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RESEARCH ARTICLE

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STRENGTH AND DURABILITY CHARACTERSTICS OF HIGH VOLUME FLY ASH CONCRETE

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ABSTRACT

Concrete is a widely used man made construction material in all Civil Engineering structures ever since its acceptance as a construction material. Researchers are trying to improve its quality, strength and durability against adverse conditions.

Fly ash is the by-product of the combustion of coal in thermal plants. Fly ash was identified as a 'pozzolan' and this has led to the use of Fly ash in production of concrete which improves many qualities of concrete. Fly ash can be used as a admixture or as replacement of cement. The use of Fly ash makes the concrete less permeable. The improvement of the strength of Concrete is not only the consequence of its pozzalonic properties but also of the ability of the very small Fly ash particles to fit in between the cement particles. Fly ash also affects the properties of the concrete by improving workability, reducing segregation, bleeding and lowering heat of hydration.

High Volume Fly ash Concrete (HVFC) consists more than 50% of Fly ash by weight in the Cement. This is an approach to maximize the Fly ash input in the concrete .The fall of strength belated rheology on account of Fly ash are counteracted through efficient control of water-cement ratio and effective role of super plasticizers. The HVFC so developed has all the attributes of high performance concrete .Viz, excellent mechanical properties, Low permeability and superior durability because of high input of Fly ash, the autogenous temperature is very much under control.

In the present work an attempt has been made to study the behaviour of high volume Fly ash concrete in compression and flexure. In the investigations, M20 and M30 Grade concrete mixes are designed at different percentages of Fly ash (0%, 20%, 40%, 60%, 80%) and tests are conducted for Compressive and Flexural Strengths at 7 and 28 days. Then the results are compared with normal concrete.

The study reveals that use of HVFC has a beneficial effect on the workability, the cost economy of concrete and Durability of the structure. Large quantities of energy replacement of cement results in energy savings since Fly ash does not need additional energy input before use. Larger the quantity of Fly ash replacement, the energy saved is proportionately more.

Key Words: Flyash, HVFC, M20 & M30.

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1. INTRODUCTION

Today the concrete industry plays a vital role and is the huge consumers of natural resources like water, sand and gravel. The ten billion concrete industries is currently consuming natural aggregates at the rate of approximately eight billion tonnes. The world consumption of Portland cement has risen from less than two billions of 1880 to 1.3 billion tonnes in 1996.Besides other raw materials each ton of Portland cement requires approximately 1.5 tonnes of limestone and considerable amounts of fossil fuel and electrical energy. This is also accompanied by the release of approximately 1 ton of Co2 for the production of each ton of Portland cement clinker. So, Co2 is the main environmental pollutant from cement industry.

India has recorded over 50-fold increase in the generation of electricity during the last five decades .The Hydro-Thermal mix was 60:40 in the seventies and it is now 18:79, which means that more coal based thermal power stations have been installed. Coal is the primary source of fuel and its combustion results in a residue known as ash. The quantum of ash generated directly linked with the quantity and quality of coal fired and percentage of ash it contains. The following Flow Chart Shows Typical Production of Fly ash.

The analysis on Fly ash production from coal based thermal power stations indicates that 82 power stations produce about 100 million tonnes of Fly ash per year and this production may increase every year.

Indian coal contains high ash content as much as 45.36% in the coal mined from Singareni coalfields. Due to high ash content in coal, the ash produced in Indian thermal power stations is also high. It is estimated that typical 200MW power station produce 50-60 MT of ash per hour. While it is only 7-8 MT of ash produced in developed countries.

The ash should be managed properly or otherwise it will cause land, air and water pollution and there is a serious concern about utilizing it to the maximum extent.

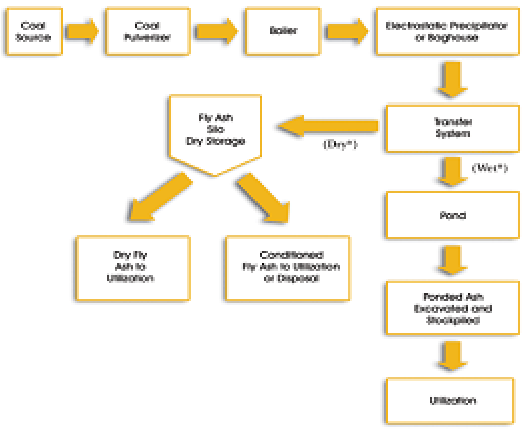

Fig -1: Flow chart of Fly ash Production

The problem of Fly ash utilization is not confined to India alone but is being experienced all over the world, However this problem is particularly acute in countries like in India where utilization of Fly ash is not received much attention. The degree of its utilization varies among different countries. In India, the present rate of utilization is only about 9 -10 percent, which is about world average of about 16 percent.

Fly ash is most widely used as a pozzolanic material all over the world. Fly ash is first used in large scale in the construction of HUNGRY HORSE DAM IN America (1948) in the approximate amount of 30% by weight of cement.

Later on, it is used in Canyon, Ferry Dams etc. In India, Fly ash is used in Rihand dam construction replacing cement up to about 15%. Over a period of time and more particularly, the last decade, there has been an increasing appreciation of Fly ash being a resource rather than waste. This has given impetus to Fly ash activities across the board, irrespective of level and nature of technology and its area of applications.

Fly ash admixed concrete can be used for making kerb stones, paving blocks, Footpath tiles etc., Fly ash can be used in internal road works, Back filling in mines. It is used in polymer composites, paints and in soil stabilization. It is also used for Wasteland development as a soil modifier and micro fertilizer. It is also used for Grouting and fire subsidence control.

HVFC is In commercial practice, the dosage of Fly ash is limited to 15-20% by mass of the total cementitious material. Usually, this amount has a beneficial effect on the workability and cost economy of concrete but it may not be enough to sufficiently improve the durability to sulphate attack, alkali-silica expansion, and thermal cracking. For this purpose, larger amounts of Fly ash are being used.

The study on HVFC indicates that the Fly ash is added to OPC without commensurate input of gypsum to the former. The strengths are derived by controlling the water/cement ratio through the help of chemical admixtures. However, it is reported that HVFC yields to surface erosion with rampant exposure to de-icing chemicals. It is desirable that HVFC be manufactured with additional gypsum input in order to engage the alumina phase of Fly ash into strength rendering mineralogy. This would not only increase strength but also may improve surface hardness.

In India early 1980 Ambuja cements used HVFA concrete for laying roads at Ropar in Punjab. This has shown good results and now many organizations are using HVFA technology which is economical and ecofriendly.

Advantages of HVFC is Low permeability and high durability,Prevents thermal cracking. Reduction in shrinkage cracking,High long term compressive and Flexural Strength,High Resistance to Sulphate Attack,High resistance to Alkali Aggregate reaction.

2. LITERATURE SURVEY

The American society for testing and materials (ASTM) defines a pozzolanic as "a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value built which will, in finely divided from and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to from compounds possessing cementations properties".

In the year 1942 [1] the Bureau of Reclamation (BOR) used Coal Fly ash concrete to repair a Tunnel Spillway at the Hoover Dam.

In the year 1946[2] the Chicago Fly ash Company was formed to market Coal Fly ash as a construction material for Manufacturing Concrete Pipes.

In the year 1949[3] The first large-scale use of Coal Fly ash was by BOR in the Construction Of The Hungry Horse Dam in Montana.

In Mid 1950's[4] The Tennessee Valley Authority began using Fly ash as a Partial Replacement For Portland cement. In the year 1967[5] The First Ash Utilization Symposium was held in Pittsburgh, PA.

In the year 1968[6] The National Ash Association was founded and is currently known as The American Coal Ash Association (ACAA).

Price[7] used addition method of mix proportioning in of the south Saskatchewan River Dam. It was found that the addition of Fly ash generally produced increased strength in all concrete at all ages.

The modified replacement method is probably originated in 1958 with the work of Lovewell and Washa [8], Who showed that by modification of mixture proportions, Fly ash concretes could be made with strength at early ages comparable to those of control mixtures.

In early 1960 [9] it was realized that if Fly ash concretes were to comply with the normally specified requirements of workability and strength, the proportioning mixtures must account for the characteristics of Fly ash most effecting those properties. This realization led to the development of several methods of proportioning that are based on the Abrams relationship between strength and water/cement.

Smith [10] was probably the first to propose a rational method of proportioning Fly ash concrete. He modified the conventional mixture proportioning procedure to obtain values for cement content and water/cement by introducing a Fly ash cementing –efficiency factor (K).

In 1968,cannon [11] reported research carried out by Tennessee Valley Authority on methods of proportioning Fly ash concrete mixtures to obtain strengths at 28 and 90 Days equal to those of conventional control mixes. This approach combined with extensive laboratory investigations and field experience, allowed cannon to develop tables and graphs to facilitate proportioning procedures.

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PROBLEM STATEMENT

In this work, extensive experimental investigations are carried out on Fly ash concretes of different mixes (M20, M30) with different cement replacement percentages of Fly ash by weight (0%, 20%, 40%, 60%, 80%) and at different ages (7days, 28days). The tests are conducted for flexural strengths and The response of Fly ash concretes of various grades to Flexural loading. In addition to this, the compressive strengths for 7 days and 28 days with different percentages of Fly ash (0%, 20%, 40%, 60%, and 80%) for both M20 and M30 mixes are studied. Results are compared with normal concrete and for different percentages of Fly ash concretes.

FLY ASH AN INGREDIENT OF CONCRETE

Fly ash is a by-product of pulverized coal in thermal power plants. The electrostatic precipitators remove the combustion gases before they are discharged into the atmosphere.

Chemistry of Fly ash

Fly ash may be represented by silica and the principal constituent of Fly ash is non-crystalline silica glass. When Fly ash is added to Portland cement, silica combines with the calcium hydroxide released on the hydration of Portland cement. Calcium hydroxide in hydrated Portland cement does not do anything for strength and so it must be used up reactive silica. Slowly and gradually it forms additional Calcium Silicate hydrate which is a binder, and which fills up the space, and gives concrete impermeability and more and more strength.The chemical formulae is expressed as below

$C_3S + H \rightarrow C\text{-}S\text{-}H + C - H + \text{Fly ash} \quad S\ C\text{-}S - H$

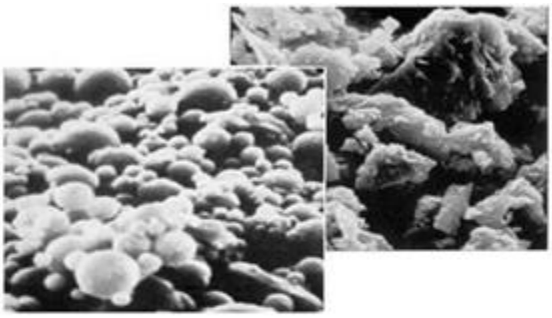


Fig -1: Microstructure of Flyash & Cement

Chemistry of Flyash

The reactivity of Fly ash and other pozzolanes with lime or cement is affected by inherent characteristics of the Fly ash such as chemical and mineralogical composition, morphology, fineness and the amount of glass phase. External factors, such as thermal treatments and the addition of admixtures also affect pozzolanic reactivity.

The sum of Silica+alumina+iron of Fly ash has been stipulated by ASTM and other standard associations as a major requirement .The silica +Alumina content of Fly ashes shows a good co-relation with long term pozzolanic activity, although silica and alumina in an amorphous from only contribute to the pozzolanic activity, whereas Mullite and Quartz, which from by partial crystallization of the glassy phases in the Fly ash, are non-reactive. Also in most Fly ashes, most of the iron oxide (Fe2O3) is present as Non-reactive hematite and magnetite. A small amount of iron, which is presenting glass, is reported to have a deleterious effect on the pozzolanic activity of Fly ashes. Hence, it has to be separated from silica and alumina when chemical requirements and pozzolanic activity of Fly ashes are considered. It was reported that the carbon content did not significantly influence pozzolanic activity index in terms of compressive strengths ratio.

Mix Design

Mix Design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible.

The first object is to achieve the stipulated minimum strength and durability. The Second object is to make the concrete the most economical manner.

Brief Description of Smith's Method

A rational method of mix design by which trial mixes of Flyash concretes could be produced with an accuracy equivalent to that obtained when applying to the design of orthodox concretes, has been formulated by smith. The method is based on extensive experimental investigations on concretes with Flyash from over twenty five generating stations. The mixes designed covered the normal strengthrange ofstructural concrete. The cementing efficiency method proposed by smith gives the required values of strength and placeability to the Flyash concrete mixes. In particular the strength of Flyash concrete is shown to depend only on the relative proportions of ash, cement land water. The method can be applied equally well to those concretes in which Flyash was considered as replacing sand as in thosewhere it replaced cement.

Brief Description of Cannon's Method

The procedure for proportioning Fly ash concrete mixes has been evolved from extensive investigations by the Tennesse Valley Authority; as a result of using Flyash in all classes of Concrete for over a decade. However, the method is intended only for proportioning Cement and Flyash and does not deal with the proportioning aggregates or the determination of basic water requirements. The method assumes that the quantity and gradation of the coarse aggregate is the same in comparable mixes and that the difference yield due to the large volume of cementations materials in the Flyash mix is balanced by a reduction of the sand content.

Brief Description of Ram.S.Ghosh Method

The method is described for portioning Fly ash concrete to produce similar compressive strengths as a normal Portland cement concrete at 3, 7,28 and 90 days. The method is primarily based on the Abrams law relating compressive strength and water cement ratio. Curves are also present at, for estimating the most economical Fly ash to the cement ratio for a particular strength and cost of Fly ash.

Two mixtures namely M20 and M30 are designed for normal concrete (0% Fly ash) and Fly ash concrete (20%, 40%, 60%and 80%). The mix design is done based on "proportioning of concrete mixtures incorporating Fly ash by RAM S GHOSH.

EXPERIMENTAL INVESTIGATIONS

The experiments have been conducted with Fly ash from Vijayawada thermal power station, Cement of 53 Grade Fine Aggregate as river sand and Crushed aggregates maximum size of 20mm as coarse aggregates are used. The tests Conducted on each are Cement,Flyash,Fine aggregate & Coarse aggregate.

Fine Cement

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Finercement offers greater surface area for hydration and hence the faster and greater the development of strength. Increase in fineness of cement is also found to increase the drying shrinkage of concrete. Fineness of cement is tested either by sieving or by determination of specific surface by Air-Permeability apparatus.

Initial & Final Setting Time

In actual construction dealing with cement mortar or concrete, certain time is required for mixing, transporting and placing. During this time cement paste, mortar or concrete should be on plastic condition. The time elapsed between the moments the water is added to the cement to the time the paste starts loosing its plasticity. The final setting time elapsed between the moment the water is added to the cement, and the time when the paste has completely lost its plasticity and has attained sufficient fineness to resist certain pressure. Once the concrete is placed in final position, compacted and finished it should loose its plasticity in the earliest possible time so that it is least vulnerable to damages from external destructive agencies. This time should not be more than 10 hours, which is referred to as final setting time. Initial setting time should not be less than 30 minutes.

Strength Test

The compressive strength of hardened cement is one of the important of all the properties. Strength of cement is indirectly found on cement sand matter in specific proportions. The standard sand, confirming to IS 650 – 1991, is used for finding the strength of cemnt.555 grams of standard sand (innore sand) and 185 grams of cement (i.e., ratio of cement to sand is 1:3) are taken in a non-porous enamel tray and mixed with a trowel for one minute. Water of quantity 1/4 +3.0% of compiled weight of cement and sand is added and the three are mixed thoroughly until the mixture is of uniform color. The time of mixing should not be less than 3 minutes and not more than 4 minutes. Immediately after mixing, the mortar is compacted on a table vibrator for 2 Minutes. The compacted angle in the mould is kept at a temperature 270 c + 20 c and at least 90% relative humidity is to be maintained for 24 hours. After 24 hours the cubes are removed from moulds and immersed fresh water 28 days and then tested.

Specific Gravity Test

Specific Gravity is defined as the ratio between weight of a given volume of material and weight of an equal volume of material and weight of an equal volume of water. To determine the specific gravity of cement, kerosene is used which doesn't react with cement.

Specific Gravity of cement = W5 (W3-W1)= 3.04(W3+W5-W4)(W2-W1)

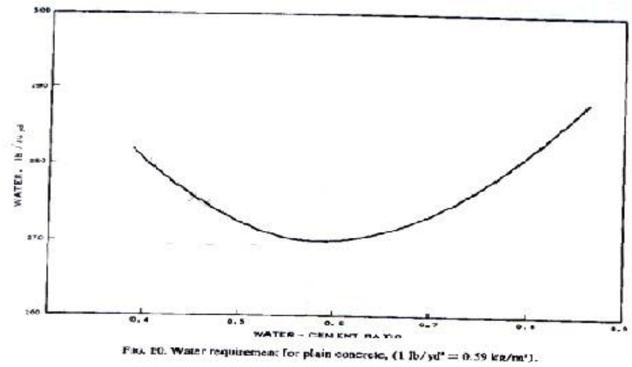
Fly ash

Specific gravity of flyash fine aggregate is The weight of empty specific gravity measuring jar is found to be W1 .The weight of jar and 150 ml sand is noted W2.

The container of 150 ml sand and 100 ml of water is weighed W3. The mix of sand and water is removed and filled with water up to the top surface of the jar W4.The specific gravity of fine aggregate =Weigh of solids / volume of solids = 2.65.

Mix Design Procedure

The method is described for portioning Fly ash concrete to produce similar compressive strengths as a normal Portland cement concrete at 3, 7,28 and 90 days. The method is primarily based on the Abrams law relating compressive strength and water cement ratio. Curves are also present at, for estimating the most economical Fly ash to the cement ratio for a particular strength and cost of Fly ash.Two mixtures namely M20 and M30 are designed for normal concrete (0% Fly ash) and Fly ash concrete (20%, 40%, 60%and 80%). The mix design is done based on "proportioning of concrete mixtures incorporating Fly ash by RAM S GHOSH.



Graph1 :Water Requirement for plain concrete

Procedure for Compression Test

The specimen are cast in steel or cast-iron moulds of size 150X150X150mm cubes, which should confirm with in narrow tolerance to the cubical shape, prescribed dimensions and planeness.The mould and its base must be clamped together during casting in order to prevent leakage of mortar. Before assembling the mould, its mating surface should be covered with mineral oil, and a thin layer of similar oil must be applied to inside surfaces of the mould in order to prevent the development bond between the mould and concrete.

The standard practice prescribed by BS 1881:Part 108:1983 is to fill the mould in three layers. Each layer of concrete is compacted by vibrating table. Ramming should continue until full compaction without segregation has been achieved because it essential that concrete in the cube be fully compacted if the test result is to be representative of the properties of full compacted concrete.

Procedure for Flexural Test

The test is currently under consideration for inclusion as an ASTM standard. The Equipment is shown in figure.. A 500mmX100mmX100mm size of specimen made by standard compressive rectangular mould. The mould should be of metal preferably steel or cast iron and the metal should be of sufficient thickness to prevent spreading or wrapping. The mould should be constructed with the longer dimension horizontal and in such a manner as to facilitate the removal of the moulded specimens without damage. The testing machine provided with two steel rollers 38mm in diameter on which the above said specimen should be supported. These rollers should be placed at a

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distance of 400mm from center to center for 100mm specimen

Table -1: Mix Proportions

Grade	F/C Ratio	Water / (C+F) Ratio	Water Content Lts /m3	Fly ash Kg / m3	Cement Kg / m3	Fine Agg. Kg / m3	Coarse Agg. Kg / m3
M20	0	0.57	160.6	0	282	904.4	1008
	0.2	0.55	159.35	48.26	240.74	898.65	1008
	0.4	0.53	160.4	84.1	211	898.5	1008
	0.6	0.49	153.22	117.3	195.4	881.08	1008
	0.8	0.47	157.67	148	185.35	851.98	1008
M30	0	0.45	162.84	0	361.87	822.29	1008
	0.2	0.44	167.44	63.55	317	779.01	1008
	0.4	0.42	163.85	110.15	276.35	776.65	1008
	0.6	0.39	166.1	159.3	265.5	736.1	1008
	0.80	0.37	189.26	223.26	284.14	630.34	1008.00

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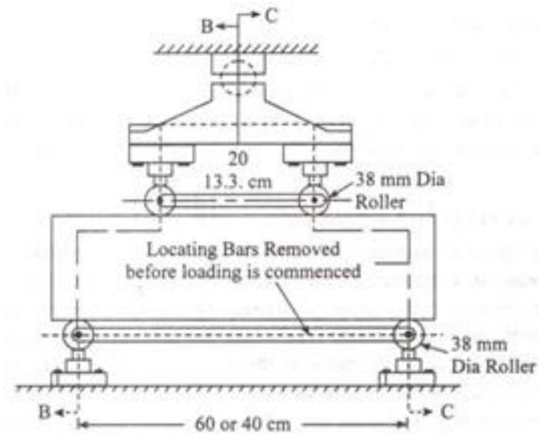


Fig -2: Arrangement for Loading of Flexural Test Specimen The bed of the testing Machine should be provide with two steel rollers, 38mm diameter, on which the specimen is to be supported and these rollers should be mounted that the distance from center to center 400mm for 100mm specimens the load is applied through two similar rollers mounted at the third points of the supporting span i.e., space at 133mm distance center to center.

The axis of the specimen carefully aligned with the axis of the lodging frame. The load is applied gradually without shock increasing continuously at a rate such that the extreme fiber stresses increase at a rate of 7 kg/cm2 /min i.e, application of the load is at the rate of 4000 N/min.The load is divided equally between the two roller points and is increased until the specimen fails. The load is measured by a load gauge. The load at first crack is noted. The modulus pf rapture is calculated for the maximum load taken by the member.

RESULTS & DISCUSSIONS

The Cube specimens are tested for compressive strength at 7 days and 28 days for two mixes M20 and M30 and the results obtained are tabulated below.

Table -2: Compressive strength of concrete with different percentages of flyash at different ages

		Compressive Cube Strength (N/mm2) at Ages (days)	
Grade	**F/C RATIO**	**7 days**	**28 days**

	0	16.9	28.8
	0.2	14.7	29.3
M20	0.4	13.1	29.8
	0.6	11.3	27.3
	0.8	9.8	22.9
	0	22.9	41.23
	0.2	22.7	41.5
M30	0.4	21.5	39.2
	0.6	20.4	35.8
	0.8	18.1	33.35

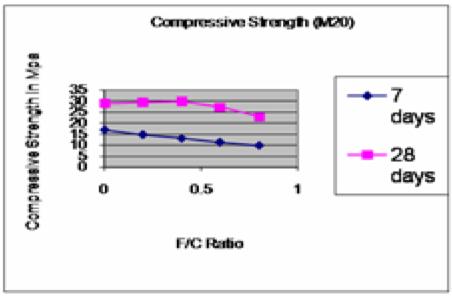
Table -3: Flexural strength of concrete & flyash of two mixes M20 & M30 at different ages are tabulated below.

		Flexural Cube Strength (N/mm2) at Ages (days)	
Grade	**F/C RATIO**	**7 days**	**28 days**
	0	4.1	5.73
	0.2	3.2	5.8
M20	0.4	3.06	5.7
	0.6	2.7	5.63
	0.8	2.4	5.36
	0	4.7	6.43
	0.2	4.3	6.5
M30	0.4	3.5	6.36
	0.6	3.1	6.33
	0.8	2.8	6.1

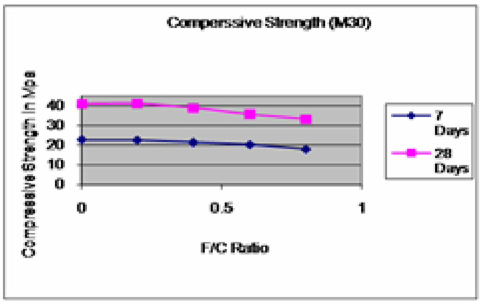
Fig -3: Typical Fracture Pattern of Cube Specimens due to Compression Load

The failure of concrete cube is shown in figure. The failure of Fly ash concrete is as that of normal concrete. The value of compressive strength may be much higher for an aggregate of superior quality.

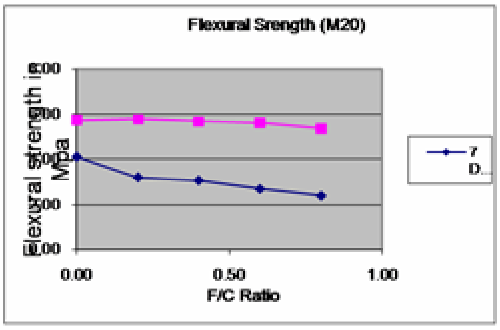
Graph 2 Indicates the Compressive strength of M20 at 7 days and 28 days with different percentage of Fly ash (0%, 20%, 40%, 60%, 80%). Graph 2 indicates the Compressive strength of M30 at 7 days and 28 days with different percentage of Fly ash (0%, 20%, 40%, 60%, 80%). The compressive strengths of cube specimens of the two grades showed relatively lower value at early ages (7 Days) for Fly ash concretes (20%, 40%, 60%, 80%) than for normal concretes of all mixes.



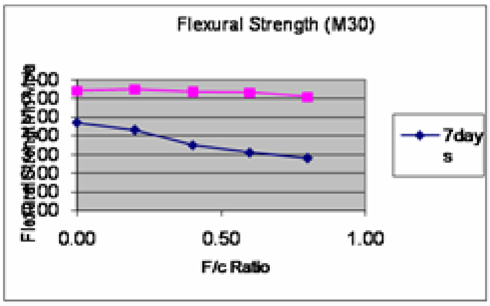
Graph2 :Compressive strength for M20 concrete



Graph3 :Compressive strength for M30 concrete



Graph4 :Flexural strength for M20 concrete



Graph 5 :Flexural strength for M30 concrete

Fig -4: Typical Fracture Pattern Of Bea Specimens due to flexural Load-M30,0% Fly ash.

Graph 3 indicates the flexural strength of M20 at 7 days and 28 days with different percentage of Fly ash (0%, 20%, 40%, 60%, 80%). Graph 4 indicates the Flexural strength of M30 at 7 days and 28 days with different percentage of Fly ash (0%, 20%, 40%, 60%, 80%). The 7 and 28 days flexural strength of normal concrete is better than the Fly ash Concrete.

CONCLUSION

Based on the study conducted on M20 and M30 grade concrete with different percentages of Fly ash at different ages the following conclusions are drawn:

- At early ages, Fly ash concrete gave lower strength as compared to normal concretes.
- Using Fly ash is Eco-friendly and Economical in Construction of Structures.
- Strength increases with the increase in age of Fly ash concrete.
- The compressive strengths of cube specimens of the two grades showed relatively lower value at early ages (7 Days) for Fly ash concretes (20%, 40%, 60%, 80%) than for normal concretes for all mixes.
- The 28 Days compressive strength of Fly ash concretes (20%, 40%) are nearly equal to normal concretes. But the Fly ash concretes of (60%, 80%) gives lower value than normal concretes. According to the present investigations, the Mix Design may not give good results for High Volume Fly ash Concretes.
- The flexural strength of the beam specimen of the two grades showed relatively lower value at early ages (7 days), for Fly ash concrete (20%, 40%, 60%, 80%) than normal concretes for all mixes.
- The 28 Days flexural strength of Fly ash concretes are nearly equal to that of normal concretes

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