Strength And Cost Comparison Of Normal And High Volume Fly Ash Concrete

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Abstract - One of the challenges of the construction industry in the future will be the use of new high performance materials and technologies produced at reasonable cost and with lowest possible environmental impact.A great deal of research and field experience on the use of fly ash in concrete has accumulated and been published during the past decade. Consequently, and for reason of both economy and performance, the use of fly ash in concrete construction is increasing. In particular, it is becoming clear that materials such as high performance concrete, high volume fly ash concrete, and RCC benefit from the use of fly ash. In the present work, a brief review is presented of the theory and the design of M40 concrete containing 0%, 20%, 30%, 40%, 50% and 60% fly ash by mass of cementitious material. The compressive strength of both mix, flexural and tensile strength of M40 after 28 and 56 days at different fly ash are checked by casting cubes, beams and cylinder and compared with their controlled mixes. It is found that characteristic compressive strength of concrete can be achieved by replacing 50 percent of cement with fly ash. After comparing the strength results, cost comparison is made to show how effective is to use high volume fly ash concrete both strength and cost wise. Comparison is made between both mixes at different fly ash content compared with controlled mixes cost wise. This investigation may open new path for the use of waste material in large quantity as raw material and to solve the disposal problem followed by techniques to reduce the environmental pollution and to achieve green construction concept.

Keywords - Fly Ash, Compressive Strength, Cost Comparison, Flexural Strength.

INTRODUCTION

Ministry of Road Transport and Highways of India has decided to move towards making rigid pavement as a default mode of construction on national highways. The decision, taken after considering factors related to service life, fuel consumption, weather conditions, maintenance costs and natural resources, primarily aims to promote environment friendly construction practices in execution of road projects. Also in recent year environmental degradation has become a major issue on international platforms. The term sustainable development was introduced in Rio summit in 1992. Sustainable development is defined as "an economic activity that is harmony with the earth`s ecosystem".

Concrete, typically composed of gravel, sand, water, and Portland cement, is an extremely versatile building material that is used extensively worldwide. Reinforced concrete is very strong and can be cast in nearly any desired shape. Unfortunately, significant environmental problems result from the manufacture of Portland cement. Worldwide, the manufacture of Portland cement accounts for 6-7% of the total carbon dioxide (CO_2) produced by humans, adding the greenhouse gas equivalent of 330 million cars driving 12,500 miles per year.

Fortunately, a waste product Fly Ash can be substituted for large portions of Portland cement, significantly improving concrete's environmental characteristics. Fly Ash, consisting mostly of silica, alumina, and iron, forms a compound similar to Portland cement when mixed with lime and water. Fly ash is a non- combusted by-product of coal-fired power plants and generally ends up in a landfill. However, when high volumes are used in concrete (displacing more than 25% of the cement), it creates a stronger, more durable product and reduces concrete's environmental impact considerably. Due to its strength and lower water content, cracking is reduced.

Objective

The main objective of the present study is to compare the strength characteristics of M40 concrete by using sample of different percentages of fly ash by mass of cementitious material, and also comparison is made between there cost. To achieve this objective following steps are to be followed:

- Design of M40 concrete mix to obtain the ratio of different components of concrete.
- By using the above calculated ratio samples for compressive and flexural strength test for 0%, 20%, 30%, 40%, 50% and60% replacement of cement by fly ash is to be made.
- Compressive strength of 7,28 and 56 days is to be calculated by casting cubes for M40 mix at 0%, 20%, 30%, 40%, 50% and60% fly ash replacement by cement.
- Flexural strength of 28 and 56 days is to be calculated by casting beam shaped samples of M40 mix at 0%, 20%, 30%, 40%, 50% and60% fly ash replacement by cement.
- Comparison of the compressive and the flexural strength obtained at different percentages of fly ash is to be made.
- Cost comparison of 0%, 20%, 30%, 40%, 50% and60% fly ash concrete is to be made.

HOW FLY ASH WORKS WITH CEMENT IN CONCRETE?

Ordinary Portland Cement (OPC) is a product of four principal mineralogical phases. These phases are Tricalcium Silicate- C_3S ($3CaO.SiO_2$), Dicalcium Silicate - C_2S ($2CaO.SiO_2$), Tricalcium Aluminate- C_3 A ($3CaO.Al_2O_3$) and Tetracalcium alumino-ferrite - C_4AF($4CaO. Al_2O_3. Fe_2O_3$). The setting and hardening of the OPC takes place as a result of reaction between these principal compounds and water. The reaction between these compounds and water are shown as under:

$2C_3S$ + 6H → $C_3S_2H_3$ + 3CH

(Tricalcium Silicate) (Water) (C-S-H gel) (Calcium Hydroxide)

$2C_2S$ +4H → $C_3S_2H_3$ +CH

(Dicalcium Silicate) (Water) (C-S-H gel) (Calcium Hydroxide)

The hydration products from C_3S and C_2S are similar but quantity of calcium hydroxide (lime) released is higher in C_3S as compared to C_2S.

The reaction of C_3A with water takes place in presence of sulphate ions supplied by dissolution of gypsum present in OPC. This reaction is very fast and is shown as under:

C_3A + $3(CSH_2)$ + 26H → $C_3A(CS)_3\ H_{32}$

(Tricalcium Alluminate) (Gypsum) (Water) (Ettringite)

C_3A + CS + 10H → C_3ACSH_{12}

(Water) (Monosulpho-aluminate hydrate)

Tetracalcium alumino-ferrite forms hydration product similar to those of C_3A, with iron substituting partially for alumina in the crystal structures of ettringite and monosulpho-aluminate hydrate.

Above reactions indicate that during the hydration process of cement, lime is released out and remains as surplus in the hydrated cement. This leached out surplus lime renders deleterious effect to concrete such as make the concrete porous, give chance to the development of micro- cracks, weakening the bond with aggregates and thus affect the durability of concrete.

If fly ash is available in the mix, this surplus lime becomes the source for pozzolanic reaction with fly ash and forms additional C-S-H gel having similar binding properties in the concrete as those produced by hydration of cement paste. The reaction of fly ash with surplus lime continues as long as lime is present in the pores of liquid cement paste.

HOW FLY ASH HELPS IN CONCRETE?

Fly ash can play a vital role in the improvement of various properties of concrete. The various ways in which fly ash helps concrete are discussed below:

1) Reduced Heat of Hydration

In concrete mix, when water and cement come in contact, a chemical reaction initiates that produces binding material and consolidates the concrete mass. The process is exothermic and heat is released which increases the temperature of the mass. When fly ash is present in the concrete mass, it plays dual role for the strength development. Fly ash reacts with released lime and produces binder as explained above and renders additional strength to the concrete mass. The zxun-reactive portion of fly ash act as micro aggregates and fills up the matrix to render packing effect and results in increased strength.

The large temperature rise of concrete mass exerts temperature stresses and can lead micro cracks. When fly ash is used as part of cementitious material, quantum of heat liberated is low and staggers through pozzolanic reactions and thus reduces micro-cracking and improves soundness of concrete mass.

2) Workability of Concrete

Fly ash particles are generally spherical in shape and reduces the water requirement for a given slump. The spherical shape helps to reduce friction between aggregates and between concrete and pump line and thus increases workability and improve pumpability of concrete. Fly ash use in concrete increases fines volume and decreases water content and thus reduces bleeding of concrete.

3) Permeability and corrosion protection

Water is essential constituent of concrete preparation. When concrete is hardened, part of the entrapped water in the concrete mass is consumed by cement mineralogy for hydration. Some part of entrapped water evaporates, thus leaving porous channel to the extent of volume occupied by the water. Some part of this porous volume is filled by the hydrated products of the cement paste. The remaining part of the voids consist capillary voids and give way for ingress of water. Similarly, the liberated lime by hydration of cement is water-soluble and is leached out from hardened concrete mass, leaving capillary voids for the ingress of

water. Higher the water cement ratio, higher will be the porosity and thus higher will be the permeability. The permeability makes the ingress of moisture and air easy and is the cause for corrosion of reinforcement. Higher permeability facilitate ingress of chloride ions into concrete and is the main cause for initiation of chloride induced corrosion.
Additional cementitious material results from reaction between liberated surplus lime and fly ash, blocks these capillary voids and also reduces the risk of leaching of surplus free lime and thereby reduces permeability of concrete.

4) Effect of fly ash on Carbonation of Concrete
Carbonation phenomenon in concrete occurs when calcium hydroxides (lime) of the hydrated Portland cement react with carbon dioxide from atmospheres in the presence of moisture and form calcium carbonate. To a small extent, calcium carbonate is also formed when calcium silicate and aluminates of the hydrated Portland cement react with carbon dioxide from atmosphere. Carbonation process in concrete results in two deleterious effects:
(i) Shrinkage may occur.
(ii) Concrete immediately adjacent to steel reinforcement may reduce its resistance to corrosion.
The rate of carbonation depends on permeability of concrete, quantity of surplus lime and environmental conditions such as moisture and temperature. When fly ash is available in concrete; it reduces availability of surplus lime by way of pozzolanic reaction, reduces permeability and as a result improves resistance of concrete against carbonation phenomenon.

5) Sulphate Attack
Sulphate attacks in concrete occur due to reaction between sulphate from external origins or from atmosphere with surplus lime leads to formation of etrringite, which causes expansion and results in volume destabilization of the concrete. Increase in sulphate resistance of fly ash concrete is due to continuous reaction between fly ash and leached out lime, which continue to form additional C-S-H gel. This C-S-H gel fills in capillary pores in the cement paste, reducing permeability and ingress of sulphate ions.

6) Corrosion of steel
Corrosion of steel takes place mainly because of two types of attack. One is due to carbonation attack and other is due to chloride attack. In the carbonation attack, due to carbonation of free lime, alkaline environment in the concrete comes down which disturbs the passive iron oxide film on the reinforcement. When the concrete is permeable, the ingress of moisture and oxygen infuse to the surface of steel initiates the electrochemical process and as a result-rust is formed. The transformation of steel to rust increases its volume thus resulting in the concrete expansion, cracking and distress to the structure.
In the chloride attack, Chloride ion becomes available in the concrete either through the dissociation of chlorides-associated mineralogical hydration or infusion of chloride ion. The sulphate attack in the concrete decomposes the chloride mineralogy thereby releasing chloride ion. In the presence of large amount of chloride, the concrete exhibits the tendency to hold moisture. In the presence of moisture and oxygen, the resistivity of the concrete weakens and becomes more permeable thereby inducing further distress. The use of fly ash reduces availability of free limes and permeability thus results in corrosion prevention.

7) Reduced alkali- aggregate reaction
Certain types of aggregates react with available alkalis and cause expansion and damage to concrete. These aggregates are termed as reactive aggregates. It has been established that use of adequate quantity of fly ash in concrete reduces the amount of alkali aggregate reaction and reduces/eliminates harmful expansion of concrete. The reaction between the siliceous glass in fly ash and the alkali hydroxide of Portland cement paste consumes alkalis thereby reduces their availability for expansive reaction with reactive silica aggregates.

TEST PROGRAMME
The following test programme was planned to investigate the results:
- To obtain the physical properties of the concrete constituents i.e. Pozzolanic Portland cement (PC), fine aggregates, coarse aggregate and fly ash.
- Development of various mix combinations for concrete.
- Casting and curing.
- Testing of specimens for Compressive Strength, flexural strength and split tensile strength.

Table 1 Compressive Strength of M40 (Rerference Mix)

Sr. No.	Mix Designation	Moist Curing Days	Load at failure (Kn)	Compressive strength (MPa)	Average compressive Strength (MPa)
1	Mix 1	7	815.40 739.80 815.40	36.24 32.88 36.24	34.59
2	Mix 1	28	1156.54 1187.32 1158.07	52.18 52.77 51.47	52.14
3	Mix 1	56	1155.60 1209.15 1230.30	51.36 53.74 54.68	53.26

Table 2 Compressive strength of Mix 2 (cement replaced by 20% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Load at failure (Kn)	Compressive strength (MPa)	Average compressive Strength (MPa)
1	Mix 2	7	711.22 702.00 708.07	31.61 31.20 31.47	31.45
2	Mix 2	28	1131.75 1156.95 1184.85	50.30 51.42 52.66	51.46
3	Mix 2	56	1232.55 1198.12 1252.35	54.78 53.25 55.66	54.56

Table 3 Compressive strength of Mix 3 (cement replaced by 30% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Load at failure (Kn)	Compressive strength (MPa)	Average compressive Strength (MPa)
1	Mix 3	7	634.27 682.20 678.82	28.19 30.32 30.17	29.56
2	Mix 3	28	1177.52 1127.70 1130.62	47.89 50.12 50.25	49.42
3	Mix 3	56	1173.15 1209.37 1173.15	52.14 53.75 52.14	53.75

Table 4 Compressive strength of Mix 4 (cement replaced by 40% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Load at failure (Kn)	Compressive strength (MPa)	Average compressive Strength (MPa)
1	Mix 4	7	596.70 596.02 596.70	26.52 26.49 26.52	26.51
2	Mix 4	28	918.00 970.20 959.62	40.80 43.12 42.65	42.19
3	Mix 4	56	1074.82 1114.20 1142.10	47.77 49.52 50.76	49.25

Table 5 Compressive strength of Mix 5 (cement replaced by 50% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Load at failure (Kn)	Compressive strength (MPa)	Average compressive Strength (MPa)
1	Mix 5	7	522.22 485.10 457.42	23.21 21.56 20.33	21.70
2	Mix 5	28	805.27 815.62 813.15	35.79 36.25 36.44	36.16
3	Mix 5	56	965.40 1004.85 1028.82	43.04 44.66 45.77	44.49

Table 6 Compressive strength of Mix 6 (cement replaced by 60% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Load at failure (Kn)	Compressive strength (MPa)	Average compressive Strength (MPa)
1	Mix 6	7	367.42 389.70 376.87	16.33 17.32 16.75	16.80

2	Mix 6	28	683.10 639.22 644.62	30.36 28.41 28.65	29.14
3	Mix 6	56	738.45 782.55 796.95	32.82 34.78 35.42	34.34

Table 7 Comparison of variation of compressive strength of M40 for different replacement Level of cement by fly ash

Mix Designation	Percentage Replacement by fly ash	Compressive Strength (MPa) Duration of moist curing (days		
		7	28	56
Mix 1	0%	34.59	52.14	53.26
Mix 2	20%	31.45	51.46	54.56
Mix 3	30%	29.56	49.42	53.75
Mix 4	40%	26.51	42.19	49.50
Mix 5	50%	21.70	36.16	44.49
Mix 6	60%	16.80	29.14	34.34

Table 8 Variation of flexural strength of M40 (Reference mix)

Sr. No.	Mix Designation	Moist Curing Days	Flexural Strength (MPa)	Average Flexural Strength (MPa)
1	Mix 1	28	7.06 7.45 6.55	7.02
2	Mix 1	56	7.02 7.25 7.18	7.15

Table 9 Variation of flexural strength of Mix 2 (Cement replaced by 20% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Flexural Strength (MPa)	Average Flexural Strength (MPa)
1	Mix 2	28	6.95 6.95 6.80	6.90
2	Mix 2	56	7.06 7.24 7.30	7.20

Table 10 Variation of flexural strength of Mix 3 (Cement replaced by 30% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Flexural Strength (MPa)	Average Flexural Strength (MPa)
1	Mix 3	28	6.09 6.12 6.54	6.25
2	Mix 3	56	6.95 7.10 7.10	7.05

Table 11 Variation of flexural strength of Mix 4 (Cement replaced by 40% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Flexural Strength (MPa)	Average Flexural Strength (MPa)
1	Mix 4	28	5.26 5.54 5.40	5.40
2	Mix 4	56	6.37 6.35 6.12	6.28

Table 12 Variation of flexural strength of Mix 5 (Cement replaced by 50% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Flexural Strength (MPa)	Average Flexural Strength (MPa)
1	Mix 5	28	4.31 4.54 4.65	4.50
2	Mix 5	56	5.19 5.12 5.44	5.25

Table 13 Variation of flexural strength of Mix 6 (Cement replaced by 60% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Flexural Strength (MPa)	Average Flexural Strength (MPa)
1	Mix 6	28	3.34 3.26 3.15	3.25
2	Mix 6	56	4.12 3.65 3.78	3.85

Table 14 Variation of Flexural strength M40 for different replacements levels of cement by fly ash

Mix Designation	Percentage Replacement by fly ash	Flexural Strength (MPa)	
		Duration of moist curing (days)	
		28	56

Mix 1	0%	7.02	7.15
Mix 2	20%	6.90	7.20
Mix 3	30%	6.25	7.05
Mix 4	40%	5.40	6.28
Mix 5	50%	4.50	5.20
Mix 6	60 %	3.25	3.85

Table 15 Variation of split tensile strength of M40 Mix 1 (Reference Mix)

Sr. No.	Mix Designation	Moist Curing Days	Split Tensile Strength (MPa)	Average split tensile strength (Mpa)
1	Mix 1	28	4.26 4.22 4.45	4.31
2	Mix 1	56	4.23 4.44 4.38	4.35

Table 16 Variation of split tensile strength of M40 Mix 2 (Cement replacement by 20% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Split Tensile Strength (MPa)	Average split tensile strength (Mpa)
1	Mix 2	28	3.98 4.20 4.36	4.18
2	Mix 2	56	4.47 4.45 4.45	4.49

Table 17 Variation of split tensile strength of M40 Mix 3 (Cement replacement by 30% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Split Tensile Strength (MPa)	Average split tensile strength (Mpa)
1	Mix 3	28	3.47 3.98 4.25	3.90
2	Mix 3	56	4.11 4.36 4.25	4.24

Table 18 Variation of split tensile strength of M40 Mix 4 (Cement replacement by 40% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Split Tensile Strength (MPa)	Average split tensile strength (Mpa)
1	Mix 4	28	3.15 3.52 3.14	3.27
2	Mix 4	56	4.15 3.45 3.95	3.85

Table 19 Variation of split tensile strength of M40 Mix 5 (Cement replacement by 50% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Split Tensile Strength (MPa)	Average split tensile strength (Mpa)
1	Mix 5	28	2.17 3.10 2.65	2.64
2	Mix 5	56	2.86 2.88 3.20	2.98

Table 20 Variation of split tensile strength of M40 Mix 6 (Cement replacement by 60% fly ash)

Sr. No.	Mix Designation	Moist Curing Days	Split Tensile Strength (MPa)	Average split tensile strength (Mpa)
1	Mix 6	28	1.72 2.21 1.72	1.97
2	Mix 6	56	2.14 2.44 2.35	2.31

Table 21 Variation of split tensile strength of M40 for different replacement levels of cement by fly ash

Mix Designation	Percentage Replacement by fly ash	Split tensile strength Duration of moist Curing days	
		28	56
Mix 1	0%	4.31	4.35
Mix 2	20%	4.18	4.49
Mix 3	30%	3.90	4.24
Mix 4	40%	3.27	3.85
Mix 5	50%	2.64	2.98
Mix 6	60%	1.97	2.31

Cost of M40 Concrete Mixes with varying fly ash

Percentage of Fly Ash	**Cost of M40/cubic meter (Rs)**
0	**4813**
20	**4274**
30	**4001**
40	**3859**
50	**3465**
60	**3196**

CONCLUSIONS

- The cost of concrete decreases with the increase in fly ash content
- Per cubic meter cost of M40 concrete with 50% fly ash content which satisfies the characteristic strength after the 56 days of curing is Rs 1358 less than that of M40 control mix.
- The compressive strength, flexural and tensile strength of M40 concrete with control mix (i.e. 0% fly ash) is maximum after the early age of curing i.e. 7 and 28 days but after 56 days of curing the strength with 20% fly ash content is slightly greater than control mix. and with the further addition of fly ash strength start reducing.
- The mix achieve their characteristic compressive strength even with the 50% fly ash content after the 56 days of curing.
- There is significant improvement in the strength of the concrete mix at later age. Maximum increase of 22 percent in compressive strength after 56 days is found to be at 50% fly ash concrete mix.
- Cost of high volume fly ash concrete is about 30% less than that of control mix and thereby can be used in green pavements.

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