Performance of Self Compacted Concrete Using High Volume of Activated Fly Ash

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Abstract— The self-compacting concrete is most important development in this concrete Era, This world needs sustainable development in the every aspect of resources utilization. The goal of this research is to replacement in concrete with activated fly ash. Activated fly ash enhances the strength and durability of concrete at an early age, as well as its corrosion resistance. The fly ash is activated using a variety of processes, including mechanical (physical), thermal, and chemical activation. Chemical activation of fly ash by alkaline activators (i.e. alkaline solutions of high alkaline concentration chemicals like gypsum, sodium silicate and calcium oxide, KOH, etc.) improves the effectiveness of fly ash by dissolving the glassy layer of fly ash particles in cement concrete, increasing corrosion resistance. Chemical treatment of fly ash using chemical activators is used in this study to increase its quality. Chemicals such as sodium silicate and calcium oxide are utilized to activate the fly ash at the ratio of 1:6 for this study. The previous results show very satisfactory that the fly ash can be used to improve the properties of self compaction concrete. In this work experiments were carried out for the effective replacement of cement activated fly ash at different proportions. The aim was to investigate the characteristics of concrete with the addition of activated fly ash and comparing it with the control mix, thereby determining the advantages and disadvantages of doing so. In this activated fly ash is added to a 50%, 60% & 75% by partial replacement of cement. The fresh concrete is tested for slump test and the compaction factor test, while the hardened concrete for compressive, tensile, flexural strength and durability.

Keywords: Conventional Concrete, Activated Fly Ash, Compressive Strength, Flexural Strength, Tensile Strength, Workability

I. Introduction

Concrete is the most widely used man made construction material in the world. Seeking aggregates for concrete and to dispose of the waste from various commodities is the present concern. Today sustainability has got top priority in construction industry. In this study the recycled plastics were used to prepare the fine aggregates thereby providing a sustainable option to deal with the plastic waste. There are many recycling plants across the world, but as plastics are recycled they lose their strength with the number of recycling. So these plastics will end up as earth fill. In this circumstance instead of recycling it repeatedly, if it is utilized to prepare aggregates for concrete, it will be a boon to the construction industry. The productive use of waste material represents a means of alleviating some of the problems of solid waste management .The recycle of wastes is important from different points of view. It helps to save and sustain natural resources that are not replenished, it decreases the pollution of the. Wastes and industrial by-products should be considered as potentially valuable resources merely awaiting appropriate treatment and application.

In many infrastructure projects, concrete is the most often utilized building material. In all fields of contemporary construction, concrete has risen to the rank of key building material. When strength, durability, permeability, fire resistance, and absorption resistance are necessary, concrete is the ideal material to use. Compressive strength is used as a measure to evaluate the entire quality of concrete, and it is widely accepted that when compressive strength improves, all other qualities increase as well. As a result, compressive strengths are usually the focus of strength tests. Although concrete mixes are proportioned to achieve the necessary compressive strength at the stipulated age, flexural strengths are often important in the production of concrete. Because of the considerations of cost savings, energy savings, environmental protection, and resource conservation, the usage of supplemental cementitious materials (SCM) for cement substitution has drastically expanded along with the expansion of the concrete industry. On the one hand, large scale cement manufacturing adds to environmental concerns while depleting natural resources on the other. Fly ash is one of the most regularly utilized mineral admixtures since it is widely accessible in many poor nations. According to the Indian government's estimates, power plants would use 1800 million tons of coal by 2031-2032, resulting in 600 million tons of fly ash. The use of fly ash as a concrete additive not only improves the technical features of concrete but also helps to reduce pollution in the environment. The fly ash may be utilized in two ways: one is to integrand a particular proportion of fly ash with cement clinker at the plant to generate Portland pozzolana cement (PPC), and the other is to use the fly ash as an additive when building concrete on the job site. The latter technique allows the user more latitude and flexibility when it comes to the proportion of fly ash to be added.

A. Definition of Self Compacting Concrete

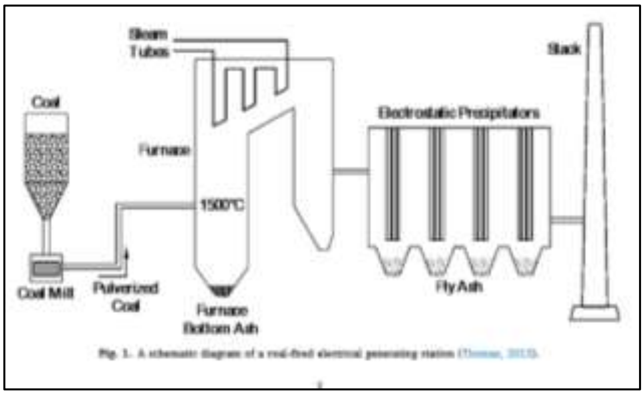
The British Standard (BS EN 206-9, 2010) defines "SCC is the concrete that is able to flow and compact under its own weight; fill the formwork with its reinforcement, ducts, boxouts etc, whilst maintaining homogeneity". Other researchers (Ozawa et al. 1989; Bartos and Marrs, 1999; Khayat, 1999) have defined SCC in almost the same terms as a highly flowable.

B. FLY ASH

Use of Fly Ash has become essential for civil engineering because of its economic and environmental benefits (Ravina and Mehta, 1986; Matković, 1990). The amount of cement that FA can replace is restricted by the amount of free lime in the ash. Aside from its chemical composition, the reactivity of FA is determined by its phase composition, the amount of glassy phase present, the burning temperature of coal or lignite, the specific surface area (SSA), etc. (Matkovi ́c, 1990). FA is a pozzolanic material (Tillman et al., 2012). The term pozzolanic refers to materials that, when exposed to lime and water, will form insoluble cementitious compounds, although they have little or no cementing action when they exist alone (Montgomery et al., 1981).

FA, or pulverised fuel ash, is a byproduct of coal-fired power plants and is used as a mineral additive in cement and concrete. Fig. 1 shows a typical layout of a coal-burning generating station. Pulverized coal is blown into the burning zone of the furnace, where its combustible constituents, mainly carbon, hydrogen, and oxygen, ignite at around 1500 ◦C (2700◦F). Quartz, calcite, gypsum, pyrite, feldspar, clay minerals, and other non-combustible minerals are melted at this temperature and form tiny liquid droplets. The droplets carried by the flue gases from the burning zone are cooled rapidly to form small spherical glassy particles. Mechanical and electrical precipitators or baghouses collect solid particles from flue gases. FA refers to the ash particles that “fly” away from the furnace with the flue gases (Thomas, 2013). The features of FA are influenced by various factors, including the type of coal used, the burning conditions, the collection mechanism, etc. (McCarthy and Dyer, 2019). The use of FA as a pozzolanic ingredient and its reaction potentials were first recognized in early 1914; however, a substantial study on the use of FA in concrete was first published in 1937 in the United States (McCarthy and Dyer, 2019; Halstead). In the earlier studies in the 1980 s, it was reported that replacing concrete with

FA can significantly improve the mechanical and durability properties of concrete (Montgomery et al., 1981) as FA can improve the microstructure of the paste (Filho et al., 2013). Depending on the application, FA properties, specification limits, geographic location, and climate, FA has traditionally been incorporated in concrete at levels ranging from 15 to 25 % by mass of the cementitious material component (Thomas, 2007). It was reported that, in some rare cases, concrete had been successfully placed incorporating up to 80 % FA (Marceau et al., 2002). The FAs used in concrete are of two types class F and class C according to ASTM. The class F FA is a byproduct of bituminous coal combustion. The iron, silica, and alumina content of class F FA is high, but the calcium content is low. It’s a glassy substance that requires either cement or lime to activate. FA from sub-bituminous coal and lignite combustion is classified as class C. It contains more calcium than class F FA. Concrete containing class C FA develops strength much more quickly than concrete containing class F FA (McCarthy and Dyer, 2019; Marceau et al., 2002). The use of FA in concrete is cost-effective, but it also changes the concrete properties in its fresh and hardened states, improving workability, strength, and drying shrinkage. Furthermore, the use of FA in concrete solves the storage and disposal problem of FA, an industrial byproduct (Atis ̧, 2003).



II. OBJECTIVES OF THE STUDY

The main objective of this research is to compare conventional concrete and concrete with activated fly ash in terms of its workability and strength. The use of various materials like phosphor-gypsum, fly ash, GGBS, quarry dust, broken bricks etc in concrete helps in minimizing the resources consumption used to develop the conventional concrete and provide benefits like improved strength and workability of concrete with useful disposal of by-products. This type of concrete will also used to control the energy consumption and will able to minimize the hazards caused to the environment. Following objectives are considered in this study –

1) To study the effect of Activated Fly ash in the properties of cement.
2) To perform the study on the property of fresh concrete like workability with the use of activated fly ash.
3) To perform the study on properties of hardened concrete like compressive strength, tensile strength, flexural strength and durability with the use of activated fly ash.
4) To enhance the economic feasibility of such concrete.

III. EXPERIMENTAL INVESTIGATION

A. Test on Constituent Materials

Cement: Ordinary Portland cement of 53 grade conforming to IS 12269:1987 was used for the study. For the cement the standard consistency test, initial setting time test, final setting time test, specific gravity test and mortar cube compressive strength were conducted. Laboratory tests are conducted on cement to determine its standard consistency, initial setting time, final setting time and compressive strength. The standard consistency of the cement used is 40%.

1) Le Chatlier’s Test – To determine the specific gravity of cement.
2) Vicat’s Apparatus – Used to determine the standard consistency, initial and final setting time of cement.
3) Compressive Strength – As per IS 4031 (Part 6) 1988, a cube of mould 70.6 mm used to determine the compressive strength of cement.

Above tests have been conducted on different samples of cement replaced with activated fly ash as mentioned below.

Cement	Activated Fly Ash	Normal Consistency In %	Initial Setting Time In Min	Final Setting Time In Min	Compressive Strength At 28 Days
100%	-	40	35	560	55.6
50%	50%	30	30	510	53.2

40%	60%	35	25	475	52.6
25%	75%	37	22	460	51.25

B. Properties of Activated Fly Ash

Chemical activation of fly ash by alkaline activators (i.e. alkaline solutions of high alkaline concentration chemicals like gypsum, sodium silicate and calcium oxide, KOH, etc.) improves the effectiveness of fly ash by dissolving the glassy layer of fly ash particles in cement concrete, increasing corrosion resistance. Chemical treatment of fly ash using chemical activators is used in this study to increase its quality. Chemicals such as sodium silicate and calcium oxide are utilized to activate the fly ash at the ratio of 1:6 for this study.

C. Mix design

M20 & M30 mix was designed as per IS10262:2009 and the mix proportion was obtained as 1:1.54: 2.77 & 1: 1.29 : 2.42 respectively. Four different mixes were made namely M!, M2, M3 & M4 for each grade of concrete to determine mechanical properties. M1 is considered as control mix. Other mixes are obtained by partial replacement of cement by 50%, 60%, & 75%. Mix designation used for mix proportions are given in Table 1.

MIX	Cementous Materials	
	Cement PPC (53 GRADE)	Activated Fly Ash
M1	100%	-
M2	50%	50%
M3	40%	60%
M4	25%	75%

Table 1: Mix designation for different mixes

D. Specimen details

The specimens are standard cubes of 150mm side and 100mm side, cylinders of diameter 150mm and 300mm height, beams of size 500x100x100mm. Details of number of specimens are given in Table 3.

S.No.	Specimen	Property	Size	Numbers
1	Cube	Compressive Strength	150mm x 150 mm x 150mm	36
2	Cylinder	Split Tensile Strength	300 mm height and 150 mm dia.	12
3	Beam	Flexural Strength	500 mm x 100 mm x 100 mm	12
Total No. Of Specimens				84

E. Tests on specimens

Testing of concrete specimens plays an important role in controlling and confirming the quality of concrete. All the specimens cast were subjected to testing in order to study the effect of partial replacement of cement with phosphor gypsum and fine aggregate with thermosetting plastics on workability and strength. Thus the experimental investigation carried out was divided in to three main headings. They are as follows:

1) Study on workability
   - Slump test
2) Study on strength
   - Compressive strength test
   - Splitting tensile strength test
   - Flexural strength test

IV. RESULTS & DISCUSSIONS

A. Tests on Fresh Concrete

Workability Test

Mix Proportions	Value of Slump In mm.	
	M30	M20
M1	90	110
M2	110	125
M3	110	125
M4	120	130

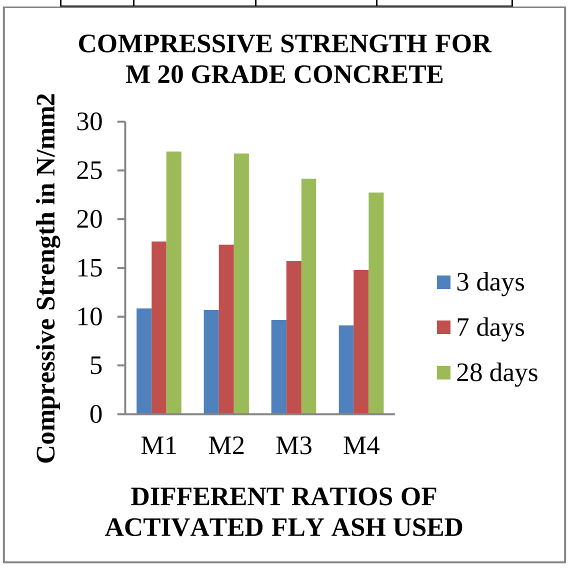
B. Tests on Hardened Concrete

1) Compressive Strength Test Results

Compressive Strength of the cubes were tested by using CTM (Compressive Testing Machine) in which compressive load is applied on the specimen till the specimen fails in compression that load at which the specimen fails is termed as compressive strength. For this study, cubes of 150 mm nominal concrete cubes were casted.

For M 20 Grade of Concrete

Mix	M 20		
	3 DAYS	7 DAYS	28 DAYS
M1	10.85	17.7	26.92
M2	10.7	17.4	26.75
M3	9.66	15.7	24.15
M4	9.1	14.8	22.75

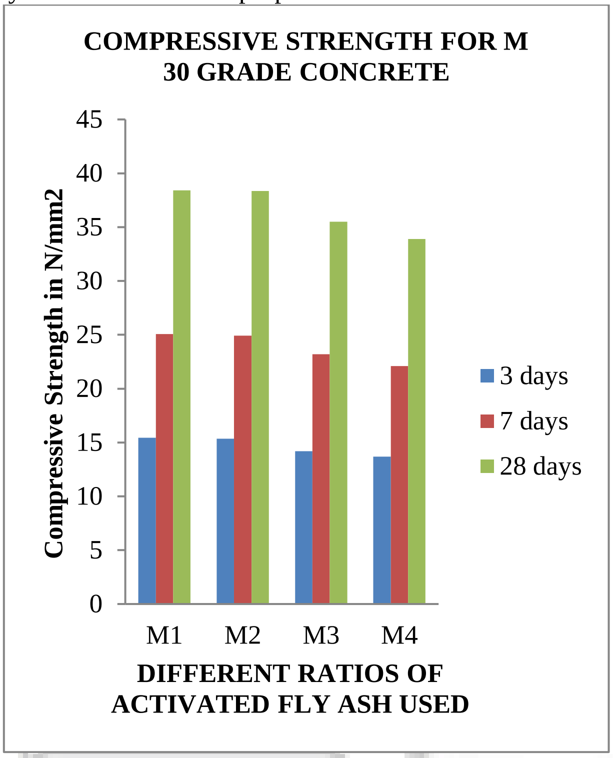


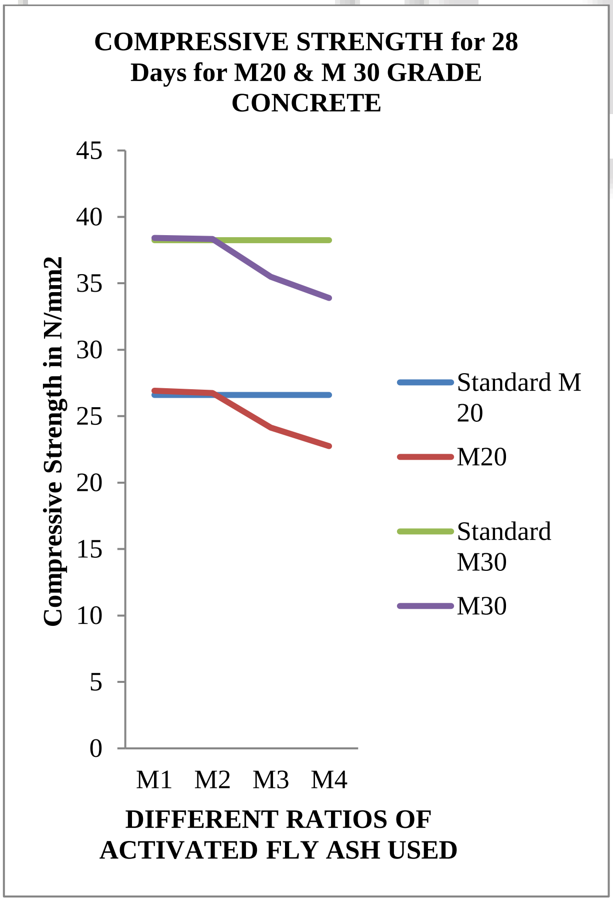
For M 30 Grade of Concrete

Mix	M 30		
	3 Days	7 Days	28 Days
M1	15.45	25.06	38.42
M2	15.34	24.92	38.35
M3	14.2	23.2	35.5

M4	13.7	22.1	33.9

Compressive Strength of M30 Grade of Concrete at 3, 7 & 28 days with different mix proportions





2) Split Tensile Strength Test Results

For M 20 Grade of Concrete

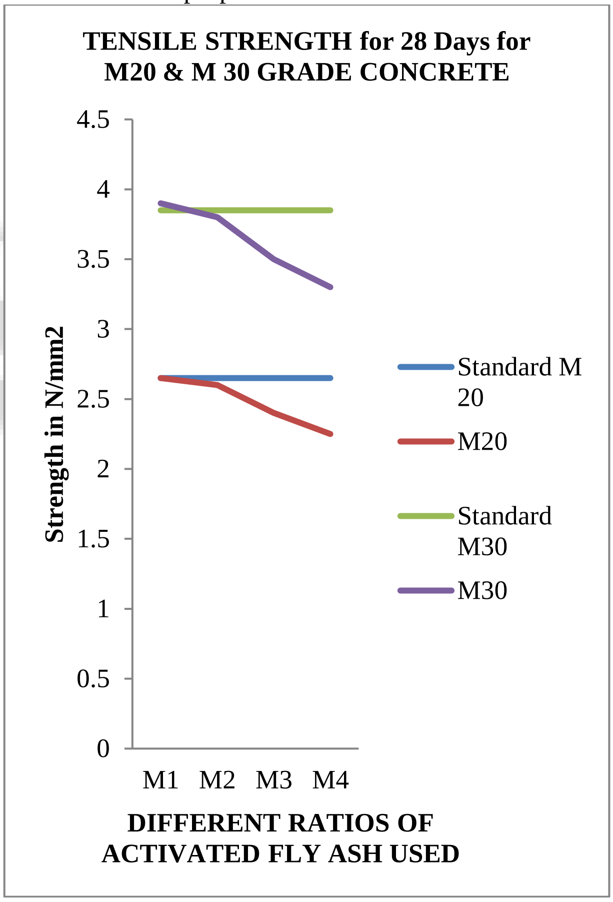
Mix	M 20
	28 Days
M1	2.65
M2	2.6
M3	2.4
M4	2.25

Split Tensile Strength of M20 Grade of Concrete at 28 days with different mix proportions

For M 30 Grade of Concrete

Mix	M 30
	28 DAYS
M1	3.9
M2	3.8
M3	3.5
M4	3.3

Split Tensile Strength of M30 Grade of Concrete at 28 days with different mix proportions



3) Flexural Strength Test Results

For M 20 Grade of Concrete

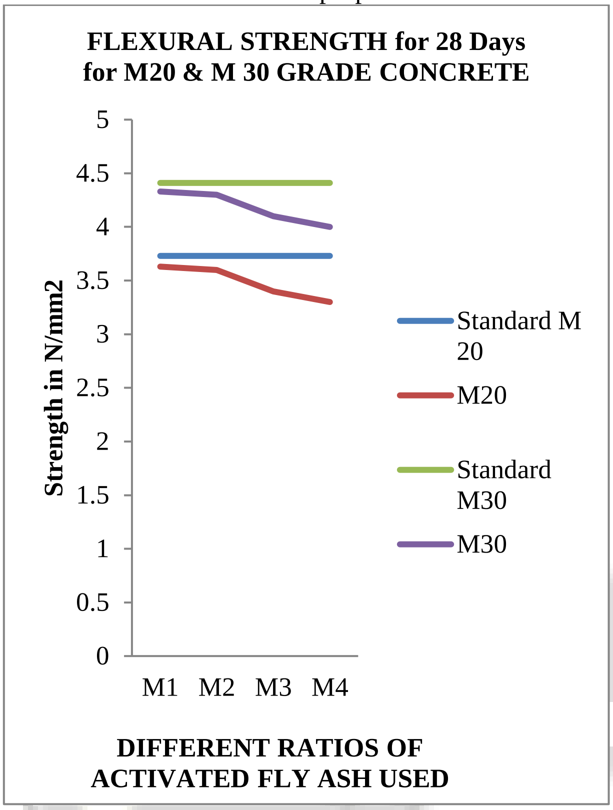
MIX	M 20
	28 DAYS
M1	3.63
M2	3.6
M3	3.4
M4	3.3

Flexural Strength of M20 Grade of Concrete at 28 days with different mix proportions

For M 30 Grade of Concrete

MIX	M 30
	28 DAYS
M1	4.33
M2	4.3
M3	4.1
M4	4

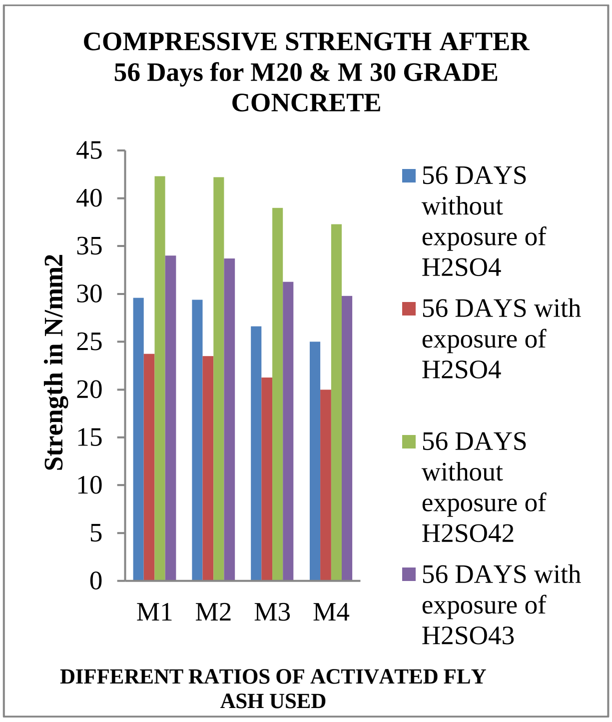
Flexural Strength of M30 Grade of Concrete at 28 days with different mix proportions



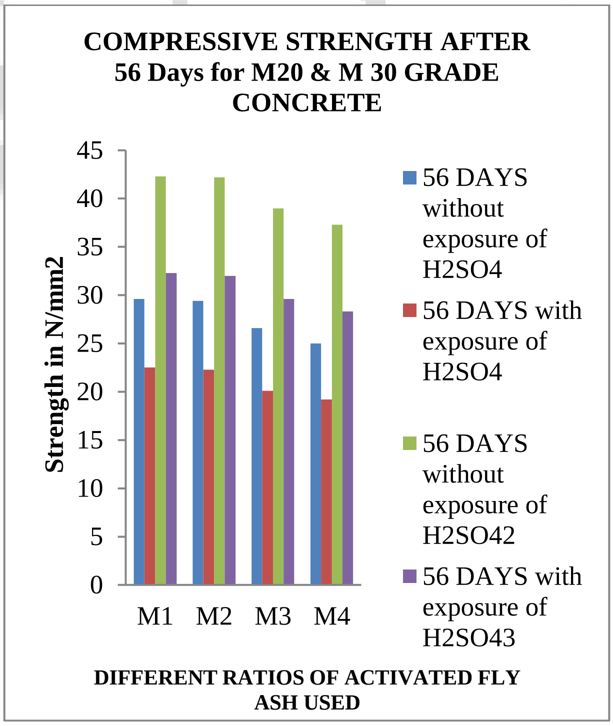
C. Durability Tests

The durability of concrete is the ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment. For the study of durability of concrete the test conducted were Acid resistance test (Sulphuric Acid attack), Alkalinity test (Sodium hydroxide attack), Sulphate attack test, Seawater attack test.

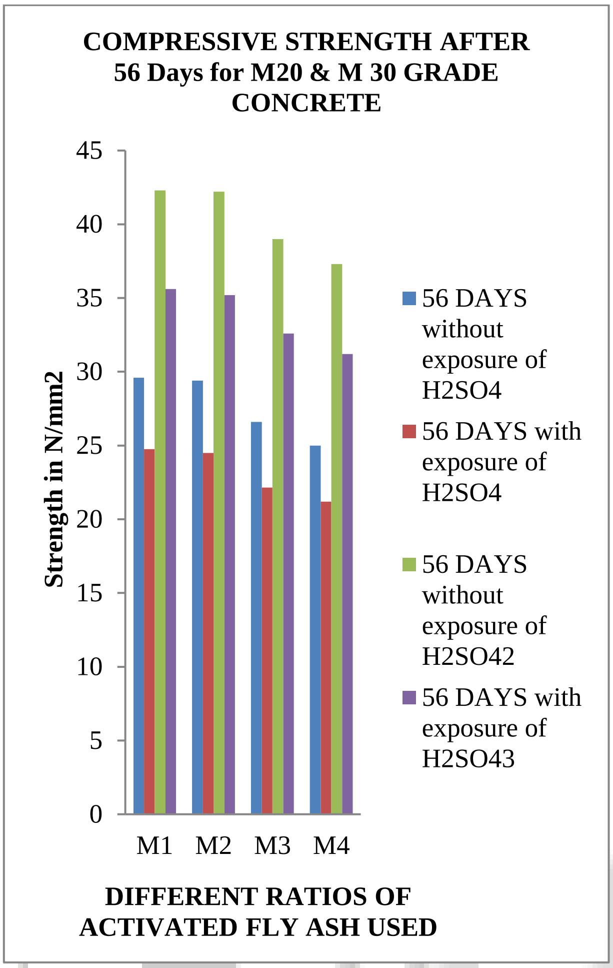
– Sulphuric Acid Attack Test - The compressive strength of specimens immersed in H_2SO_4 solution at 56 days were determined and compared with normal cured specimen at 28 days. Below table shows the percentage strength loss.



– Sodium Hydroxide Test: The compressive strength of specimens after NaoH exposure at 56 were determined and compared with normal cured specimen at 28 days. Below table shows the percentage strength loss in alkaline solution.



– Sea Water Attack Test - The compressive strength of specimens after sea water exposure at 56 were determined and compared with normal cured specimen at 28 days. Below table shows the percentage strength loss in NaCl solution.



D. Cost Analysis Results

Cost Analysis For Per Cubic Meter of Concrete of Grade M20

Cost Comparison Of M20 Grade Concrete For 1 M^3 Concrete									
S. No.	Materials	M1		M2		M3		M4	
		QTY (KG)	AMT (Rs.)	QTY (KG)	AMT (Rs.)	QTY (KG)	AMT (Rs.)	QTY (KG)	AMT (Rs.)
1	CEMENT	394	2600	200	1300	158	1030	100	650
2	Activated Fly Ash	-		194	970	236	1170	294	1450
3	M Sand	608	600	608	600	608	600	608	600
4	Coarse Aggregates	1092	900	1092	900	1092	900	1092	900
TOTAL			4100		3770		3700		3600
% Cost Increment			0		-8%		-9.7%		-12%

V. CONCLUSION

It was important to note that the quantity of by-product played a vital role to the properties of concrete. From all the previous studies, following points have been concluded:

- Workability increased with increase in ratio of Activated Fly Ash by partial replacement of cement. Maximum workability was obtained at 75% of replacement of cement with activated fly ash.
- Compressive strength decreased up to 3% for the 50% replacement of cement by activated fly ash. Further, the strength values have decreased up to 10 – 15% while increasing the ratio of activated fly ash.
- The splitting tensile strength of cylinder was higher for conventional mix. The percentage of decrease in splitting tensile strength is up to 5% than M1.
- The flexural strength of beam is found to be higher for M1. The decrease in strength of remaining mix proportion shows a considerable decrement of 10% than conventional mix.
- Concrete with Activated Fly Ash shows more durability property in acid test as compared to other materials. After 56 days exposure in sulphuric acid solution the compressive strength of M4 was reduced considerably up to 10% only.

- On curing in NaOH solution, the percentage strength loss for mix proportions with activated fly ash was about 15% at 56 days.
- With the increment in ratio of activated fly ash, the durability in sea water also decreases, but it seems considerable increment than other durability tests.
- The cost of use of activated fly ash decreases the cost of concrete from 8% to 12%. The economical solutions can be achieved by using admixtures for higher grade of concrete. For nominal concrete, the solution is uneconomical but it can reduce the amount of natural resources used for concrete.

The optimum percentage which can be used for activated fly ash is up to 50% replacement of cement which gives satisfactory results. The above test results are obtained without using any admixtures. And the design mix is based on the design mix ratio.

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