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Probabilistic Service Life Period of Glass Fiber Engineered Concrete with Supplementary Cementitious Materials

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ABSTRACT: Now a day, we need to look at a way to reduce the cost of building materials, particularly cement is currently so high that only rich people and governments can afford meaningful construction. Studies have been carried out to investigate the possibility of utilizing a broad range of materials as partial replacement materials for cement in the production of concrete. This study investigated the strength properties of Silica fume concrete. This would save not only the natural resources and energy but also protect the environment with the reduction of waste material. As a recent development, supplementary cementitious materials (SCM's) are being increasingly used in concrete for improvement in its properties and for reducing amount of cement. The commonly used SCMS such as silica fume, Calcium carbon material, Metakaolin and slag are widely used because of their significant contribution and availability in improving the concrete properties. To produce environment friendly "green concrete" at low cost and in view of sustainability, the partial replacement of cement by SCMS in concrete is employed Silica Fume is a very fine powder consisting mainly of spherical particles or microspheres of mean diameter about 0.15 microns, with a very high specific surface area (15,000-25,000 m²/kg). To fulfil the objective various properties of concrete using silica fume have been evaluated. Further to determine the optimum replacement percentage comparison between the regular concrete and concrete containing silica fume is done. In this research cement is replaced by silica fume 15% and 30% by weight. Due to increase in the growth of industrial sectors the power requirement of the country is rapidly increasing. India depends on Thermal Power as its main source, thus increase in power requirement every year. Present scenario of our country shows 75 % of country's total installed power generation is thermal of which coal-based generation is 90%. The coal reserves of the country are predominately of lower grades (average of 35% ash content), non cooking and as a result more than 110 million MT coal ash is being generated every year. Ash generation may likely reach to 170 million MT by 2012. Use of coal brings huge amount of ash every year. Lots of research has been carried out for effective utilization of silica fume in construction industries due to its fine particles and Pozzolonic properties. But little literature is available on pond ash utilization. Pond ash being coarser and less Pozzolonic than silica fume can be used as fine aggregates in concrete by partial replacement of sand. Extensive study has been undertaken through the project to explore the possibility of utilizing the silica fume and pond ash in the construction industry. Especially in concrete and from view of sand becoming scarce & contaminated with harmful chemicals & pond ash accumulation posing environmental problems, replacement of sand by pond ash in concrete attempted without compromising on workability and strength. Pond ash sample was procured from NSPCL, Bhilai. Characterizations of silica fume and pond ash sample were carried out and results indicated that pond ash sample can be tried as fine aggregate in concrete and silica fume as cement. The goal of this project is to develop a "green" Engineered Cementitious Concrete (ECC) and to demonstrate the good performance of this "green" ECC. In this thesis, "green" refers to sustainable and environmental-friendly. Hence in this project the cement is replaced with silica fume upto 40% and sand is replaced with pond ash upto 20% simultaneously and workability, durability and strength of this composite concrete is studied. It is concluded that the replacement of silica fume with cement gives positive result in workability but replacement of sand with pond ash restricted upto 20%.

KEYWORDS: Green Concrete, Engineered Cementitious Concrete (ECC), Silica Fume, Pond Ash, Supplementary Cementitious Materials (SCMs), Fine Aggregate Replacement, Industrial Waste Utilization, Sustainability.

I. INTRODUCTION

1.1 GENERAL

Concrete is the most versatile construction material because it can be designed to withstand the harshest environments while taking on the most inspirational forms. Concrete is the second most consumed material after water by mankind. Thus it is not surprisingly that the second most populous country in the world, that is India, is also the second highest consumer of cement in the world after China. The concrete structures stands without any reported distress even today, although exposed to extremely aggressive marine environment. Concrete possesses a high compressive strength and is usually more economical than steel and is not subjected to corrosive weathering. It has the distinction of being formed into any shapes. Hence concrete is used in all present day construction and also engineers are continually pushing the limits to improve its performance with the help of innovative chemical admixtures and supplementary cementitious materials.

1.2 CEMENT CONCRETE

The cement concrete is specified by proportions of different ingredients. It is composite man made material obtained by mixing cement, fine aggregate, coarse aggregate and water in predetermined proportions. Sometimes admixtures are also added to improve certain qualities. In this way or by substitution for the cementitious and aggregate phase, the finished product can be tailored to its application with varying strength, density, or chemical and thermal resistance properties.

The moulded concrete mix after sufficient curing becomes hard like stone due to chemical action between the water and binding material. Concrete is most widely used for making architectural structures, bridges, pavements etc. The major factor responsible for most wide usage of cement concrete are mouldability, early hardening, suitability for guniting, pumpability and durability.

The basic ingredients are as follows: Cement, Sand, Aggregate, Water, Admixture,

1.3 FIBRE –REINFORCED CONCRETE

In recent years, several studies have been conducted to investigate the flexural Strengthening of reinforced concrete (RC) members with fiber reinforced composite fabrics. In this composite material, short discrete fibers are randomly distributed throughout the concrete mass. The behavioural efficiency of this composite material is far superior to that of plain concrete and many other construction materials of same cost. Due to this benefit, the use of FRC has steadily increased during last two decades and its current field of application includes airport and highway pavements, earthquake resistant and explosive resistant structures, mines and tunnel linings, bridge deck overlays, hydraulic structures, rock slope stabilization.

Extensive research work on FRC has established that the addition of various types of fibers such as

- Steel fiber
- Glass fiber
- Synthetic fiber
- Carbon fiber

It concrete improves strength, toughness, ductility, and post cracking resistance etc. The major advantages of fiber reinforced concrete are resistance to microcracking, impact resistance, and resistance to fatigue, reduced permeability, and improved strength in shear, tension, flexure and compression.

FRC is defined as “concrete made primarily of hydraulic cements, aggregates, and discrete reinforcing fibres” by the American Concrete Institute (ACI) Committee 544 (2008). The fibres can be made from a variety of materials such as steel, carbon, glass, plastic, polypropylene, nylon, and cotton. ACI committee 544 (2008) categorized FRC into four major groups: Steel Fibre Reinforced Concrete (SFRC), Glass Fibre Reinforced Concrete (GFRC), Synthetic Fibre Reinforced Concrete (SNFRC), and Natural Fibre Reinforced Concrete (NFRC). Not all fibres are ideal for the concrete matrix; the following properties are important for fibres in order to obtain satisfactory performance as reinforcement for the concrete matrix.

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- The fibres should have a higher tensile strength than the matrix in order to carry the tensile stresses after cracking.
- The fibres should be able to withstand high tensile strains in order to have significant deformation before fracturing; this helps to provide significant toughness to the FRC matrix.
- The fibres should have a higher elastic modulus than concrete to reduce the post cracking composite strain.
- The fibres' Poisson's ratio should be low to avoid fibre debonding.
- The fibres should be elastic and not prone to creep to avoid stress relaxation.
- The fibres should be physically and chemically compatible with the concrete matrix..

1.4 GLASS FIBER REINFORCED CONCRETE

Fibre is a natural or synthetic string or used as a component of composite materials, or, when matted into sheets, used to make products such as paper, papyrus, or felt. Concrete is brittle by nature and is weak in flexure as well as direct tension therefore in order to improve these properties fibres are added to concrete. Fibres may be short discrete or in forms of rods or may be even in form of textile fibres or woven mesh fibres.

II. LITERATURE SURVEY

2.1 GENERAL

Fibre reinforced concrete (FRC) is a concrete made primarily of hydraulic cements, aggregates and discrete reinforcing fibres. FRC is a relatively new material. This is a composite material consisting of a matrix containing a random distribution or dispersion of small fibres, either natural or artificial, having a high tensile strength. Due to the presence of these uniformly dispersed fibres, the cracking strength of concrete is increased and the fibres acting as crack arresters. Fibres suitable of reinforcing concrete having been produced from steel, glass and organic polymers. Many of the current applications of FRC involve the use of fibres ranging around 1% by volume of concrete. Recent attempts made it possible to incorporate relatively large volumes of steel, glass and synthetic fibres in concrete. Results of tensile tests done on concretes with glass, polypropylene and steel fibres indicate that with such large volume of aligned fibres in concrete, there is substantial enhancement of the tensile load carrying capacity of the matrix. This may be attributed to the fact fibres suppress the localization of micro-cracks into macro cracks and consequently the apparent tensile strength of the matrix increases.

III. METHODOLOGY

The main purpose of this research was to investigate the potential of replacing the cement and fine aggregate by silica fume and pond ash in concrete mixtures and identify the properties of the mixture, its workability, durability, and strength. This will also avert the exhaustion of natural resources, enhancement of the usage of waste materials, safe guarding global environment, and overall a change over from the mass-production, mass consumption, mass waste society to a zero-emission society. This chapter introduces the details of raw material used, their characterization, parameters investigated, detail procedure of experimental works and the methodologies adopted.

Table-: Service Life Period of Various Mixes

Mix	K($\Omega\text{cm}^3/\text{year}$)	ρ_0 (k Ω cm)	r	CD (mm)	X (cm)	t (years)
w/c=0.45						
C0-0	5000	27	1.8	10	1.5	94.3
F0-0	2850	30	1.8	7	1.8	264.7
F20-0	2850	34.5	1.8	12	1.3	158.8
F40-0	2850	39	1.8	15	1	106.2
F0-10	2850	33	1.8	11	1.4	176.1
F0-20	2850	36	1.8	12	1.3	165.7
F20-10	2850	40.5	1.8	14	1.1	133.4
F20-20	2850	45	1.8	16	0.9	99.2
F40-10	2850	46.5	1.8	17	0.8	81.0
F40-20	2850	51	1.8	20	0.5	34.7
w/c=0.35						

C0-0	5000	33	1.8	7	1.8	165.9
F0-0	2850	37.5	1.8	5	2	408.4
F20-0	2850	43.5	1.8	8	1.7	342.3
F40-0	2850	49.5	1.8	12	1.3	227.8
F0-10	2850	40.5	1.8	8	1.7	318.7
F0-20	2850	45	1.8	9	1.6	313.7
F20-10	2850	51	1.8	10	1.5	312.4
F20-20	2850	55.5	1.8	12	1.3	255.4
F40-10	2850	58.5	1.8	14	1.1	192.7
F40-20	2850	63	1.8	17	0.8	109.8

Table:- Mix Proportions of Concrete Containing Different Water to Cementations Materials Ratios

Mix	Cement (kg/m ³)	Sand (kg/m ³)	Aggregate (kg/m ³)	S.F. (kg/m ³)	Pond Ash (kg/m ³)	Water (kg/m ³)	Admixture (kg/m ³)	Fiber (kg/m ³)
w/c=0.35								
C ₀₋₀	450	902	948	0	0	167	3.4	0
F ₀₋₀	450	902	948	0	0	167	3.4	2.65
F ₂₀₋₀	360	902	948	90	0	166	3.4	2.65
F ₄₀₋₀	270	902	948	180	0	166	3.4	2.65
F ₀₋₁₀	450	812	948	0	90	170	3.4	2.65
F ₀₋₂₀	450	722	948	0	180	173	3.4	2.65
F ₂₀₋₁₀	360	812	948	90	90	170	3.4	2.65
F ₂₀₋₂₀	360	722	948	180	180	173	3.4	2.65
F ₄₀₋₁₀	270	812	948	90	76	170	3.4	2.65
F ₄₀₋₂₀	270	722	948	180	152	173	3.4	2.65
w/c=0.45								
C ₀₋₀	367	919	966	0	0	175	2.75	0
F ₀₋₀	367	919	966	0	0	175	2.75	2.65
F ₂₀₋₀	294	919	966	73	0	174	2.75	2.65
F ₄₀₋₀	220	919	966	146	0	174	2.75	2.65
F ₀₋₁₀	367	874	966	0	92	178	2.75	2.65
F ₀₋₂₀	367	735	966	0	184	182	2.75	2.65
F ₂₀₋₁₀	294	874	966	73	92	178	2.75	2.65
F ₂₀₋₂₀	294	735	966	73	184	181	2.75	2.65
F ₄₀₋₁₀	220	874	966	146	92	177	2.75	2.65
F ₄₀₋₂₀	220	735	966	146	184	181	2.75	2.65

IV. EXPERIMENTAL RESULTS

4.1 GENERAL

Engineered Cement Concrete is the modified High Performance Fiber Reinforced Cementitious Composites with significant strain hardening behavior under tension. It possesses high ductility and improved durability due to tight crack width. This type of cracking better protects the concrete from the introduction of solvents and corrosive elements while also promoting the reactions that cause self healing. Both ductility and self healing properties is developed in side Engineered Cement Concrete due to small size of coarse aggregate.

Now a days most of people concern rarely on material sustainability in the development of High Performance Fiber Reinforced Cement Concrete (HPFRCC). Hence pond ashes are introduced to replace the sand partially up to 20%. Additional testing also showed that the introduction of silica fume to the Engineered Cementitious Concrete mixture would increase the mechanical properties and decrease average crack width to around ten micrometers, thus promoting a quicker and more filled self-healing sample [Yang etal (2007)]. Also addition of silica fume increases the workability

of concrete. To achieve above qualities silica fumees are introduced which replaces the cement upto 60%. In this experiment glass fibers are used instead of PVA fiber in ECC, because glass fiber has more tensile strength than PVA fiber. This experiment is carried out to examine High Performance Cementitious Concrete incorporating binary blends of silica fume (SF) and pond ash (PA) for the purpose of workability and strength of new mix. This study demonstrates the feasibility of creating greener ECC, which maintain the tensile ductility characteristics but also incorporate sustainability consideration.

During the last three decades, great strides have been taken in improving the performance of concrete as a construction material. Particularly Silica Fume (SF) and silica fume individually or in combination are indispensable in production of high strength concrete for practical application. The use of silica fume as a pozzolana has increased worldwide attention over the recent years because when properly used it as certain percent, it can enhance various properties of concrete both in the fresh as well as in hardened states like cohesiveness, strength, permeability and durability. Silica fume concrete may be appropriate in places where high abrasion resistance and low permeability are of utmost importance or where very high cohesive mixes are required to avoid segregation and bleeding. Silica fume is a by-product in the production of silicon alloys such as ferro-chromium, ferro-manganese, calcium silicon etc. which also creates environmental pollution and health hazard. Due to superfine nature of SF particles, SF concrete has shown more cohesiveness than standard ordinary Portland cement concrete. All the mixes have exhibited satisfactory character in relation to workability. But with the increase in percentage of SF, the stickiness in concrete was observed.

In all the mix, the compacting factor, i.e, workability increases as percentage of SF is increased from 3% till 17%. SF concrete is just as susceptible to poor workmanship as ordinary concrete and all normal site operations should be performed to the optimum requirements.

4.2 COMPARATIVE STUDIES OF WORKABILITY TESTS

The objective of the research is to investigate the workability of new eco-friendly engineered cement composites like slump value, compaction factor by replacing cement and sand partially with silica fume and pond ash. The above three tests of workability's are carried and tabulated in previous chapter. From Table-3.1 it is seen that the slump value of low water cement ratio is very less. When the sand replacement material increases slump value gradually decreases. This phenomenon happens due to water demanding of pond ash. High volume of sand absorbs water on its surface; hence the slump cone material does not subside with higher percentage. The lower value slump indicates the harassment of material. Figure-4.1 indicates the slump value of different mixes of new fiber reinforced concrete. As the silica fume increases, the lubrication action in between the particles of composite accelerates. Replacement 40% silica fume with cement gives higher value of slump as well as percentage of flow as shown in Figure-4.1.

Similarly greater value of compaction factor is obtained for control volume. As the percentage of cement and sand replacement material increases the compaction factor decreases gradually. The weight density of sand is more than the weight density of silica fume and pond ash. Therefore the partial compaction of sand due to freely falling of its own weight is more than the partial compaction values of silica fume and pond ash. The numerator value of compaction factor is more for control volume results the highest value of compaction factor.

Silica fume does not affect the compaction factor seriously, but the replacement of pond ash decreases the compaction factor. As the pond ash replaced 20% the compaction factor gives lower value. The reason behind for decrement of compaction factor due to pond ash is increment of voids. When pond ash comes in contact with water its volume slightly increased. It created pores inside the concrete and results the decrement of compaction factor value.

Similarly the percentage of flow of mixed material is very less than the control volume. When the percentage of pond ash increases it demands water more. Hence the increment of pond ash results the low flow percentage. On the other way the value of flow percentage increases by addition of silica fume. Hence workability increases gradually as percentage of silica fume in mix increases. The following observations are seen from the experiment.

- (i) It is seen that slump height and percentage of flow is more for 0.45 water cement ratios than the 0.35 water cement ratios.
- (ii) When 0.1% volume of fraction fiber was introduced in concrete the workability was reduced near about to 13% and percentage flow decreased near about to 24%. Compaction factor was also decreased w.r.t. control concrete by 6%.

(iii) When the percentage of replacement of cement with silica fume increased both slump and percentage of flow increased. It was seen that highest slump and percentage of flow achieved when 40% cement was replaced with silica fume. Compaction factor is also increased about 3 to 4% than the control concrete for both w/c.

(iv) Similarly the increment of percentage replacement of sand with pond ash decreased the workability of concrete. The lowest slump height and flow percentage was noted when 20% of sand was replaced by pond ash. Compaction factor also decreased 12% than control concrete when 20% sand replaced with pond ash.

(v) On both replacement slump height and flow percentage was remained in between 40% replacement of cement with silica fume and 20% replacement sand with pond ash. But on both replacement of cement and sand by silica fume and pond ash shows maximum compaction factor among fiber reinforced mix. The compaction factor of F20-10 has greater value above fiber reinforced mix and it is nearer to compaction factor of control concrete. are detected.

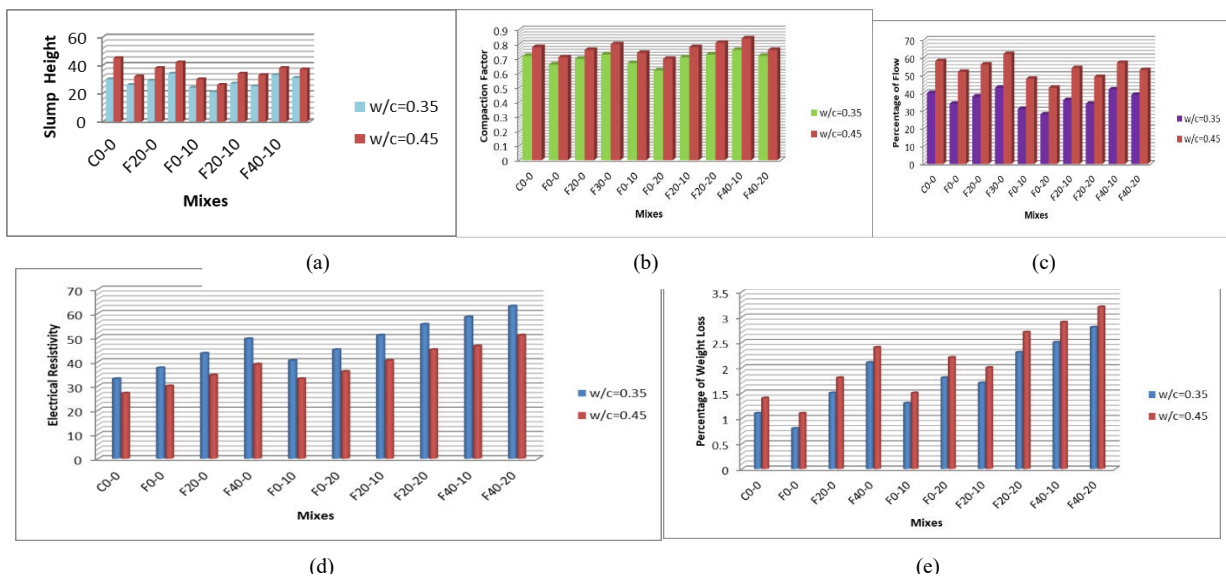


Fig. 1: Workability of Different Mixes of Concrete on Different Water Cement Ratios (a) Test Results of Slump Value for Different Mixes (b) Test Results of Compaction Factor for Different Mixes (c) Test Results of Percentage of Flow for Different Mixes (d) Electrical Resistivity of Different Mixes of Concrete on Different Water Cement Ratios (e) Weight Loss due to Acid Attack of Different Mixes of Concrete on Different Water Cement Ratios.

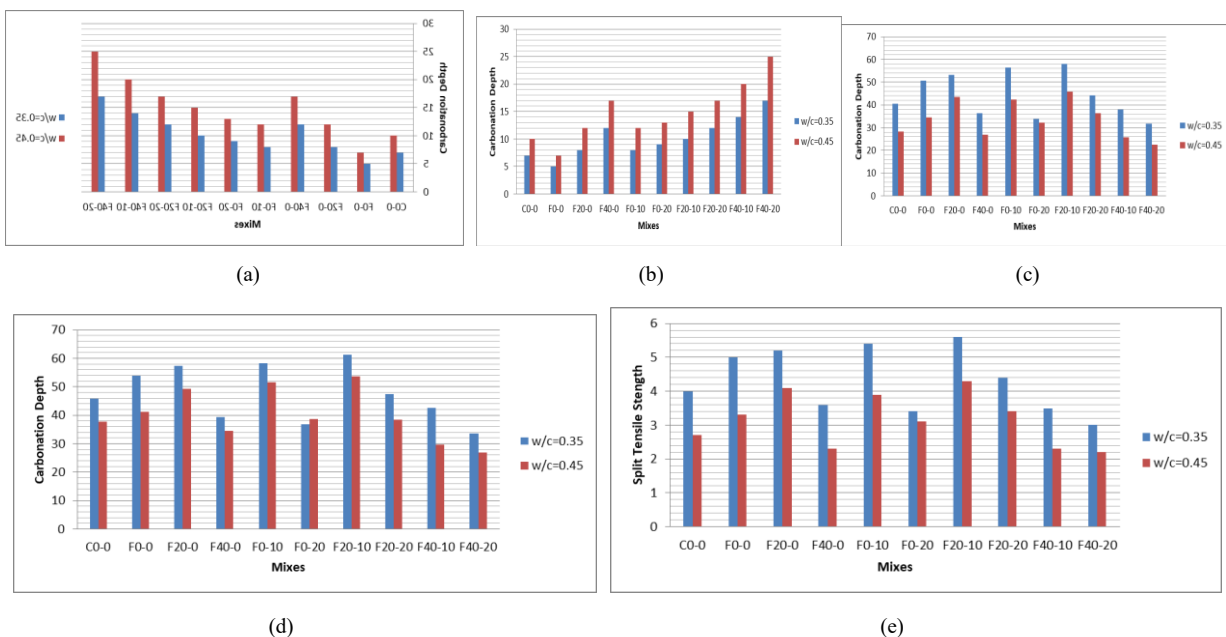
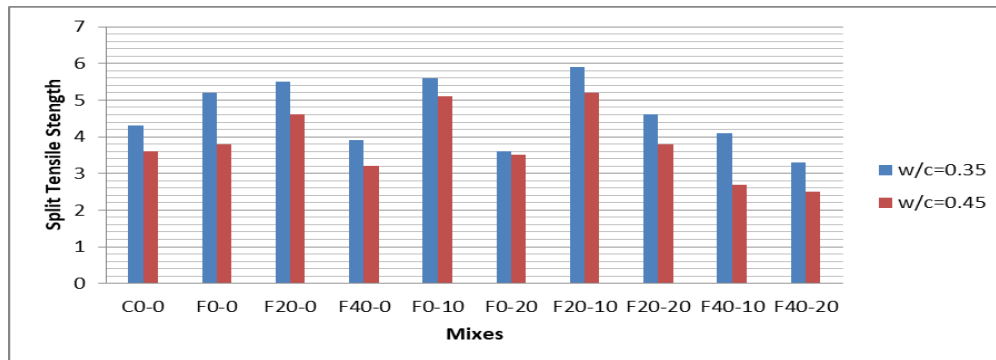


Fig. 2 Effect of SEM on Carbonation Depth of Concrete on Different Water Cement Ratios, Compressive Strength of Different Mixes for Different Curing Periods, Split tensile Strength of Different Mixes for Different Curing Periods, (a) Weight Loss due to Acid Attack of Different Mixes of Concrete on Different Water Cement Ratios (b) 28 days Compressive Strength of Different Mixes (c) 28 days Compressive Strength of Different Mixes (d) 28 days Split Strength of Different Mixes (e) 90 days Split Strength of Different Mixes.



(a)

Fig. 3 : Split tensile Strength of Different Mixes for Different Curing Periods.

V. CONCLUSION

The following points are concluded in our research project

- (i) The silica fume and pond ash act as best sustainable material in Engineered Cement Concrete.
- (ii) Silica fume increases the workability of concrete. As the percentage of replacement of cement with silica fume increases, the slump cone value and the percentage flow increases correspondingly.
- (iii) Replacement of sand with pond ash demands water more in concrete. As the percentage of pond ash increases, the slump value and percentage of flow decreases gradually. It also decreases the compaction factor value.
- (iv) For workability point of view the percentage of silica fume may increase above 40% but the percentage of pond ash should not be increase more than 20%. Beyond the 20% replacement of sand with pond ash makes the concrete harsh.
- (v) So it is the better option to replace cement and sand should be replaced simultaneously. The water demand due to addition of pond ash may counter balance with the addition of silica fume.
- (vi) The surface area of glass fiber is more. Therefore it also absorbs more water on its surface than other fiber, which hampers on workability. So ECC will act as best in lower volume of fraction of glass fiber.
- (vii) The other disadvantage of glass fiber is mixing process with dry materials of concrete. It requires separating small fibers from the fiber lumps. The spinning action of glass fiber takes more time to prepare the concrete. It also does not mix homogeneously in concrete.
- (viii) As the amount of sand is more in Engineered Cement Concrete, it requires more cement. Therefore ECC is an expensive material. So it is suggested to replace cement and sand with silica fume and pond ash partially solves the problem of sustainability and makes the concrete economic.
- (ix) The introduction of 0.1% glass fiber of total volume decreased the carbonation depth 30% and improved the both electrical resistivity, compressive strength and split tensile strength.
- (x) When cement is replaced with silica fume up to 40% in concrete by weight the electrical resistivity increases 33%, resistance against acid attack decreases 14%, carbonation depth increases 17% but compressive strength decreases up to 14% at this replacement. Hence durability increases at high volume silica fume concrete.
- (xi) Replacement of 20% sand with pond ash affect on the strength of concrete adversely. Compressive strength increases 31% for 10% replacement of sand with pond ash by volume. Beyond that replacement compressive strength decreases.
- (xii) The compressive strength is achieved 43% more than control concrete, when 20% cement is replaced with silica fume and 10% sand is replaced with pond ash simultaneously at water cement ratio 0.35. It is recommended that 20% replacement of cement with silica fume by weight and 10% replacement of pond ash by volume should be followed for better durability and strength with low cost.

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- (xiii) The electrical resistivity test result showed higher values for F40-10 mix. Hence 40% cement replacement with silica fume and 10% sand replacement with pond ash along with 0.1% glass fiber is highly recommended for durable concrete at comparable strength and cost with control concrete without fiber.
- (xiv) Replacement of cement and sand with silica fume and pond ash respectively save the natural resources, reduces the construction cost and keeps the environment green and hence highly recommended.
- (xv) It is noticed that silica fume, pond ash and fiber helps to increase the durability of concrete by reducing the effect of acid attack and increasing the electrical resistivity and strength values.
- (xvi) Electrical resistivity, split tensile strength and compressive strength values for both control and fiber reinforced concrete shows higher values at long term curing age i.e. 90 days for all mixes. Hence proper curing of concrete with silica fume should be strictly followed by local contractor and builder.
- (xvii) Addition of fiber to concrete increases durability at higher cost. Higher use of Silica fume and reduction of cement is required for sustainable concrete. However partial replacement of cement with higher volume of silica fume reduces 28 days compressive strength which highly desired by contractors. Partial replacement of sand with pond ash is also very important but reduces workability of concrete. Proper combination of fiber, silica fume and pond ash produces a high 28days strength and durable concrete at lower cost. Hence it is recommended to use a combination of fiber, silica fume and pond ash as discussed in this research to produce sustainable concrete.

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