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Study and Investigate Strength and Durability of Concrete Replaced with Silica Fume and Fly Ash

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ABSTRACT

The last few decades are well thought-out to be the era of the self-compacting concrete and thousands of researches has been carried out. In India, the development of concrete possessing self-compacting properties is still very much in its initial stages. Over the past couple of years, few attempts were made still the cost of production of such concrete is a challenging issue for the present concrete engineers. Hence, in the present study an attempt is done to understand the effect of copper slag as a mineral admixture on the properties of self compacting concrete. Hence, our attempt is to produce more economical, durable and sustainable SCC using mineral admixture. Basically the Fly Ash and Silica Fumes are industrial by-products. In this study, the optimal percentage of these by-products for partial replacement of cement is studied in respect of their resulting concrete's strength properties. For fly-ash, 5%, 10%, 15%, 20%, 25%, 30% and 35%, of replacement is tried and for silica fume, 0%, 4%, 6%, 8%, and 10%, of replacement is tried to arrive at their optimal replacement to get the desired strength and durability properties of the concrete. Compressive strengths were tested on cubes, split tensile strengths were tested on cylinders and flexural strengths were tested on beams. The specimen's durability properties were tested with sulphate and acid attacks.

Keywords : Self compacting concrete, Admixture, silica fume, fly ash, Durability test, Strength test.

I. INTRODUCTION

Concrete is a most frequently used building material which is a mixture of cement, sand, coarse aggregate and water. It is used for construction of multi-storey buildings, dams, road pavement, tanks, offshore structures, canal lining. The method of selecting appropriate ingredients of concrete and determining their relative amount with the intention of producing a concrete of the necessary strength, durability and workability as efficiently as possible is termed the concrete mix design. The compressive strength of hardened concrete is commonly considered to be an index of its extra properties depending upon a lot of factors e.g. worth and amount of cement water and aggregate batching and mixing placing compaction and curing. The genuine cost of concrete is related to cost of materials essential for produce a minimum mean strength called characteristic strength that is specific by designer of the structures. This depends on the quality control measures but there is no doubt that quality control add to the cost of concrete. The level of quality control is often an inexpensive cooperation and depends on the size and type of job now a days engineers and scientists are trying to enhance the strength of concrete by adding the several other economical and waste material as a partial substitute of cement or as a admixture fly ash, silica fume, steel slag etc are the few examples of these types of materials. These materials are generally by-product from further industries for example fly ash is a waste product from power plants and silica fume is a by-product resulting from decrease of high purity quartz by coal or coke and wood chips in an electric arc furnace during production of silicon metal or ferrosilicon alloys.

The use of micro silica as a pozzolana material has enhanced in recent years because when mixed in definite proportions it improves the properties of both fresh and hard concrete like durability, strength, permeability and compressive strength, flexural strength and tensile strength.

Silica Fume

Silica fume concrete is composed of cement, silica fume, fine aggregate, coarse aggregate, and water. Fresh and hardened properties of silica fume concrete is superior to conventional concrete. For instance, it has higher compressive and flexural strength.

The durability of this type of concrete is superior to conventional concrete. Resistance against freezing, thawing and chemical attacks is better than concrete without silica fume. Segregation and bleeding is low in silica fume concrete, and the mixture is adhesive compared to traditional concrete.

The applications of the silica fume concrete in construction are seen in high-rise buildings, parking structure, dam structure, nuclear waste storage facility, and shotcrete rehabilitation.

Advantages of Silica Fume

- Silica fume enhances the properties of fresh and hardened concrete.
- Silica fume reduces segregation and bleeding.
- High durability
- The finishing process is efficient due to low bleeding.
- High early compressive strength
- High flexural strength and modulus of elasticity
- High bond strength
- Suitable for mass concreting since it prevents thermally induced cracking

Fly Ash

Fly ash is a heterogeneous by-product material produced in the combustion process of coal used in power stations. It is a fine grey coloured powder having spherical glassy particles that rise with the flue gases. As fly ash contains pozzolanic materials components which reach with lime to form cementitious materials. Thus Fly ash is used in concrete, mines, landfills and dams.

Type of Fly Ash as per IS Codes (IS 3812-1981)

Grade I

This grade of Fly ash is derived from bituminous coal having fractions $SiO_2+Al_2O_3+Fe_2O_3$ greater than 70 %.

Grade II

This grade of Fly ash is derived from lignite coal having fractions $SiO_2+Al_2O_3+Fe_2O_3$ greater than 50 %.

Uses of Fly Ash

- Used in the manufacture of Portland cement.
- Typically used for embankment construction.
- Used as a soil stabilisation material.

- Fly ash is also used as a component in the production of flowable fill.
- Used as the filler mineral in asphalt road laying to fill the voids.
- Fly ash is used as component in geoploymers.
- Used in Roller compacted concrete dams.
- Used in the manufacture of fly ash bricks
- When flyash is treated with silicon hydroxide, it acts as a catalyst.

II. Objectives behind the research

The primary objectives behind the experimental investigation are listed below:

1. Study the various properties of fly ash and silica fume used as mineral admixture for partial cement replacement.
2. To study the workability properties of concrete when cement is partially replaced with fly ash with percentage 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% and silica
fume in concrete.
3. To study the various mechanical properties of concrete such as compressive, split tensile, flexural strengths and durability of concrete.

III. SURVEY OF LITERATURE

R. R. Parmar and Dr. J. D. Rathod (2022) Durability indices for medium strength concrete containing OPC, silica fume and fly ash in binary and ternary blending are evaluated by testing the specimens at 28 days, 56 days and 90 days. Oxygen permeability, water sorptivity and chloride conductivity tests are conducted to evaluate effectiveness of mineral admixtures in enhancing various transport mechanisms.

It is observed that macroscopic pore structure of the concrete material plays an important role in durability of the concrete instead of compressive strength. Results show that blending of silica fume and fly ash as a part replacement of OPC improvises durability performance which helps to elongate service life of reinforced structures in marine environment.

Vishal Prashar et.al (2022) research paper presented an experimental program to investigate the strength and durability properties of high-strength selfcompacting concrete (HSSCC) with and without steel fibers. Crimped-type steel fibers, fly ash and Alccofine was used as mineral admixtures to fulfil the power requirement. Chemical admixture was used for workability.

Results of plain and fibrous HSSC concrete indicated that steel fiber increases the tensile strength and makes concrete more durable and impermeable. Non destructive testing (NDT) results of concrete were found in good co-relation with actual test results. The results of acid and alkaline resistance test indicate that loss in strength and weight of concrete specimen was more in case of concrete without fibres as compared to fibrous concrete. The acid solution has more severe effect and both RCPT and water absorption test indicated that the concrete has dense matrix and hence very low permeability.

M.D.V.S.Sravani et.al (2021) objective of the research paper was to determine the optimal replacement percentages that can be appropriately used in Indian conditions and find the optimal replacement GGBS with the addition of silica fume in M60 grade concrete with maintaining water cement ratio of 0.32. Different concrete mixtures were prepared and tested with different levels of cement replacement (0 %, 10 %, 20 %, 30% and 40 %) of GGBS with active silica fume as addition (0 %, 5 %, 10 % and 15 % by weight of cement). Experiment was planned to compare 7 days and 28 days the strength parameters of concrete i.e., compressive strength, split tensile strength and flexural strength.

The compressive strength, flexural strength and split tensile strength are increased in combination of partial replacement of cement by GGBS in 30% and addition of silica fume in 10%. The use of Glenium B233 as Superplasticizer at a dosage of 0.3% shows better workability and uniformity in mixing of concrete. It is a good water reducing agent. For M60 grade, maximum compressive strength of 70.66 Mpa, Split tensile strength of 4.4 Mpa and Flexural strength of 7.8 Mpa had occurred for HPC3 i.e., 10% Silica Fume, 30% GGBS. In case of durability the HPC 3 i.e., 10% Silica Fume, 30% GGBS has shown better results in attaining resistance when compared with other trail mixes to resist acid action.

S. M. Ashar et.al (2021) experimental research investigated the effect of silica fume on the fresh and hardened properties of geopolymer concrete such as workability, compressive strength, split tensile strength and flexural strength.

Test results shows that as the percentage of silica fumes was increasing there was an increase till 12% there was increase in all three type of strength but further increment in the percentage of silica fumes leads to the reduction of strength as well as workability and makes the concrete tough to handle.

IV. MATERIAL AND PROPERTIES

Cement

A cement is a binder, a substance used for construction that sets, hardens, and adheres to other materials to bind them together. Cement is seldom used on its own, but rather to bind sand and gravel (aggregate) together. Cement mixed with fine aggregate produces mortar for masonry, or with sand and gravel, produces concrete. Concrete is the most widely used material in existence and is behind only water as the planet's most-consumed resource.

Cements used in construction are usually inorganic, often lime or calcium silicate based, which can be characterized as non-hydraulic or hydraulic respectively, depending on the ability of the cement to set in the presence of water (see hydraulic and non-hydraulic lime plaster).

Portland cement, a form of hydraulic cement, is by far the most common type of cement in general use around the world. This cement is made by heating limestone (calcium carbonate) with other materials (such as clay) to 1,450 °C (2,640 °F) in a kiln, in a process known as calcination that liberates a molecule of carbon dioxide from the calcium carbonate to form calcium oxide, or quicklime, which then chemically combines with the other materials in the mix to form calcium silicates and other cementitious compounds. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make ordinary Portland cement, the most commonly used type of cement (often referred to as OPC). Portland cement is a basic ingredient of concrete, mortar, and most non-specialty grout. The most common use for Portland cement is to make concrete. Concrete is a composite material made of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape, and once it hardens, can be a structural (load bearing) element. Portland cement may be grey or white.

Here in the research, Ordinary Portland Cement (OPC) of 53 Grade is used.

Constituents of Ordinary Portland Cement

The principal raw materials used in the manufacture of Ordinary Portland Cement are:

1. Argillaceous or silicates of alumina in the form of clays and shales.
2. Calcareous or calcium carbonate, in the form of limestone, chalk and marl which is a mixture of clay and calcium carbonate.

The ingredients are mixed in the proportion of about two parts of calcareous materials to one part of argillaceous materials and then crushed and ground in ball mills in a dry state or mixed in wet state. The dry powder or the wet slurry is then burnt in a rotary kiln at a temperature between 1400 degree C to 1500 degree C. the clinker obtained from the kiln is first cooled and then passed on to ball mills where gypsum is added and it is ground to the requisite fineness according to the class of product.

Composition and compound content of Portland Cement:

Table 1 Chemical constituents of Portland cement

Lime (CaO)	60 to 67%
Silica (SiO2)	17 to 25%
Alumina (Al2O3)	3 to 8%
Iron oxide (Fe2O3)	0.5 to 6%
Magnesia (MgO)	0.1 to 4%
Sulphur trioxide (SO3)	1 to 3%
Soda and/or Potash (Na2O+K2O)	0.5 to 1.3%

Table 2 Composition and Compound content of Portland Cement

Portland Cement	**Normal**	**Rapid hardening**	Low
(a) Composition: Percent			
Lime	63.1	64.5	60
Silica	20.6	20.7	22.5
Alumina	6.3	5.2	5.2
Iron Oxide	3.6	2.9	4.6
(b) Compound: Percent			
C3S	40	50	25
C2S	30	21	35
C3A	11	9	6
C3A	12	9	14

Table 3 Properties of OPC Cement

Properties	**Values**
Specific Gravity	3.12
Normal Consistency	29%
Initial Setting time	65min
Final Setting time	275 min
Fineness	330 kg/m2
Soundness	2.5mm
Bulk Density	830-1650 kg/m3

Fig 1 Ordinary Portland Cement (OPC)

Fine Aggregate

In the present investigation locally existing river sand is used as fine aggregate. The fine aggregate obtained from silt and clay and organic substances. In some standard tests were conducted for its various properties of sand like specific gravity and water absorption and fineness modulus. The fineness modulus of fine aggregate were initiate to be less than 4.75mm as per IS: 383-1970 and confirms the zone: II of sand.. The physical properties of fine aggregate shown in Table II. The sand particles should be free from any clay or inorganic materials and found to be hard and durable. Silt test is carried out to specify the limits of presence of organic matter and silt in fine aggregates. It was stored in open space free from dust and water.

Table 4 Physical properties of Fine Aggregate

Properties	Average values
Water absorption	2.52
Fineness Modulus	3.18
Specific Gravity	2.76
Silt content (%)	5.65
Organic matter	Nil
Particle Size and shape	4.75 mm irregular
Bulking of sand	4.15 %

Coarse Aggregate

If locally available angular size, machine crushed granite metal of normal size 20mm aggregate used as coarse aggregate. If is permitted some impurities such as powered dust, clay minerals and organic substances etc. in coarse aggregate also conducted some standard tests for its various properties. Coarse aggregate are available in different shape like rounded, Irregular or partly rounded, Angular, Flaky etc. It should be free from any organic impurities and the dirt content was negligible. There has been a lot of controversy on the subject whether the angular aggregate or rounded aggregate will make better concrete. They suggest that if at all the rounded aggregate is required to be used for economical reason; it should be broken and then used. But the angular aggregate are superior to the rounded aggregate from the following two points.

- It exhibits a better interlocking effect in concrete.
- The total surface area of rough textured angular aggregate is more than smooth rounded aggregate for the given volume.

Dried angular coarse aggregate of 20 mm maximum sized and 10 mm minimum size locally available was used for experimental work.

Table 5 Physical properties of Coarse Aggregate

Properties	Average values
Water absorption	2.03
Fineness Modulus	6.67
Specific Gravity	2.86
Organic matter	Nil
Partial size and shape	20 mm, angular
Bulk Density	1.795g/cc
Surface Moisture	0.5%

Water

Water is an important ingredient of concrete, as it actively participates in the chemical reaction with cement. Since, it helps to form the strength giving cement gel and required workability to the concrete. The quantity and quality of water is required to be checked very carefully. Portable water is used in concrete. Portable water is used and pH value is 6-7.

Silica Fume

Silica fume is the one of the pozzolonic material used in experiment. Silica fume is a byproduct produced from the manufacture of silicon or Ferro silicon industry from the reduction of large amount quartz with coal in electric arc. The physical and chemical properties of Silica Fume shown in table below.

Table Physical Properties of Silica Fume

Color of silica fume	Light to Dark grey
Specific gravity	2.2
Surface area	20000 m^2 /kg
Bulk density	450 /m^3

Table Chemical Properties of Silica Fume

Sio_2 %	91.45
Al_2O_3	0.6
Fe_2o_3	1.57
Cao	0.59
MgO	0.36
Na_2O	0.42
SO_3	0.14

Fly Ash

Fly ash is another pozzolonic material used in experiment. Fly ash is ensuring from the explosion of powered coal and transported by fuel gases and composed by electrostatic precipitation. Fly ash is purchased from Global Power Services for experimental purpose.

Table Physical Properties of Fly Ash

Fineness property	2.36
Specific gravity	3.1
Consistency property	45%
Grade of fly ash	C

Table Chemical Properties of Fly Ash

Sio_2 %	46.85
Al_2O_3	26.52
Fe_2o_3	11.38
Cao	6.96
MgO	2.15
Na_2O	1.04
SO_3	1.75

Superplasticizer

A commercially available sulphonated naphthalene formaldehyde based super plasticizer (MYK PC-20) was used as chemical admixture to enhance the workability of the concrete.

Experimental Investigation and Procedure

Mixing: Mixing as per mix design the silica fume is added to the conventional concrete by the different percentages of 0%, 2%, 4%, 6%, 8%, and 10% by weight. The maximum compressive strength rises from 2% to 6% after that it begins to decline this can be represented by the graph. The 0ptimum value is taken as 6% which gives higher compressive strength properties to cement mortar. This optimum mix of silica fume and cement is further replaced by the fly ash 0%, 10%, 15%, 25%, 35% to get the desired strength properties to the specimen.

Casting: To perform investigation in the above context the research proceeds with casting of 24 cubes of size 150mm*150mm*150mm, cylinders of size 150mm diameter and 300mm height, and size 2200mmx150mmx300mm. These specimens are undergone under various tests such as compressive strength, flexural and split tensile strength.

Curing: After completion of casting the curing is required for specimens. The curing duration may be varied for different type of specimens. For the cubes and cylindrical specimens are cured by ages of 7 and 28 days and beams were cured 28days curing period.

Mix Proportion

The main objective is to enhance the required workability, compressive, split tensile, flexural strengths and durability properties by adding blended materials such as silica fume and fly ash. As per IS: 10262-2009, guide lines were followed throughout the mix design. Here M30 grade concrete is used which yields the percentages of cement, fine aggregate and coarse aggregate by 1:1.960:3.720 with water/cement ratio of 0.42.To enhance the workability of concrete, Super plasticizer (MYK PC-20) of 1.77lit was used for 100 kg of cement.

V. RESULTS AND DISCUSSION

7 and 28 days of Compressive Strength between cement and silica at a time.

Silica Fume in %	7 days	28 days
0%	25.01	34.87
4%	39.01	48.91
6%	41.11	57.12
8%	32.62	46.78
10%	29.13	45.05

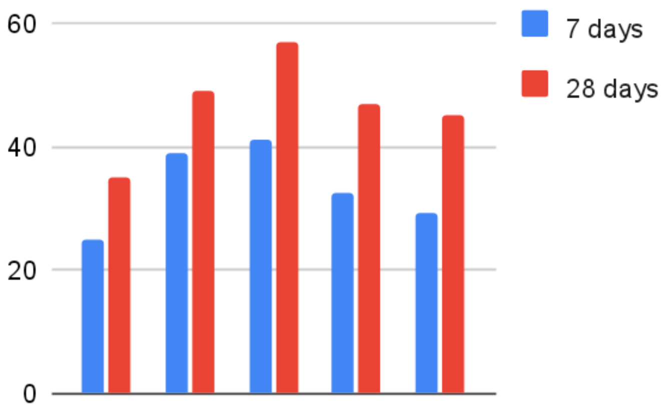
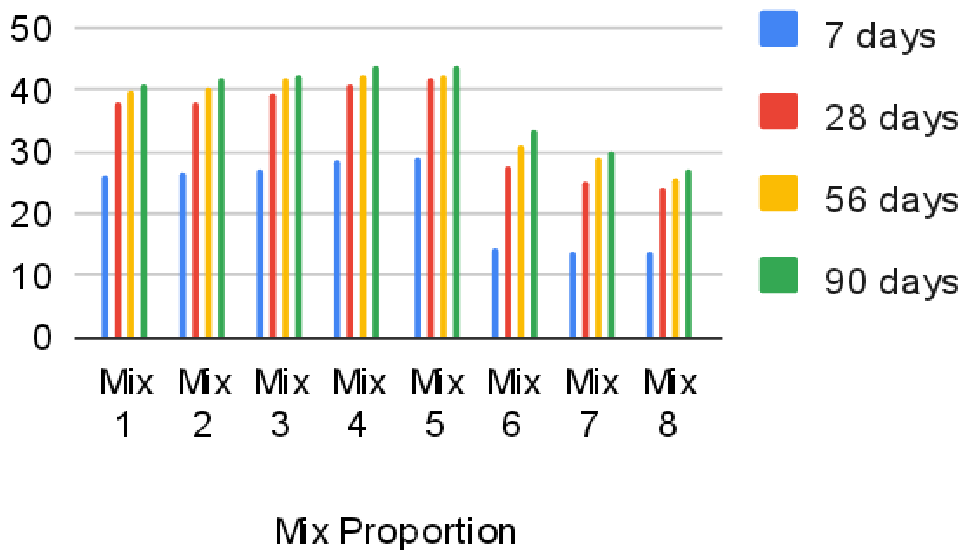


Fig 2 and 28 days of Compressive Strength between Cement and Silica Fumes.

Discussion: the most appropriate results were found with 6% of silica fumes providing the desirable results for strengthening the concrete mix.

Table Compressive Strength for the different mix in (N/mm2)

Mix Proportion	7 days	28 days	56 days	90 days
Mix 1	26.07	37.87	40.01	41.21
Mix 2	26.81	38.001	40.56	41.85
Mix 3	27.35	39.69	41.71	42.55
Mix 4	28.66	41.21	42.55	43.91
Mix 5	28.98	41.84	42.61	44.04
Mix 6	14.14	27.62	31.04	33.36
Mix 7	13.92	25.14	28.89	29.89
Mix 8	13.66	24.22	25.55	26.96



Discussion: the optimum workability in Concrete is found with 6% silica fume and 20% fly ash in the mix 5. The compressive strength gradually increases till mix 5 and a serious downfall in seen in further addition of Fly ash in the mixture. The compressive strength is evaluated for 7, 28, 56 and 90 days. The maximum compressive strength is achieved in mix 5 as 28.98 N/mm2 for 7 days, 41.84 N/mm2 for 28 days, 42.61 N/mm2 for 56 days and 44.04 N/mm2 for 90 days.

Split tensile Strength

Mix Proportion	7 days	28 days	56 days	90 days
Mix 1	2.51	3.14	3.48	3.71
Mix 2	2.56	3.21	3.59	4.03
Mix 3	2.61	3.26	3.88	4.19
Mix 4	2.75	3.34	3.91	4.36
Mix 5	2.76	3.49	3.96	4.41
Mix 6	2.46	2.91	3.42	3.52
Mix 7	2.44	2.68	3.29	3.42
Mix 8	2.43	2.52	3.11	3.39

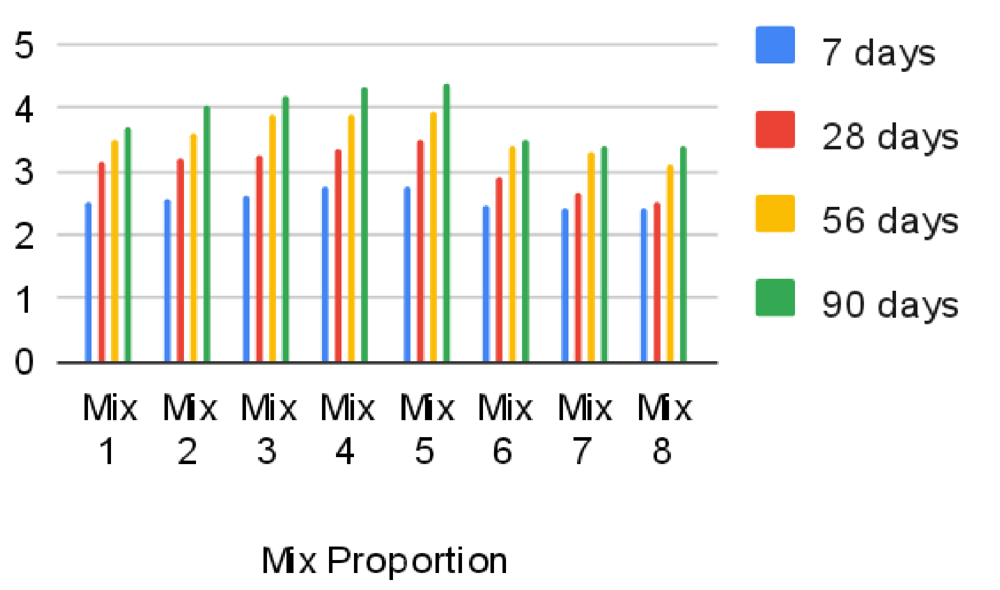


Fig 4 split tensile strength test on Concrete

Discussion: the maximum strength is achieved for mix 5 which is 6% silica fume and 20% fly ash. The maximum tensile is acieved as 2.76 N/mm2 for 7days, 3.49 N/mm2 for 28 days, 3.96 N/mm2 for 56 days and 4.41 N/mm2 for 90 days.

Durability Test on Concrete

H2SO4

Durability of H2SO4

Mix Proportion	Compressive Strength
Mix 1	27.89
Mix 2	28.45
Mix 3	28.98
Mix 4	30.09
Mix 5	30.33
Mix 6	26.41
Mix 7	24.25
Mix 8	21.16

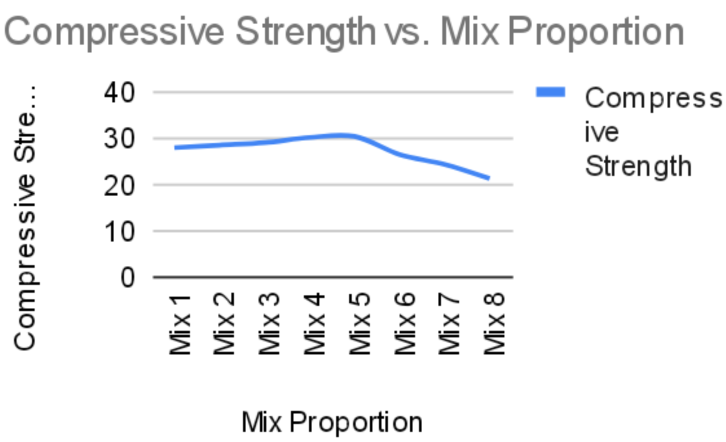


Fig durability of H2SO4

Discussion: the compressive strength of concrete is valuated for the cubes exposed to H2SO4. Here the maximum compressive strength is acthieved with mix 5 as 30.33 N/ mm2 and it reduced with further mixtures.

Nacl

Table Durability of Nacl

Mix Proportion	Compressive Strength
Mix 1	31.21
Mix 2	33.65
Mix 3	34.44
Mix 4	34.69
Mix 5	34.97
Mix 6	27.27
Mix 7	22.91
Mix 8	18.66

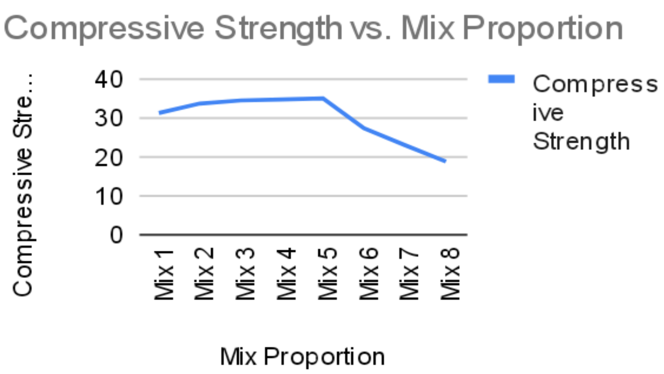


Fig Durability of Nacl

Discussion: here the maximum strength is achieved for mix 5 as 34.97N/mm2.

Conclusion

As the percentage of silica fume and fly ash in concrete mix increases, the workability of concrete increases. This is because fly ash is unable to absorb the water in large proportion.

- the most appropriate results were found with 6% of silica fumes providing the desirable results for strengthening the concrete mix.
- the optimum workability in Concrete is found with 6% silica fume and 20% fly ash in the mix 5. The compressive strength gradually increases till mix 5 and a serious downfall in seen in further addition of Fly ash in the mixture. The compressive strength is evaluated for 7, 28, 56 and 90 days. The maximum

compressive strength is achieved in mix 5 as 28.98 N/mm2 for 7 days, 41.84 N/mm2 for 28 days, 42.61 N/mm2 for 56 days and 44.04 N/mm2 for 90 days.

- the maximum strength is achieved for mix 5 which is 6% silica fume and 20% fly ash. The maximum tensile is acieved as 2.76 N/mm2 for 7days, 3.49 N/mm2 for 28 days, 3.96 N/mm2 for 56 days and 4.41 N/mm2 for 90 days.
- the compressive strength of concrete is valuated for the cubes exposed to H2SO4. Here the maximum compressive strength is acthieved with mix 5 as 30.33 N/ mm2 and it reduced with further mixture.
- the maximum strength is achieved for mix 5 as 34.97N/mm2 when the concrete is exposed to Nacl.
- The compressive strength of composite concrete (Fly ash + silica fume) attains its optimum value at 15% when compared with the acid attack concrete (NACl and H2SO4) for 28 days.

Future Scope

- The effect of EPS with FA on the mechanical properties of concrete may be studied.
- The effect of EPS on the mechanical properties of concrete may be studied.
- The effect of EPS with silica fume may be determined by By analyzing the experimental results of concrete.
- The effect of combined SF/FA may be determined by analyzing the mechanical properties of concrete.
- The effect of combined SF/FA with EPS may be determined by analyzing the concrete properties.

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