**IMPACT: Journal of Modern Developments in Civil Engineering
Architecture & Construction Management (IMPACT: JMDCEACM)
Vol. 1, Issue 1, Jun 2017, 25-40**

AN EXPERIMENTAL INVESTIGATION ON PARTIAL REPLACEMENT OF CEMENT BY SILICA FUME AND FINE AGGREGATE BY GLASS POWDER IN CONCRETE

L. SUMIT KUMAR SHUKLA

Department of Civil Engineering, Dhanalakshmi College of Engineering, Chennai, Tamil Nadu, India

ABSTRACT

Concrete is the most important engineering material and the addition of some other materials may change the properties of concrete like workability, durability, strength, and permeability. Engineers are trying to improve its performance with the help of innovative chemical admixtures, SCMs and waste materials thereby minimizing the consumption of natural resources.

Silica fume (SF) is very fine non-crystalline material, non-metallic and non-hazardous waste of industries. It is produced in electric arc furnace as a by-product of the production elemental silicon's or alloys containing silicon. It is usually grey color powder and SCMs .The effect of silica fume in concrete is because of its fineness and ability to replace certain amount of cement. SF improves both strength and durability of concrete and used in making high strength and high impermeability concrete.

Glass is widely used in our lives through manufactured products such as sheet glass, bottles, etc. In various places, damaged glass sheets & sheet glass cuttings are go to waste and usually delivered to landfills for disposal. We can conserve environment by using GP in concrete production.

The experiments aim is to find the strength of concrete by mixing highest % of replaced material together. By replacing different percentages of Silica fume as cement replacement (up to 20%) and Glass powder as fine aggregate replacement (up to 40%) for M25 grade concrete mix.

The concrete specimens were tested for compressive and splitting tensile strength at 7 and 28 days for 150 mm cubes and cylinder. The ingredients are mixed in 1: 1.43: 2.73 proportions with 0.45 w/c ratio. The results have indicated that the strength increases up to certain percentage (15% replacement of cement by SF), (20% replacement of FA by GP).

KEYWORDS: Silica Fume, Glass Powder, Cement, Natural Sand, Tensile Strength, Compressive Strength

INTRODUCTION

Concrete is a mixture of different materials like cement, sand, gravel and water. Its success lies in its versatility as can be designed to withstand harshest environments while taking on the most inspirational forms. Research Engineers are further trying to increase its limits with the help of innovative chemical admixtures and various supplementary cementitious materials SCMs. Nowadays, most concrete mixture replacement are done with mainly by-products or waste materials from other industrial processes.

Silica Fume

Silica fume also referred to as micro silica or condensed. it is a by-product material that is used as a pozzolan. This by-product is a result of the reduction of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume is replaced with cement to improve its properties like strength. Addition of silica fume also reduces the permeability of concrete to chloride ions, thereby protecting the reinforcing steel in concrete from corrosion, especially in chloride-rich regions such as coastal regions. During the last decade, considerable attention has been given to the use of silica fume as a partial replacement of cement to produce high-strength concrete.

Silica fume rises as an oxidized vapor from the 2000°C (3630°F) furnaces. When it cools it condenses and is collected in huge cloth bags. The condensed silica fume is then processed to remove impurities and to control particle size. It is extremely fine with particles less than 1 μm in diameter and about 100 times smaller than cement particles. Silica fume is used in amounts between 5% and 20% by mass of the total cementitiousmaterial.

Schematic diagram of silica fume production is in Figure 1.1.

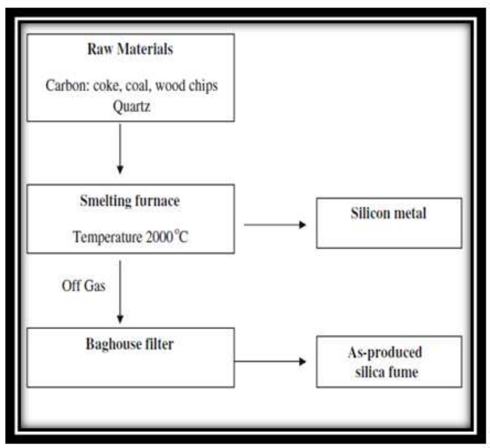

Figure 1.1: Schematic Diagram of Silica Fume Production

Reaction Mechanism

The silica fume reacts with this calcium hydroxide to form additional binder material called calcium silicate hydrate similar to cement. It is an additional binder that gives silica-fume concrete its improved properties. Silica fume Mechanism in concrete can be studied basically under three roles:

- Pore-size Refinement
- Reaction with Free-Lime (From Hydration of Cement)
- Cement Paste–Aggregate Interfacial Refinement

Availability and Handling

Silica fume is available dry and wet condition. Dry silica can be densified with or without dry admixtures and can be stored in silos and hoppers. Silica Fume slurry with dosages of chemical admixtures are available. Slurried products are stored in tanks. Global consumption of silica fume exceeds 1 million tonnes per annumdepending on the application and the available handling facilities. If required in bags, these can be tailored to suit the customers' needs for handling and batch weight per cubic metre of concrete.

Glass Powder

Natural resources are depleting worldwide while at the same time the generated wastes from the industry are increasing substantially. So development for construction involves the use of non-conventional, dumped materials, and recycled of waste materials in order to compensate the lack of natural resources and to find alternative ways conserving the environment.

In the backdrop of such a changed atmosphere, there is a huge demand for new materials from industrial waste. The materials like waste glass are collected from the dump yard are used. These collected glasses are crushed and make into small pieces like sand size and it could be used an alternate material for natural sand as partial replacement. So Utilization of glass as fine aggregate will turn this waste material into a valuable resource.

Glass is a transparent material produced by melting a mixture of materials such as silica, calcium carbonate etc. at high temperature followed by cooling where solidification occurs without crystallization. It is widely used in our lives through manufactured products such as sheet glass, bottles, glassware, and vacuum tubing and which are materials that can be recycled. The use of recycled glass saves lot of waste glasses and the increasing awareness of glass recycling speeds up focus on the use of waste glass with different forms in other fields. One of its important contributions is the construction field where the waste glass was reused for concrete production.

If fine aggregate is replaced by glass powder by specific percentage and in sand size range, it will reduce fine aggregate content and thereby reducing the ill effects of river dredging and thus making concrete manufacturing industry sustainable. The amount of waste glass produced has gradually increased over the recent years due to an ever growing use of glass products. When glass powder is reused in making concrete products, the production cost of concrete will go down and it will be environment friendly thereby reducing usage of natural resources.

But its applications are limited due to the damaging expansion in the Concrete caused by ASR between high-alkali pore water in cement paste and reactive silica in the waste glass is lower with lesser particle size of glass.

OBJECTIVES

The main objectives of this study are about:

- To partially replace cement by silica fume and sand by glass in concrete and to study the compressive strength of concrete.
- To determine the suitable percentage of silica fume and glass in concrete that gives the highest value concrete compressive strength.
- To find the compressive strength of concrete by mixing highest percentage of replaced materials together.
- To determine the compressive strength (7 and 28 days) and Split tensile strength (28 days) and compare it with the conventional concrete.

- To minimize demand, usage and cost of cement and fine aggregate (sand) in concrete construction.

METHODOLOGY OF THE STUDY

The materials and methodology used for producing the concrete mix are represented in Figure 2.1.

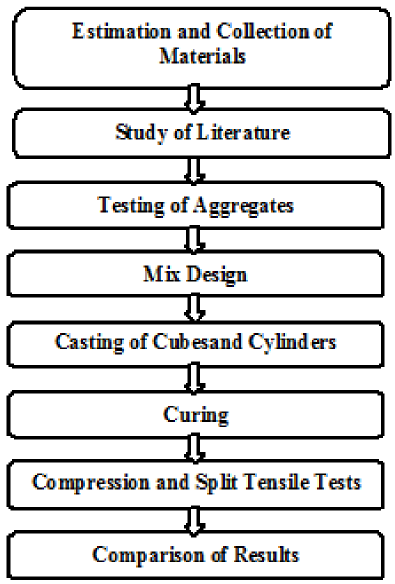

Figure 2.1: Methodology Flow Chart

MATERIAL USED

CEMENT

OPC from Zuari Cement Company was used for casting concrete. The Cement of 53 grade confirming to IS: 12269-1987 was used in the present study. The properties of cement used in the investigation are presented in Table 2.1.

Table 2.1: Properties of Cement

Sl No	Property	Value
1	Specific gravity	3.61
2	Fineness	97.8
3	Initial Setting Time	30 min
4	Final Setting Time	600 min
5	Standard Consistency	33%
6	Fineness Modulus	6%

WATER

The role of water is important because the water to cement ratio is the most critical factor in the design of perfect concrete. Excess of water reduces strength and workability of concrete. Potable tap water available in the plant conforming to the requirements of IS456 - 2000 was used for casting concrete & curing the specimens as well.

FINE AGGREGATE

An aggregate that passes through 4.75mm and is retained on 75 micron sieve is known as fine aggregate. Natural river sand passing through 2.36mm sieve was used and tested as per IS2386 (part 1) - 1963. The properties of fine aggregate investigated are presented in Table 2.2.

Table 2.2: Properties of Fine Aggregate

Sl No	Property	Value
1	Specific Gravity	2.62
2	Fineness Modulus	3.38
3	Water Absorption	0.5%
4	Surface Texture	Smooth
5	Bulk Density (kg/m^3)	1720

COARSE AGGREGATE

Aggregate that are retained on 4.75mm sieve passing through 80mm sieve are known as coarse aggregate. Cube specimens casted for M25 mix using coarse aggregates of maximum sizes 20mm. The physical properties were tested as per IS2386 (part 1) - 1963. Crushed aggregate confirming to IS: 383-1987 was used. The properties of the coarse aggregate are shown in Table 2.3.

Table 2.3: Properties of Coarse Aggregate

Sl. No	Property	Value
1	Specific Gravity	2.71
2	Fineness Modulus	7.22
3	Water Absorption	0.51%
4	Particle Shape	Angular
5	Impact Value	15.3
6	Bulk density (kg/m^3)	1646

SILICA FUME (MICRO SILICA)

Silica fume was procured from Rock fit Industries in tamilnadu. The Silica fume is used as a partial replacement of cement as specified with **IS 15388:2003** specification**.**it finer than cement and used by replacing cement in different percentages. Silica Fume is taken in, 5%, 10%, 15%, 20% by weight of cement.

Properties of Silica Fume

Silica fume particles are extremely small, with more than 95% of the particles finer than 1 µm. Its typical physical and chemical properties are given in Table 2.4. Silica fume colour is either premium white or grey (Figure 2.2). All the properties were given by the manufacturer and compared with Silica fume specification of Indian standards.

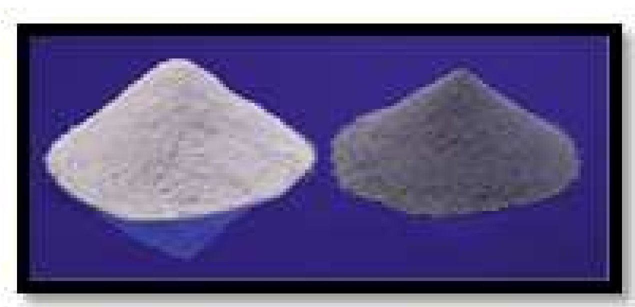

Figure 2.2: Silica Fume

Table 2.4: Physical and Chemical Properties of SF

Properties	Silica Fume
State	Amorphous - Sub-micron powder
Color	Gray to medium gray powder
Specific Gravity	2.10 to 2.40 (2.2 used)
Solubility	Insoluble
Bulk Density	550- 650 kg/m^3
Constituent	**Silica Fume**
Silicon Dioxide (SiO_2) ((%))	> 85
Free Si (%)	0.14
Free CaO (%)	<0.1 (lower limit detection)
SO_3 (%)	0.25
Na_2O eq (%)	0.5
CI (%)	<0.1
Pozzalanic Activity Index Normal Curing (28d)	110
Pozzalanic Activity Index Normal Curing (7d)	120
H_2O (%)	0.5
>45 µm (%)	<10
pH	8
Moisture Content (%)	Maximum 3.0 (%)
Loss on Ignition (LOI) (%)	2.0-3.0 (%)
Oversize percent retained on 45-µm (325 sieve)	Maximum 10.0 (%)
Specific Surface (BET)	>18 m^2/g

Glass Powder

Waste glass was collected from Glass industry, Chennai, India, consisting of Waste glass obtained from broken bus glass is used for this project. Crushing of glass pieces is done manually by hand crushing. Glass material is sieved through 2.36mm sieve. Then fine aggregate are partially replaced with glass powder in different percentages. Glass powder is taken in, 5%, 10%, 15%, 20%, 30% and 40% by weight of fine aggregate.

Properties of Glass Powder

The physical properties and chemical Composition of glass powder is given in Table 2.5 and Table 2.6. Sieved Glass powder is in Figure 2.3.

Table 2.5: Physical Properties of Glass Powder

Property	Glass Powder
Specific gravity	2.4-2.8 (2.49 used)
Bulk density	2.53
Moisture content (%)	Nil
Fine particles less than 0.075mm (%)	12-15
Sieve analysis	Zone

Table 2.6: Chemical Composition of Glass Powder

Constituent	Glass Powder (%)
Silica (SiO_2)	72.5
Alumina ($Al2O_3$)	01.06
Iron Oxide ($Fe2O_3$)	0.36
Lime (CaO)	08
Magnesia (MgO)	4.18
Sodium Oxide (Na_2O)	13.1
Potassium Oxide (K_2O)	0.26

Figure 2.3: Sieved Glass Powder

EXPERIMENTAL INVESTIGATION

A. Mix Proportioning

For this study, M 25 grade of concrete with mix ratio 1: 1.43: 2.73 and water cementitious ratios (w/cm 0.45), the quantities of materials used for w/cm ratio are worked out. Different types of concrete mix are prepared.

B. Fresh Concrete Test

Slump Cone Test (IS 1199 - 1959) is done with normal concrete and with replacement as shown in Table 3.1.

Table 3.1: Slump Cone Values

S. No	Cast Type	Values in Mm
1	Conventional Concrete	120
2	Silica fume - 5%	88
3	Silica fume - 10%	69
4	Silica fume - 15%	51
5	Silica fume - 20%	42
6	Glass powder - 10%	59
7	Glass powder - 20%	74
8	Glass powder - 30%	90
9	Glass powder - 40%	105
10	Silica fume - 15% + Glass powder -20%	63

Figure 3.1: Slump Test for Fresh Concrete

A true slump is obtained as in Figure 3.1.

Workability of Concrete

Workability is defined as the properties of freshly mixed concrete. In general terms, workability represents the amount of work which is to be done to compact the concrete in a given mould. A workable mix should not segregate, while measuring workability by conducting slump cone test (IS 1199-1959).

EXPERIMENTAL PROCEDURE

The specimen of standard cube of (150 mm x 150 mm x 150 mm) and standard cylinder (300 mm x 150 mm) was used to determine the compressive strength and split tensile strength of concrete. Two specimens were tested for 7 & 28 days with each proportion of silica fume and glass powder replacement. Total 48 cubes and 8 cylinders were casted for test. The material was weighed and the materials were mixed by manual mixing. The water cementitious ratio (w/cm) adopted was 0.45. The concrete was filled in different layers and each layer was compacted. The cast specimen was removed from mould after 24 hrs and were cured under normal conditions as per IS 516-1959 for 7 & 28 days and then tested for compressive strength as per IS 516-1959 and splitting tensile strength as per IS 5816-1999. The temperature of the cured water and the test room was 27 ± 2° C. The materials for each batch of moulds mixed separately using the quantities of dry materials, adapted to the proportions and the quantity of water was determined. In this paper M25 grade is used for designing mix proportions. The design procedure is detailed below. (Based on IS: 10262 – 1982) and mixing and casting is in Figure 3.2 and Figure 3.3.

Table 3.2: Mix Proportions for Concrete for 1m^3

Water	Cement	Fine Aggregate	Coarse Aggregate
191.58 liters	425.733 kg/m^3	605.22 kg/m^3	1162.59 kg/m^3
0.45	1	1.43	2.73

Figure 3.2: Concrete Mixing

Figure 3.3: Concrete Casting

TESTS RESULTS

COMPRESSION STRENGTH TEST

Procedure

Mixing the total material required for preparing the concrete with given proportions by hand mixing until proper concrete is obtained. Then prepared mixed concrete is poured in cube moulds in two layers each of approximately 75mm and ramming each layer with 35 blows. After 24hrs specimens are removed from the moulds and cured in water for 28 days and the cube and cylinder specimens are tested after removal from curing tank. The specimens are placed centrally on the compression testing machine and load is applied continuously without shock. The compression testing machine for concrete cubes as shown in figure 4.1.

Figure 4.1: Compression Test for Concrete Cubes

Compression Test on 7th day

The compression test for concrete cubes at 7 days is given in Table 4.1.

Table 4.1: Compression Test on 7 Days

S. No	Cube Trails	Average Maximum Load Applied (Kn)	Average Compression Strength(N/Mm^2)
1	Conventional Concrete	645	28.78
2	Silica Fume - 5%	654	29.05
3	Silica Fume - 10%	659	29.39
4	Silica Fume - 15%	691	30.72
5	Silica Fume - 20%	527	23.43
6	Glass Powder -5%	763	33.92
7	Glass Powder - 10%	752	33.45
8	Glass Powder - 15%	937	41.62
9	Glass Powder - 20%	1.57	46.96
10	Glass Powder - 30%	1003	44.56
11	Glass Powder - 40%	954	42.4
12	Silica Fume - 15%+ Glass Powder -20%	820	36.42

Compression Test on 28th day

The compression test for concrete cubes at 28 days is given in Table 4.2 and concrete curing and testing as in figure 4.2.

Table 4.2: Compression Test on 28 Days

S. No	Cube Trails	Avg Maximum Load Applied (Kn)	Avg Compression Strength(N/Mm^2)
1	Conventional Concrete	1038	46.13
2	Silica Fume - 5%	997	44.31
3	Silica Fume - 10%	1006	44.71
4	Silica Fume - 15%	1041	46.24
5	Silica Fume - 20%	927	41.2
6	Glass Powder - 5%	1107	49.18
7	Glass Powder - 10%	1150	51.09
8	Glass Powder - 15%	1163	51.67
9	Glass Powder - 20%	1480	65.76
10	Glass Powder - 30%	1214	53.93
11	Glass Powder - 40%	1127	50.07
12	Silica Fume - 15% Glass Powder -20%	1170	52

Inference

Compressive strength is the capacity of a material to withstand axially directed pushing forces. Normal casting of concrete when tested during its 7^{th} day of testing gives the lowest compressive strength value and when tested on its 28^{th} day of testing gives the maximum compressive strength value.

Figure 4.2: Cube Curing and Testing

Split Tensile Strength of Concrete Cylinder

Procedure

Test specimens are stored in water for 28 days and then tested in wet condition immediately after removal from the water. The weight and dimension of each specimen should be noted. The cylindrical specimen is placed horizontally and centrally between the loading surfaces of a compression testing machine. Then a narrow packing strips of suitable material such as plywood are placed centrally is to reduce the high compression stresses that acts during testing and the load is applied continuously till the specimen fails and the maximum load applied during the test is recorded. The split testing test for concrete cylinder as given in figure. 4.3.

Figure 4.3: Split Tensile Test for Concrete Cylinder

Split Tensile Test Result on 28Days: It is shown in table 4.3.

Table 4.3: Split Tensile Test on 28days

S. No	Cylinder Trials	Maximum Load Applied (Kn)	Average Compression Strength (N/Mm^2)
1	Conventional Concrete	127	1.80
2	Silica fume - 15%	132	1.86
3	Glass powder - 20%	227	3.22
4	Silica fume - 15%+Glass powder -20%	174	2.46

Inference

Tensile strength is the capacity of a material or structure to withstand axially directed pushing forces. When cylindrical specimen is tested during its 28th day gives the maximum tensile strength value. *C. RESULT COMPARISON*

Compression Test on Concrete Cube

The compression test Strength of concrete cube with SF and Glass Powder replacement can be seen in Chart. 4.1 and 4.2. A mixed concrete cube made with both 15%SF and 20%Glass Powder replacement is compared with other concrete cube can be in Chart. 4.3.

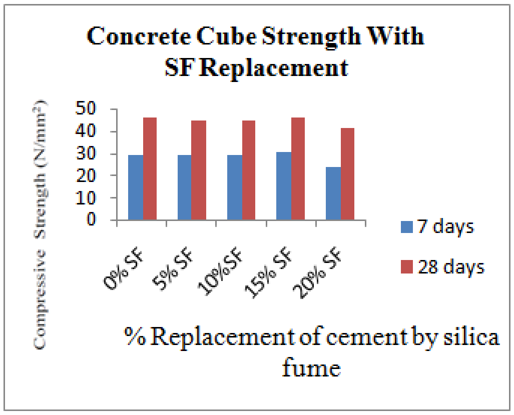

Chart 4.1: Graphs for Compressive Strength for SF Replacement

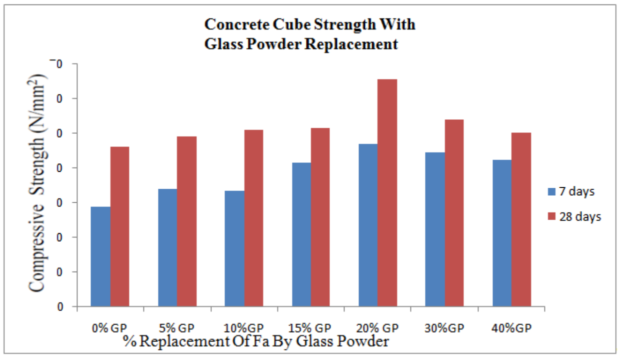

Chart. 4.2 Graphs for Compressive Strength for Glass Powder Replacement

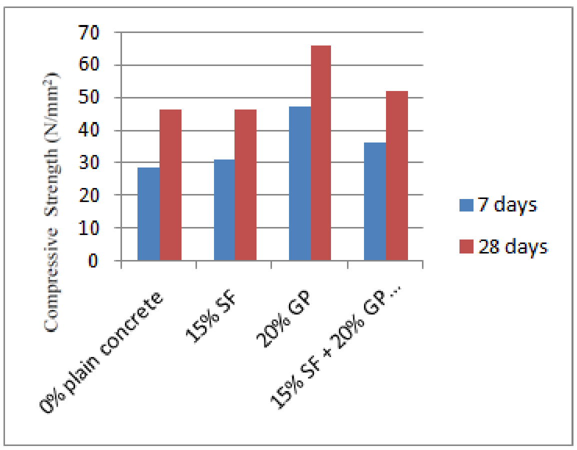

Chart. 4.3: Comparison of Compressive Strength of Concrete Cube

Split Tensile Test for Concrete Cylinder

The split tensile test for cylinder at 28 days strength is compared with plain concrete and 15%SF and 20%Glass Powder cylinder together as detailed in Chart. 4.4.

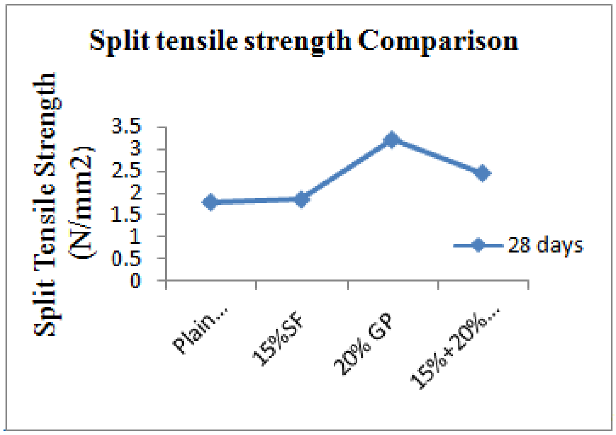

Chart 4.4: Graphs for Split Tensile Strength

RESULTS AND DISCUSSIONS

It have been observed that maximum compressive strength noted for 15% replacement of cement with silica fume with values (30.72 N/mm2 and 46.24 N/mm2) are higher than those of the conventional concrete (28.78 N/mm2 and 46.13 N/mm2) at 7 and 28 days, whereas split tensile strength of the Silica fume concrete (1.86 N/mm2) is increased by about 3.33% over those of the normal concrete (1.8 N/mm2) when 15% of cement is replaced by SF at 28 days and the characteristic strength of higher grade of cement concrete is achieved only by using the M25 grade designed mix proportion. Hence silica fume can be successfully used partially up to 15% as an alternate for cement with the increase in strength and durability of the concrete.

It is also observed that, up to 20% replacement of fine aggregate by glass powder the strength of concrete after 28 days is increased and however above 20% concrete strength decreases. GP can be successfully used partially up to 20% as an alternate for fine aggregate thereby reducing the environmental effects and scarcity of sand. GP concrete is strong and durable compared to sand concrete.

The cube compressive strength of GP concrete is 4.26% higher than conventional concrete and cylinder tensile strength of GP concrete is 7.89% higher than normal concrete at 28 days.

The compressive and split tensile strength of replaced concrete with SF and GP together values are (52 N/mm2 and 3.67 N/mm2) higher than normal concrete (46.13 N/mm2 and 1.8 N/mm2) and can be used as preservation of environment and natural resources.

CONCLUSIONS

In this paper it is concluded that the study on the partial replacement of cement with silica fume and thereby the results of the compression test and split tensile test reveals that silica fume can be used as an alternate for cement. Silica fume decreases the workability of the concrete with increase in % replacement in concrete. SF also reduces the cost of concrete and increases the compressive strength and split tensile strength of concrete.

It also concluded about the study on the partial replacement of fine aggregate with Glass powder and thereby the results of test reveals that glass powder can be used as an alternate for fine aggregate. GP increases the workability of the concrete with increase in % replacement in concrete.GP reduces the cost and increases the compressive strength and split tensile strength of concrete. The strength increases due to the interlocking properties of particles in the glass powder and Split tensile strength of concrete increases for glass powder is due to variation of shape and texture of glass powder.

The project main aim is to replace higher percentage of SF and GP in a single concrete together and find its strength. We have concluded from the test results that the cost and quantity of materials is reduced by using SF and GP together in a single concrete cube and cylinder.

On the basis of results obtained, following conclusions can be made:

- The strength of replacement of highest percentage of SF and GP together in concrete is more than conventional concrete.
- The highest percentage of SF is 15% and GP is 20% that can be replaced in concrete gives maximum strength with this replacement percentage.
- Both SF and GP concrete give higher strength then conventional concrete
- SF and GP can be replaced together in concrete to reduce cost and usage of cement and natural resources.
- SF can be used as replacement material to conserve cement and to produce ultra-high-strength and highly impermeable concrete.
- GP can prove to be light weight and economical as it is non-useful waste and free of cost.
- GP will eradicate the disposal problem of glass material and prove to be environment friendly thus paving way for greener concrete.
- GP will preserve natural resources particularly river sand and thus make concrete construction industry sustainable.

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