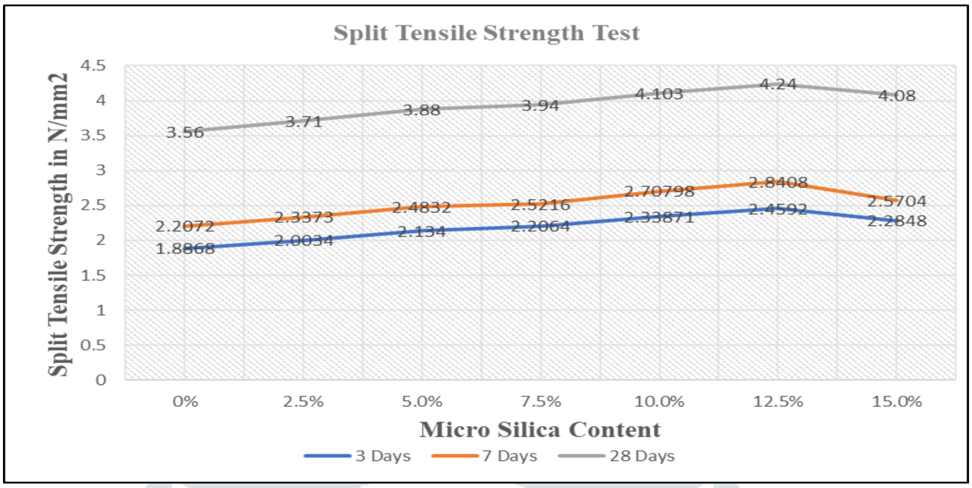
Graph No.4.2 : Compressive Strength Test for partial replacement of cement with silica fume at 3, 7 and 28 days

- **Split tensile strength.**

Cylinders of size 15cm (dia.) x 30cm (height) are casted. The test is carried out by placing a cylindrical specimen horizontally between the loading surface of a compression testing machine and the load is applied until the failure of the cylinder, along the vertical diameter. When the load is applied along the generatrix, an element on the vertical diameter of the cylinder is subjected to a horizontal stress of 2P/πld.

Where, 'P' is the compressive load on the cylinder, 'l' is the length of the cylinder, 'd' is diameter of the cylinder.

Replacement of cement up to by 12.5% will increase the split tensile strength up to 4.24 N/mm^2 compared to 100% cement concrete and further increase within the proportion of silica fume resulted in the decrement of the ultimate strength up to 4.08 N/mm^2



Graph No.4.3 : Split Tensile Strength Test with partial replacement of cement with silica fume at 3, 7 and 28 days

4.6 Flexural Test

Beams of size 150x150x700mm are tested using a flexure testing machine. The specimen is simply supported on the two rollers of the machine which are 600mm apart, with a bearing of 50mm from each support. The load shall be applied on the beam from two rollers which are placed above the beam with a spacing of 200mm. The load is applied at a uniform rate such that the extreme fibers stress increases at 0.7N/mm2/min i.e., the rate of loading shall be4 KN/min. The load is increased till the specimen fails. The maximum value of the load applied is noted down. The appearance of the fracture faces of concrete and any unique features are noted.

The modulus of rupture is calculated using the formula.

$\sigma s = Pl/bd^2$, where,

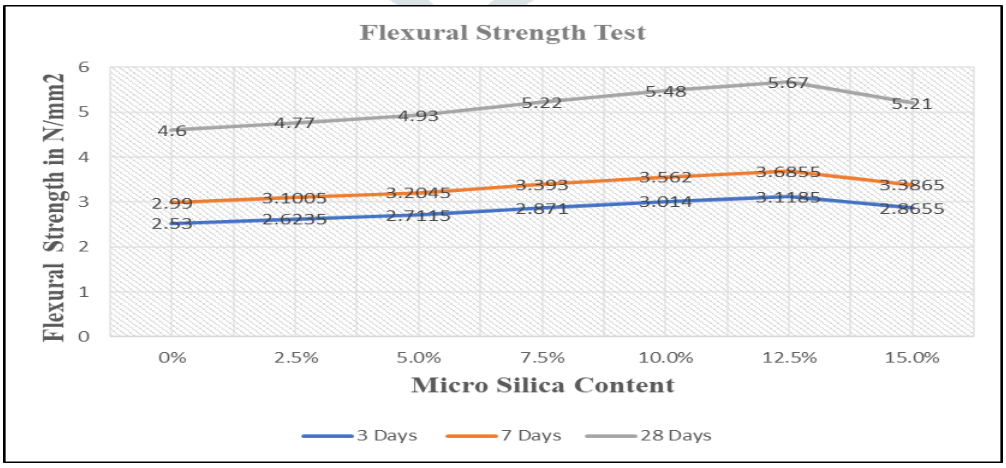
P = load in N applied to the specimen

l = length in mm of the span on which the specimen is supported (600)

b = measured width in mm of the specimen

d = measured depth in mm of the specimen at point of failure.

Partial replacement of cement with silica fume by 12.5% will increase the flexure strength up to 5.67 N/mm^2 compared to conventional concrete and further increase within the proportion of silica fume resulted in the decrement of the ultimate strength upto 5.21 N/mm^2.



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Graph No.4.4 : *Flexural Strength Test with partial replacement of cement with silica fume at 3, 7 and 28 days*

VI CONCLUSION

In the present work the effect of silica fume as partial replacement of cement on the compressive strength and split tensile strength, flexural strength of concrete is investigated. As well as workability of fresh concrete is studied. This work involves the study on the hardened and fresh properties of the concrete at M40 grades containing silica fume (SF) with various replacement percentages. Investigation on the performance of the SF was performed for M40 grades concrete with 0, 2.5, 5, 7.5, 10, 12.5 and 15 % replacement levels at 3, 7, 28 days the following observations were made from the experimental investigation conducted.

- For workability, compare with 7.50% replacement with silica fume it reduces upto 27% and when replaced by 15% of silica fume, workability reduces by 61%.
- For compressive strength compare with control mix, which means 100% cement 28 days strength is 47.4 N/mm2. As compressive strength increases by 20% when cement is partially replaced by silica fume by 12.5%. Then after again increases in replacement % upto 15% compressive strength lowers by 5% compared with its optimal value at 12.5% replacement. Beyond that proportion, there is no improvement in the strength achievement due to the large amount of fine particles in it.
- For split tensile strength compare with control mix, which means 100% natural sand 28 days strength is 3.56 N/mm2. As split tensile strength increases by 19.1% when cement is partially replaced by silica fume by 12.5%. Then after again increases in replacement % upto 15% split tensile strength lowers by 6% compared with its optimal value at 12.5% replacement.
- For flexural strength compare with control mix, which means 100% natural sand 28 days strength is 4.6 N/mm2. As flexural strength increases by 23% when cement is partially replaced by silica fume 12.5%. Then after again increases in replacement % upto 15% flexural strength lowers by 10% compared with its optimal value at 12.5% replacement.
- So, it was confirmed that, even though the strength properties are decreased for 15% replacement of cement by silica fume, blending upto of 12.5% silica fume with 87.5% cement gives better results.
- The smaller particle size of the silica fume has higher activity with lime resulting in higher compressive strength in the concrete mix.
- Increase in the percentage of silica fume decreases the workability of concrete as the finer silica fume having higher surface area tends to absorb more water reducing the slump value of the concrete.
- The strength increases with addition of silica fume at 2.5%, 5.0% 7.5%, 10% and 12.5% after that declines gradually for replacement of 15%.
- Flexural and split tensile strength of concrete also increase as compared to control mix upto 12.5% replacement but after that strength starts reduces.
- So finally, it concludes that upto 12.5% replacement by Silica fume is possible without any adverse effect on concrete.

REFERENCES

1) ACI234R-96 : Guide for Silica fume in concrete
2) Ali Mardani-Aghabaglou et. al, “Comparison of fly ash, silica fume and metakaolin from mechanical properties and durability performance of mortar mixtures view point”, Construction and Building Materials, 70 (2014) pp.17–25
3) A.M. Said et.al, “Properties of concrete incorporating nano-silica”, Construction and Building Materials, 36 (2012) , pp.838–844
4) Ashhad Imam et.al, “Review study towards effect of Silica Fume on the fresh and hardened properties of concrete”, Advances in Concrete Construction, Vol. 6, No. 2 (2018) pp.145-157
5) Arihant S. Baid et.al, “Effect of Micro-Silica on Mechanical Properties of Concrete”, International Journal of Engineering Research & Technology (IJERT), Vol. 2 Issue 8, August – 2013, pp230-238
6) Erhan Guneyisi, “Strength, permeability and shrinkage cracking of silica fume and metakaolin concretes”, Construction and Building Materials 34 (2012) pp.120–130
7) Gaurav Chand et.al, “Assessment of the properties of sustainable concrete produced from quaternary blend of portland cement, glass powder, metakaolin and silica fume”, Cleaner Engineering and Technology, 4 (2021) 100179
8) Hasan Biricik, “Comparative Study of the Characteristics of Nano Silica–, Silica Fume– and Fly Ash–Incorporated Cement Mortars, Materials Research. 2014; 17(3): pp.570-582
9) Hongjian Du et.al, “Durability performances of concrete with nano-silica”, Construction and Building Materials, 73 (2014) pp.705–712
10) IS 15388:2003: SILICA FUME — SPECIFICATION
11) IS 10086:1982: Specification for moulds using test of cement and concrete.
12) IS 1199:1959: Methods of sampling and analysis of concrete.
13) IS 516:1959: Methods of tests for strength of concrete.
14) IS 383:2016: Coarse and fine aggregate for concrete.
15) IS 10262:2019: Concrete mix proportioning – guidelines.
16) IS 5513:1976: Vicat apparatus – specification.
17) IS 4031 (Pat 4) - 1988 :Methods of physical tests for cement, Determination of consistency of standard of cement paste
18) IS 4031 (Pat 5) - 1988 : Methods of physical tests for cement, determination of initial and final setting times
19) IS 7320:1974: Specification for concrete slump test apparatus.
20) IS 456:2000: Plain and reinforced concrete -Code of practice.
21) IS15388:2003: Silica Fume Specification
22) Rafat Siddique, “Utilization of silica fume in concrete: Review of hardened properties”, Resources, Conservation and Recycling, 55 (2011) pp.923– 932

23) Rishav Garg et. Al,"Experimental study on strength and microstructure of mortar in presence of micro and nano-silica", Materials Today: Proceedings.2020
24) Rishav Garg, "Strength and microstructural analysis of nano-silica based cement composites in presence of silica fume", Materials Today: Proceedings
25) Manthar Ali Keerio et.al, "Effect of Silica Fume as Cementitious Material and Waste Glass as Fine Aggregate Replacement Constituent on Selected Properties of Concrete", Springer Nature B.V. 2020
26) M. Berra, "Effects of nanosilica addition on workability and compressive strength of Portland cement pastes", Construction and Building Materials 35 (2012) pp.666–675
27) Nayana A M et.al, "Strength and durability study on cement mortar with ceramic waste and micro-silica", International Conference on Advances in Materials and Manufacturing Applications [IConAMMA 2017]. Materials Today: Proceedings 5 (2018), pp24780–24791
28) S. Jagan et.al, "Effect of silica fume on the hardened and durability properties of concrete", International Review of Applied Sciences and Engineering, 12 (2021) 1, pp.44–49
29) Ye Qing et.al , "Influence of nano-SiO2 addition on properties of hardened cement paste as compared with silica fume", Construction and Building Materials 21 (2007) pp.539–545