Fly Ash-Fibre Reinforced Concrete (FAFC) Pavement-An Alternative to RCC/PCC Pavement

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Abstract

Techno–economic superiority of the cement concrete road is now well established. A considerable R and D effort has gone into several aspects of concrete pavements or roads and runways. This is particularly so in the areas of strengthening and repair, design and evaluation, improvement of concrete as a paving material by incorporation of innovative & cost effective material and techniques used for road construction in the country. Nowadays a major use of cementetious materials such as fly ash, silica fumes, slag, recycled aggregates in concrete resulted in significant decrease in the use of valuable natural resources and lowering of fuel consumption through reduced transport and production processes as well as to reduce co_2 emissions. These alternative materials not only benefit the environment but also add value to, in the form of enhancement of performance characteristics by judicious selection, proportioning and use. However, in the context of International practice the Indian projects have not been cost effective. The pavement thickness is high. Concrete mix design practices are obsolete, leading to wasteful consumption of cement. Use of cement fly ash fiber reinforced concrete in place of plain cement concrete will, not only enable substantial savings in the consumption of cement, but also provide an economic and useful avenue for disposal of fly ash, which is now a recognized national problem, along with improved performance characteristics in terms of durability and low maintenance requirement It has been hereby suggested that by adopting proper mix proportioning methods of available methods, for the same design strength more economical mixes can be produced with cement-fly ash-fiber concrete as compared to plain cement concrete.

Keywords: fly ash, fibre, mix proportioning, innovative material, cement-flyash-fibre

1.0 Introduction

Cement concrete pavements, adequately designed and constructed, are known for their long service life, limited maintenance requirements, and high stability of their surface profile. The concrete pavement has its own characteristics with regard to design, construction and maintenance and is not amenable to the direct application of norms adopted for flexible pavements. The service life of the concrete pavement is determined almost entirely by the single layer of the concrete slab which, if of the requisite quality and size, can yield several maintenance-free years of service periods(Dhir,1984), often as long as 40-50 years than a flexible pavement. It is said that life of a concrete slab is limitless can, in fact, be exploited to prolong it to almost any desirable period.

2.0 Background – Techno-Economic Superiority of Concrete Pavement:

The concrete pavement structure is also relatively less sensitive to the strength of its foundation and to the intensity of loading; a factor which makes its adoption particularly advantageous when building on poor sub grades or when long trouble-free service is required under heavy loading. The riding quality of concrete roads is best because of its capacity to withstand heavy traffic without suffering deformation.

Another advantage of concrete roads is its good abrasion resistance. Roads on gradient & curves, roads at ports & warehouses, airport runway ends suffer abrasion-induced damages. So in these places concrete pavements generally find preferential use. They have superior night visibility as concrete roads have got good reflectivity characteristics, and are considered to enhance night driving safety. They can withstand harsh operational conditions than the bituminous pavements, particularly where exposure to water, or oil-drippings, is involved (Phull, 1993).It has been observed, the concrete pavements are quieter than bituminous surfaces, thus making less noise pollution.

Further, construction of roads in concrete result in conservation of materials as the typical thickness of concrete pavement, for heavily trafficked highway, is about 400 mm as against 600 to 10000 mm for a flexible pavement.

Thus the concrete pavements prove to result in the road making technologies that are environment friendly. Also, it will result in overall economy especially when viewed against the life cycle costs.

Depending on the design traffic, soil condition and design period etc, the initial construction cost of concrete road is usually 15% to 25% more expensive than asphalt road. However, concrete road offer long term value because of their long life expectancies and minimal maintenance requirements. The average age of concrete road is about 1.5 to 2 times greater than the service life of asphalt roads. In addition to longer service life, the concrete roads carry considerably more traffic. On a life cycle cost analysis, concrete roads offer long term benefits with longer service life and low maintenance cost (Sheikh, 2004; Ashok, 2004). It has been estimated that nearly 50% in maintenance expenditure could be saved if the entire NH system was concreted (CMA, 1997).

2.1 Recent Trends

Concrete pavements have been built all over the world for decades now, and the recent emerging trends, the state-of-the-art pertaining to their design, advancement in construction and maintenance have indicated that concrete roads are gaining wider acceptance and are being used for highways.

Considerable development work has also been done on the incorporation of fiber reinforcement, on vacuuming, on the impregnation of polymers, and on the use of additives and admixtures to improve the performance of concrete pavements. As a result, sophisticated design and construction techniques characterize the autobahns in Germany, the interstate system in U.S.A. and the more recent motorways in U.K., some of which indeed mark important milestones in the use of concrete as material for paving roads.

In India, the policy on concrete roads has been some-what inconsistent. The earliest concrete roads date back to more than five decades. Those which had adequate structural capacity in relation to use have yielded long service. These early constructions had a slab thickness of about 150mm, but at some later stage there was a switch to constructing thinner slabs, ranging from 75mm to 100mm. The emerging road investment policies are now being based on highway design models which consider design, construction, and maintenance and user costs as integral parts of the same planning system thus considering the life cycle cost. In its general report, the World Road Congress (PIARC, 1999) stated that it can be concluded that concrete pavements are a potential alternative. Cement association of Canada (2001) describes concrete roads as smart environmental solutions that offer major economies of scale for the industry and added security for motorists. There is general consensus among road engineers that choice of pavement type should strictly depend upon the techno-superiority, based on life cycle analysis.

3.0 Fly Ash - Cement Concrete

Out of various cementing materials, Fly ash is the most widely used material worldwide. Fly ash is by product from the combustion of pulverized coal in thermal power plants. Fly ash, if not utilized has to be disposed of in landfills, ponds or rejected in river systems, which may present serious environmental concerns since it is produced in large volumes. This is particularly an important issue for India, which currently produces over 100 million ton of fly ash annually. A concerted effort is required for the concrete producers & end users to take a pro-active approach to find optimum utilization areas for supplementary cementing materials, which will enhance the concrete product and efficiently utilize its properties. Use of Fly ash concrete in place of PCC will not only enable substantial savings in the consumption of cement and energy but also provide economy (about 10-15 percent) with following advantages:

The use of fly ash in concrete in optimum proportion has many technical benefits and improves concrete performance in both fresh and hardened state. Fly ash use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. Generally, fly ash benefits concrete by reducing the mixing water requirement and improving the paste flow behavior.The decrease in water content combined with the production of additional cementetious compounds reduces the pore interconnectivity of concrete, thus increasing durability and resistance to various forms of deterioration.This brings several associated technical benefits, such as resistance to alkali-silica reaction and resistance to sulphate reaction .The design of a highway pavement is based on flexural strength and fly ash concrete continues gaining strength with age.

The pozzolanic activity between fly ash and lime generate less heat resulting in reduced thermal cracking when fly ash is used to replace Portland cement. The tremendous growths in urbanization and rapidly changing construction scenario have put pressure on the performance and durability of the concrete product. Therefore

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there is an urgent need to develop and popularize alternate materials and technologies that may improve the inherent weakness & deficiencies of the conventional materials.

a. Fly Ash Fiber Reinforced Concrete

Using fly ash in concrete may both provide economical advantages and better properties in the production of concrete as said earlier. However, according to the results of the study, the use of fly ash in concrete is found to affect strength characteristics adversely,and addition of fibers compensate the early –age strength loss associated with the usage of fly ash(Siddique,2004) which have been proved very efficient in enhancing the strength characteristics such as static flexure strength, impact strength, tensile strength, ductility and flexure toughness (Mohammdi, singh , Kaushik, 2004; Atis, Duran, Okan, 2009) while fly ash in the mixture may adjust the workability losses caused by fibers, and improve strength gain(Bayasi, Soroushian, 1989).
Engineering and chemical properties of Indian fly ashes of various power plants tested at CRRJ have been found to be favorable to construction of roads. Properties of fly ash from different power plants may vary as the properties of ash depend primarily on type of coal and its pulverization, burning rate and temperature, method of collection, etc. Individual fly ash particles are spherical in shape, generally solids, though sometimes hollow.

A brief review of the action of fly ash in concrete, together with the outcomes of past investigations on pozzolanic applications to steel fiber reinforced concrete is given below:-

The round particle shape and fineness of fly ash particle improve the flow ability of the mix increases due to the lower specific gravity of fly ash compared with that of cement. Thus, a more effective coating of fibers and lubrication of the mix is achieved.

In addition to improving the fresh mix workability and fiber disperse ability, the application of fly ash to steel fiber reinforced concrete imparts the following improvements to the material performance:-

- Fly ash contributes to the strength of fiber reinforced concrete by reducing the water content without damaging workability, increasing the volume of paste in the mixture, and by its pozzolanic reaction.
- The increase in cementetious paste volume in the presence of fly ash leads to a better coating of fibers by the matrix material and improves fiber-matrix interfacial bond characteristics. This may cause significant improvements in the composite material performance.

All other advantages of using fly ash in plain concrete (enhanced pore system, reduced permeability and improved durability, reduced alkali-aggregate, economic and ecological advantages, etc.) already discussed above would also apply to steel fiber reinforced concrete.

4. Mix proportioning of fly ash- fiber concrete

Despite enormous technical, economical and environmental benefits associated with the use of fly ash and fiber, codal provisions exist in India needs to be updated to promote its utilization, not only to minimize the construction cost but also to produce the durable concrete structures. There is a need of proper understanding and confidence building measure needed for the proper utilization of this resource. Properly designed concrete mix is an essential prerequisite to obtain the desired properties of concrete, both in the fresh and hardened states. The present research is concerned with developing an optimum mix design of concrete pavement involving Fly Ash and Fiber. This involved ascertaining of optimum use of fly ash by partial substitution of cement in typical steel fiber reinforced concrete mixes without compromising on its properties, For this, the effect of percentage replacement of fly ash in fiber reinforced concrete on fresh mix workability Flexural & compressive strength is established to decide the optimum influence of fly ash in fiber reinforced concrete. An effort is made to develop an optimum Mix proportioning for concrete Pavement which incorporates utilization of good quality pozzolanic fly ash to replace parts of cement in fiber reinforced cement concrete so that it can be used in all pavement construction works where plain cement concrete is used.

It has been hereby suggested that by adopting proper mix proportioning methods of available methods, for the same design strength more economical mixes can be produced with cement-fly ash-fiber concrete as compared to plain cement concrete.
Different mix design methods help us to arrive at the trial mix that will give us required strength, workability, cohesion etc. These mix design methods have same common threads in arriving at proportions but their method of calculation is different. This paper has followed the

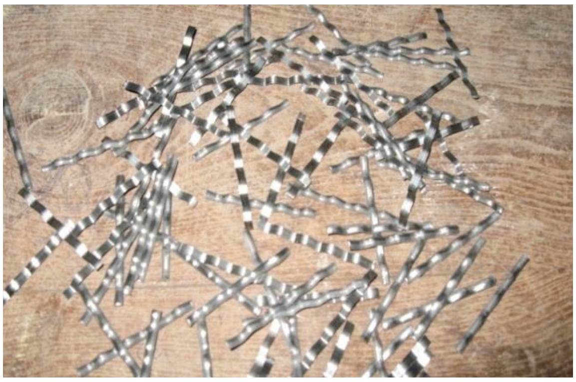
- *Indian Standards for the mix design ,*
- *Mix design as per IRC: 44-1976.*
- *British Doe method*
- *ACI method for mix proportioning*

The basic assumption made in mix design is that the compressive strength of workable concretes, by and large, governed by the water/cement ratio. Another most convenient relationship applicable to normal concrete is that for a given type, shape, size and grading of aggregates, the amount of water determines its workability. However, there are various other factors which affect the properties of concrete, for example the quality & quantity of cement, water and aggregates; batching; transportation; placing; compaction; curing; etc.

4.1 Fibers

Straight Crimped-type flat steel fibers supplied by Ms. R & L industries, Byculla West, Mumbai were used throughout the investigation. The fibers were 50-mm in length with a cross section of 2-mm x 0.6-mm (equivalent diameter = 1.24 mm). The aspect ratio of fibers, defined as the ratio of fiber length to (Equivalent) diameter was determined as 40. The chemical composition of the fibers as supplied by the manufacturer was: Carbon = 0.095%, Manganese = 0.9% Sulphur = 0.016% and Chromium = 0.060%. The Ultimate Tensile Strength crimped –type flat steel fibers were determined as 776.20. Plate-4.1 shows fiber used in this investigation.

Plate 4.1



4.2 Fly Ash

Fly ash samples taken from Kahalgaon Thermal Power Plant, NTPC were used in this study. Fly ash was not processed and, used as received. The sample satisfied the requirements of IS 3812(Part I).

Table 4.1: Physical Properties of Fly Ash

Sl no.	Physical Properties	Observed values
1	Specific Gravity	2.51
2	Initial Setting	45 min
3	Final Setting	280 min
4	Consistency	35

Table 4.2: Chemical Properties of Fly Ash

Sl. No.	Test Conducted	Observed Values (%)	Requirement as per IS:1320-1981
1	Loss of Ignition	2.32	5.0(max)
2	Silica as SiO_2	42.04	SiO_2+ Fe_2O_3+ Al_2O_3=70
3	Iron as Fe_2O_3	4.40	-
4	Alumina as Al_2O_3	33.60	-
5	Calcium as CaO	12.73	-
6	Magnesium as MgO	0.00	5.0
7	Sulphate as SO_3	0.40	3.0
8	Chloride	-	
9	Lime Reactivity	4 N/mm^2	4.5

Table showing mix proportions for steel fiber- Fly Ash-Cement Concrete Mix for pavement

To facilitate compaction and workability of steel fiber fly ash concrete, superplasticiser CONPLAST SP-430 1.5% of binder is used. Based on test result, the Mix was re-proportioned for fine to coarse aggregate to cater to some consideration particular to SFRC.

	PLAIN CONCRETE (0%)	MIX-II .I (20%)	MIX-II.II (30%)	MIX-II.III (40%)
W/C+F	0.45	0.43	0.39	0.36
W	175	165	160	155
C	389	307	284	258
F	-	77	122	172
S	530	408	406	347
A	1218	1345	1340	1353
Fiber	118	118	118	118

The trial Mix Proportion after re-proportion is summarized in the following Table

	PLAIN CONCRETE (0%)	MIX-II .I (20%)	MIX-II.II (30%)	MIX-II.III (40%)
W/C+F	0.45	0.43	0.39	0.36
W	175	165	160	155
C	389	307	284	258
F	-	77	122	172
S	530	585	582	567
A	1218	1168	1164	1133
Fiber	118	118	118	118
Super Plasticisers 1.5% of Binder	5.8	5.76	6.09	6.45

5. *Results and discussion:*

5.1 Compressive Strength Characteristics:

The result of Compressive strength of steel fiber fly ash concrete with 20%, 30% & 40 % fly ash are shown in the **Table 5.1** and **Figure 5.1**

Table 5.1: Test Results on Compressive Strength

	Mix No.	Compressive strength(28 Days)
Plain Concrete		47
With fiber & 0% Fly Ash	M1	50.24
With fiber & 20% fly Ash	M2	52.35
With fiber & 30% fly Ash	M3	48.7
With fiber & 40% fly Ash	M4	46.7

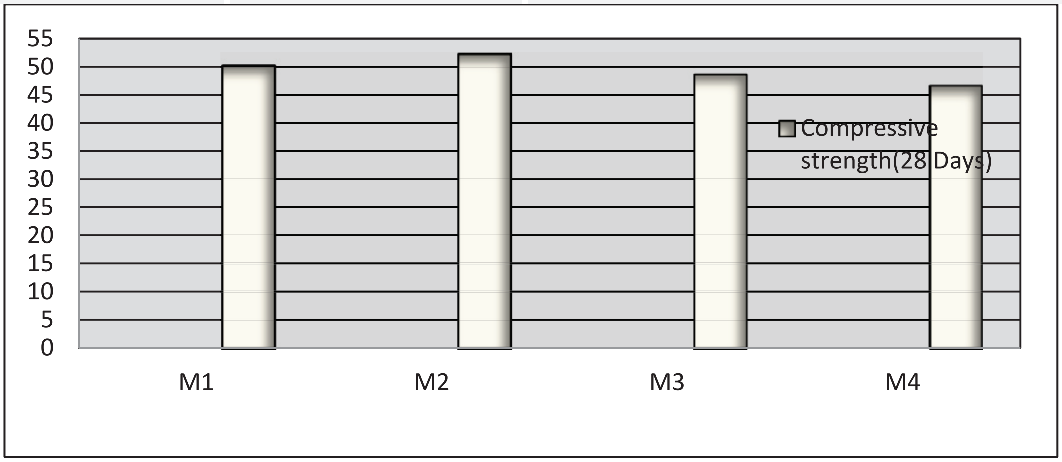


Figure 5.1 Effect of fly ash on Compressive Strength of fiber reinforced Concrete

The test results on steel fiber reinforced fly ash concrete presented in **Table 5.1** and **Figure 5.2** indicate that the compressive strength of fiber reinforced concrete increase with an increase in fly ash-binder ratio up to 20 percent. Whereas at higher percentage of replacement of fly ash with cement, showed a decreasing trend.

5.2 Development of Strength with Time:

For the fly ash fiber reinforced concrete mixtures, the effect of fly ash content on the development of compressive strength with time was assessed. The trends in the development of compressive strength with time for steel fiber reinforced concrete incorporating different fly ash contents are shown in **Table 5.2**and **Figure 5.2** **& Figure 5.3**

Table 5.2: Result of Development of Strength with age of different mixes

Mix No.	Compressive strength (1-day)	Compressive strength (7-day)	Compressive strength (28-day)
M1	24.8	33.7	50.24
M2	27.8	35	52.35
M3	18.1	30.3	48.7
M4	12.4	28.6	46.7

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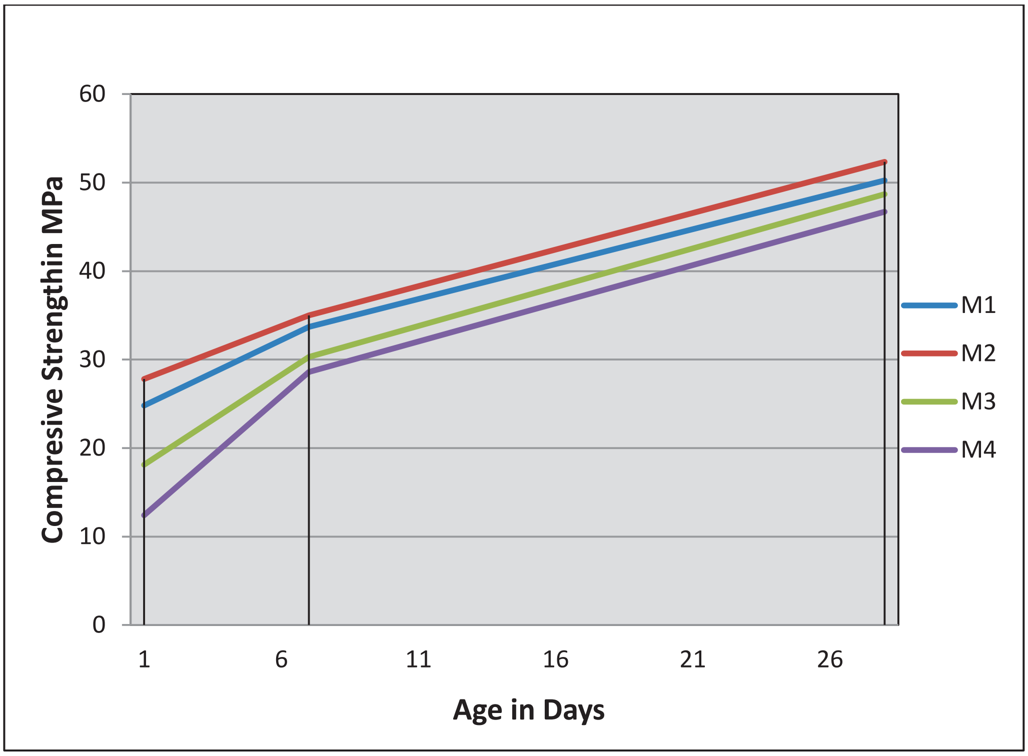

Figure 5.2 Development of Strength with age of different mixes

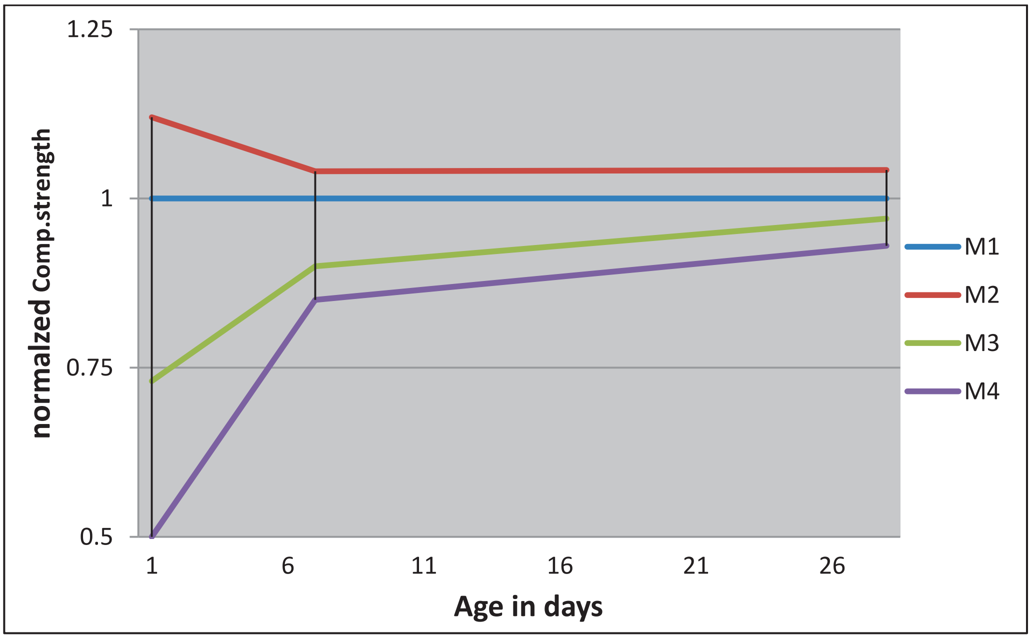

Fig 5.3 strength development with age of various percentage of fly ash in fiber reinforced concrete

The development of compressive strength with time for steel fiber reinforced concretes incorporating different fly ash percentage are shown in figure 5.2. In fig 5.3 ,the development of compressive strength with age of fiber reinforced concrete with 0 percent fly ash, taken as reference line and strength of other mixes with fly ash replacement of (20 to 40 percent were normalized with respect to the reference mix. It can be inferred from the said figures that the substitution of 20 percent of cement with fly ash increases the compressive strength of steel

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fiber reinforced concrete even at early ages, when compared with the corresponding mix without fly ash. When 30 percent or 40 percent of cement is substituted by fly ash, there is evidential drop in the rate of strength development with time.

5.3 Flexural Strength characteristics

The flexural strength of steel fiber fly ash concrete with 20%, 30% & 40 % fly ash are shown in the **Table 5.3** and **Figure 5.4**

Table 5.3: Test Results on Flexural Strength

Concrete Mix	MIX NO.	Flexural strength(28 Days)
Plain Concrete	-	4.6
With fiber & 0% Fly Ash	M1	5.0
With fiber & 20% fly Ash	M2	5.5
With fiber & 30% fly Ash	M3	6.6
With fiber & 40% fly Ash	M4	5.7

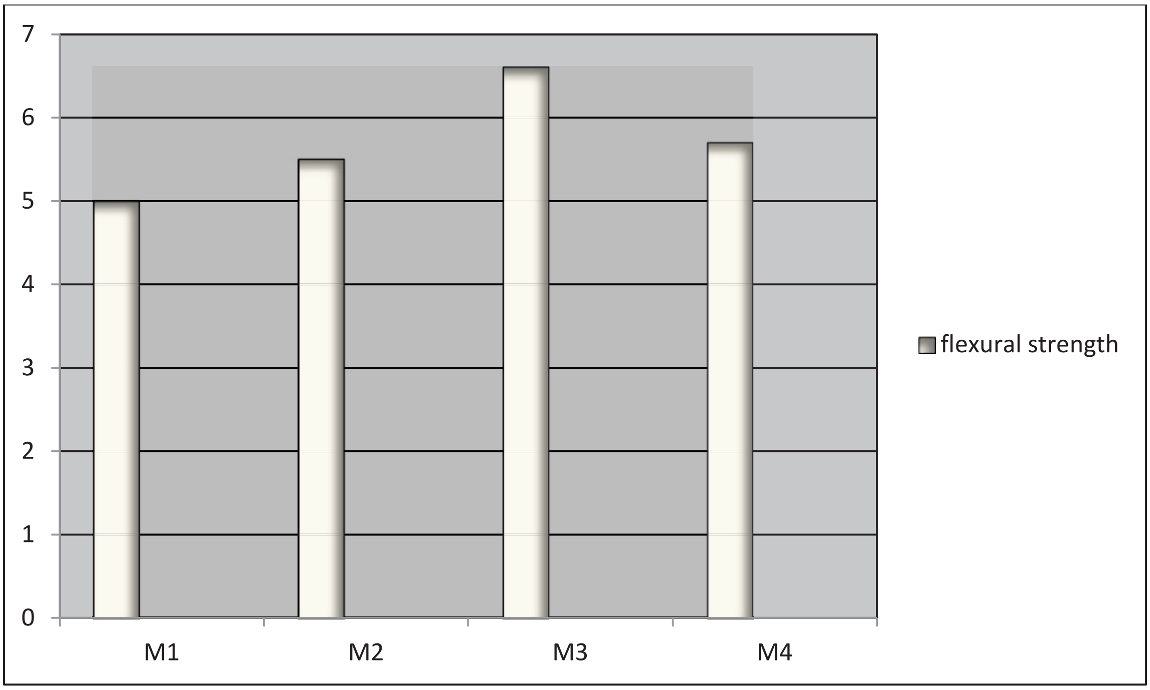

Figure 5.4 Effect of fly ash on Flexural Strength of fiber reinforced Concrete

6.0 Conclusions

Mix proportioning of plain concrete by British DoE is more economical as it involves least consumption of cement. The Guidelines provided by EN:206 for the mix proportioning of admixture is more rational and gives better results.IRC :68-1976,guidelines on cement fly ash concrete for rigid pavement construction is rather arbitrary and does not take into account the effects of fly ash on water demand and other durability criteria.

However, Mix Proportioning for fly ash fiber reinforced concrete requires special consideration regarding fine content..

The following conclusions are arrived at on the basis of present investigation.

On the basis of available information, general conclusion derived from auxiliary experimentation for fixing mix proportion and the main conclusions concerning the structural properties of fly ash fiber concrete to find an optimum replacement of fly ash in fiber reinforced concrete mix obtained from the present study are stated. It is emphasized that the validity of these findings is asserted only within the range of variables covered in the investigation.

- Use of Pozzolana is beyond the scope of Indian standard recommended guidelines for concrete Mix design IS: 10262:1982.
- The IS code uses highest amount of cement and lowest sand content when compared with concrete mix design method such as British DoE, ACI and IRC for the same target strength.
- The new IS: 10262:2009 is in line with ACI. In mix proportioning with fly ash ,water reducing ability of fly ash is not taken into account as well as efficiency of fly ash is also ignored.
- Fly ash concrete mixture to be equivalent in strength to a plain cement mixture, the W/(C+FA) must be lower than the W/C. This is acceptable due to the fact that fly ash acts like a water reducer. Where cement is replaced by an equivalent weight of fly ash and the strengths are equal, they both have the same weight of cementitious materials but the fly ash mix will have a lower water demand.
- The significance of cementing efficiency factor cannot be ignored for fixing water –cement ratio. Reduction of water content when additives are used is also an important aspect that has to be looked into. Indian codes should adopt recommendation from British DoE.
- IRC: 68-1976 Tentative Guidelines on Cement Fly ash Concrete for Rigid pavement Construction requires complete modifications in line with IS 456:2000 & recently modified IS 10262:2009.
- British DoE method gave fine deficient mix for fly ash fiber reinforced concrete. FAFRC required higher ratio of sand to coarse aggregate. A range of 1:1.5 to 1:2.5 of sand -aggregate ratio for fly ash fiber reinforced concrete is necessary to maintain compactability.
- A higher requirement of cement content for fiber in fly ash fiber reinforced concrete is compensated by the use of fly ash.
- Separate guidelines for fly Ash Fiber reinforced concrete has to be developed to popularize its use.
- The compressive strength of fiber reinforced concrete increase with an increase in fly ash-binder ratio up to 20 percent. Higher fly ash contents, however, adversely affected the compressive characteristics.
- The substitution of 20 percent of cement with fly ash increases the compressive strength of steel fiber reinforced concrete even at early ages, when compared with the corresponding mix without fly ash. When 30 percent or 40 percent of cement is substituted by fly ash, there is evidential drop in the rate of strength development with time.
- Flexural strength of fly ash fiber reinforced concrete shows increasing trend with increasing fly ash content up to a fly ash binder ratio of 0.3 but drops at higher fly ash content.
- The optimum fly ash-binder ratio observed for achieving desirable fresh mix workability and hardened material flexural and compressive properties in steel fiber reinforced concrete mixtures was in the range of 0.20-0.30.
- For rigid Pavement, addition of 1.5% steel fiber and 20 percent replacement of cement with fly ash offer an optimum solution.

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