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Strength Appraisal of Light Weight Green Concrete Made with Cold Bonded Fly Ash Coarse Aggregate

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Abstract- ***This study focusses on the development of fly ash concrete made with water/cement ratio of 0.5.To develop fly ash concrete in this study, 40% of cement is replaced with fly ash, manufactured sand is used as fine aggregate, light weight fly ash aggregate as used coarse aggregate and for mixing concrete instead of tap water 12% lime concentrated water is used. The fly ash concrete compressive strength obtained is equivalent to that of M30 grade concrete made with OPC. Two sets of samples are prepared one set with 40% fly ash concrete made with river sand and natural crushed stone coarse aggregates and another set of sample with 40% fly ash concrete made with manufactured sand and artificial light weight fly ash coarse aggregates. Experimental studies revealed that use of manufactured sand enhanced compressive, tensile and flexural strengths by 6-8% only. Even permeation properties such as water absorbtion and porosity of fly ash concrete made with manufactured sand and artificial light weight fly ash coarse aggregates is almost similar to that of fly ash concrete made with made with river sand and natural crushed stone coarse aggregates. The results conclude that fly ash coarse aggregates can be used for structural applications instead of natural coarse aggregates but not feasible for use in pavement as per IS 2386. Manufactured sand can be used as 100% replacement to river sand in fly ash based concretes with improved properties of concrete.***

Index terms- ***cold bond technique, fly ash aggregate, artificial aggregate, light weight aggregate, polymerization***

I. INTRODUCTION

Fly ash is produced plentifully in India from power plants whose disposal is a major problem and also an environmental concern. So construction industry finds the application of fly ash in concrete development. Fly ash can be used in concrete as cement replacement upto 30% but research is going on to use high volume of fly ash in concrete. Similarly use of river sand as fine aggregate is almost stopped due to depletion of sand resources so an alternative fine aggregate replacement is found in the form of manufactured sand. Similarly for coarse aggregate now-a-days artificial coarse aggregates such as slag, fly ash etc. are being used as coarse aggregate replacement.

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II. OBJECTIVES

a) To develop fly ash concrete with fly ash as partial cement replacement
b) Fly ash aggregates are developed using cold bond technique
c) To develop fly ash concrete with fly ash as partial cement replacement, manufactured sand as fine aggregate and artificial light weight fly ash as coarse aggregates
d) Strength studies are made on fly ash concrete made with manufactured sand and artificial light weight fly ash coarse aggregates

III. MIX DESIGN

Mix quantities computed as per IS method are presented below-
Cement = 390 kg/m^3 Water = 191 kg/m^3
Fine aggregates = 887 kg/m^3 Coarse aggregate = 982 kg/m^3
Water-cement ratio = 0.50

IV. DETERMINATION OPTIMUM CONCENTRATION OF LIME WATER AS MIXING WATER

Based on prior study, fly ash mortar cubes are casted with four types of mixing water to determine the optimum concentration of lime water .They are tap water, 30 grams, 60 grams and 120 grams of lime powder into 1L of tap water respectively. Powder lime is dissolved one day before the casting to make saturated lime water so that top water is used for study but not the water containing the sediment lime solids. The pH of lime water is higher than the tap water which activates the fly ash in fresh state. Mortar specimens made with 120 grams lime water found to give optimum strengths so for further study 12% concentration lime water is to be used as mixing water for fly ash concretes.

Since fly ash has high amount of silica and alumina content, to react with it equal amount of $Ca(OH)_2$ should be made available for optimal pozzolonic action. So based on the literature, 12% concentration lime water is used as mixing water in case of fly ash based concretes for better early strengths. Studies revealed that pozzolonic action does not start at least before 7 days. Addition of lime will stimulate pozzolonic reaction during early age. In this study, 23 kg of lime is added to 172 liters of tap water to make 12% concentration lime water to be used as mixing water for fly ash concretes.

Table 1 – Quantities of concrete mixes made with various percentage replacements of fly ash

Type	Cement %	Fly ash %	Cement (kg/m^3)	Fly ash (kg/m^3)	12% Concentration Lime water as mixing water (kg/m^3)	Fine Aggregate (River sand) (kg/m^3)	Coarse Aggregate (Natural Crushed stone) (kg/m^3)
Mix1(FAC0)	100	0	390	0	195	887	982
Mix2(FAC10)	90	10	351	39	195	887	982
Mix3(FAC20)	80	20	312	78	195	887	982
Mix4(FAC30)	70	30	273	117	195	887	982
Mix5(FAC40)	60	40	234	156	195	887	982

Table 2- Compressive strengths of concrete mixes made with various percentages of fly ash

Type	Cement %	Fly ash %	Compressive Strength (MPa)		
			7 days	28 days	60days
Mix1(FAC0)	100	0	28.12	39.78	41.11
Mix2(FAC10)	90	10	26.78	37.19	43.23
Mix3(FAC20)	80	20	24.12	35.18	44.98
Mix4(FAC30)	70	30	21.11	27.10	45.61
Mix5(FAC40)	60	40	17.55	24.34	33.04

Table 3- Split tensile strengths of concrete mixes made with various percentages of fly ash

Type	Cement %	Fly ash %	Split tensile strength (MPa)		
			7 days	28 days	60days
Mix1(FAC0)	100	0	1.91	2.27	2.31
Mix2(FAC10)	90	10	1.86	2.20	2.37
Mix3(FAC20)	80	20	1.77	2.14	2.41
Mix4(FAC30)	70	30	1.53	1.87	2.43
Mix5(FAC40)	60	40	1.37	1.70	2.07

Table 4- Flexural strengths of concrete mixes made with various percentages of fly ash

Type	Cement %	Fly ash %	Flexural Strength (MPa)		
			7 days	28 days	60days
Mix1(FAC0)	100	0	3.18	3.78	3.85
Mix2(FAC10)	90	10	3.10	3.66	3.94
Mix3(FAC20)	80	20	2.95	3.56	4.02
Mix4(FAC30)	70	30	2.55	3.12	4.05
Mix5(FAC40)	60	40	2.29	2.84	3.45

V. COLD BOND TECHNIQUE

This phase is planned into 2 steps

1) Optimization of alkaline activators for fly ash aggregates
Cubes of size 70.6mm are prepared with cement and fly ash of 10:90 and with the optimal molar quantities of alkaline activator solutions (8M to 16M NaOH and Na_2SiO_3 (SiO_2/Na_2O ratio= 2)) that produces the maximum strength at 60°C temperature cured for 24 hrs. for polymerization process to occur through formation of alumina-silicate oxides. Usually activators are prepared 30 minutes before the casting begins. The ratio of Na_2SiO_3/NaOH is optimally maintained at 2.5. It was found that NaOH of 14 molarity and Na_2SiO_3 with SiO_2/Na_2O ratio 2 yields maximum strength.

2) Dry mix quantities for fly ash aggregates
Quantities required to make one cubic metre of paste, 10 parts of cement and 90 parts of fly ash are mixed with alkaline activators (Na_2SiO_3 +NaOH) in the ratio of 0.35.
Mass of fly ash = 0.90 x 2.13 g/cm^3 x 10^3= 1917 kg/m^3
Mass of cement= 0.10 x 3.15 g/cm^3x 10^3= 315 kg/m^3
Mass of Total Binder= 1917+315=2232 kg/m^3
Mass of Alkaline activators= 0.35 x 2232 = 781.2 kg/m^3

Since Na_2SiO_3/ NaOH ratio is adopted as 2.5 which means that Na_2SiO_3/ NaOH= 5/2

So mass of Na_2SiO_3 solution is 781.2 x 5/7 = 558 kg/m^3 and mass of NaOH solution is 781.2 x 2/7 = 223.2 kg/m^3

3) Preparation of NaOH solution from solid flakes available in the market Since molecular weight of NaOH is 40 gm/mol. So to prepare NaOH solution of 14 molarity, amount of flakes required to be added to one litre water is 14x40=560 gm. Since the solubility of NaOH in water is 1110 gm per 1000ml at 20°C, So to prepare 1000ml of NaOH solution mix 560 gm of NaOH flakes into one litre of water.

NaOH flakes/ Water= 560/1000=0.56

NaOH solution = 0.56 x water + water = 1.56 x Mass of Water. Mass of NaOH solution calculated is 223.2 kg/m^3. So 223.2 =

1.56 x mass of water required to mix NaOH flakes. From which, the mass of water required is obtained as 143 kg/m^3 to mix NaOH flakes of 80.2 kg/m^3 (0.56*143)

So quantity of NaOH required to prepare one m^3 volume of dry mix is 80.2 kg/m^3 and similarly the quantity of Na_2SiO_3 required in one m^3 volume of dry mix is 80.2 x2.5= 200.5 kg/m^3.

Preparation of fly ash coarse aggregate

Fly ash, cement and alkaline activator solutions are mixed to make paste and placed in a tray and flattened to required thickness of aggregate. Cut the flattened paste into square or rhombus shapes of 20mm size and heat treated for 24 hrs. in oven at 60°C. After 24 hrs. heat treatment the hardened aggregates are kept in the abrasion testing drum with abrasion charge and rotate for 15 minutes to attain cubically angular shape to aggregates. These developed light weight fly ash coarse aggregates are tested as per IS: 2386.

VI. PROPERTIES OF FLY ASH AGGREGATES

Fly ash coarse aggregates are angular in shape with a bulk density of 996 kg/m^3 when compared to natural coarse aggregate whose bulk density is 1675 kg/m^3. Specific gravity of fly ash coarse aggregates is found to be 1.84 when compared to natural coarse aggregate whose specific gravity is 2.55. Aggregate crushing value (crushing strength), Aggregate impact value (toughness) and Aggregate abrasion value (wear and tear) are 35.23%, 37.14% and 30% respectively which can be used in structures other than pavements. Water absorption is little higher but within permissible limits of usage for structures other than pavements as per IS 2386.

Table 4- Mix proportions and quantities required to prepare one m^3 volume of dry mix

Ingredients	Quantity	Proportions
Fly ash	1917 kg/m^3	6.08
OPC	315 kg/m^3	1.00
NaOH solid flakes	80.2 kg/m^3	0.25
Na_2SiO_3 Liquid	200.5 kg/m^3	0.64

Fig 1: Artificial fly ash aggregates

Table 5: Quantities of fly ash concrete mixes made with fly ash coarse aggregate

Type	Cement %	Fly ash %	Cement (kg/m^3)	Fly ash (kg/m^3)	12% Concentration Lime water as mixing water (kg/m^3)	Fine Aggregate (Manufactured sand) (kg/m^3)	Coarse Aggregate (Fly ash based) (kg/m^3)
Mix11(FAC0)	100	0	390	0	195	887	982
Mix21(FAC10)	90	10	351	39	195	887	982
Mix31(FAC20)	80	20	312	78	195	887	982
Mix41(FAC30)	70	30	273	117	195	887	982
Mix51(FAC40)	60	40	234	156	195	887	982

Table 6- Compressive strengths of fly ash concrete mixes made with fly ash coarse aggregate

Type	Cement %	Fly ash %	Compressive Strength (MPa)		
			7 days	28 days	60days
Mix11(FAC0)	100	0	30.37	42.96	44.40
Mix21(FAC10)	90	10	28.92	40.17	46.69
Mix31(FAC20)	80	20	26.05	37.99	48.58
Mix41(FAC30)	70	30	22.80	29.27	49.26
Mix51(FAC40)	60	40	18.95	26.29	35.68

Table 7- Split tensile strengths of fly ash concrete mixes made with fly ash coarse aggregate

Type	Cement %	Fly ash %	Split tensile strength (MPa)		
			7 days	28 days	60days
Mix11(FAC0)	100	0	1.99	2.36	2.40
Mix21(FAC10)	90	10	1.93	2.29	2.46
Mix31(FAC20)	80	20	1.84	2.23	2.51
Mix41(FAC30)	70	30	1.59	1.94	2.53
Mix51(FAC40)	60	40	1.42	1.77	2.15

Table 8- Flexural strengths of fly ash concrete mixes made with fly ash coarse aggregate

Type	Cement %	Fly ash %	Flexural Strength (MPa)		
			7 days	28 days	60days
Mix11(FAC0)	100	0	3.31	3.93	4.00
Mix21(FAC10)	90	10	3.22	3.81	4.10
Mix31(FAC20)	80	20	3.07	3.70	4.18
Mix41(FAC30)	70	30	2.65	3.24	4.21
Mix51(FAC40)	60	40	2.38	2.95	3.59

Fig 2 – Concrete made with fly ash aggregate and natural aggregate

VII. CONCLUSIONS

1. Concrete mix is designed for water/cement ratio of 0.5 and for strength of M30 grade
2. Instead of tap water, 12% concentration of lime water is used for mixing concrete for early age pozzolonic activity
3. Cement replacement upto 40% fly ash in concrete is reported here beyond which strengths are rapidly degrading and need other methods to improve the strengths.
4. One set of sample with 40% fly ash concrete made with river sand and natural crushed stone coarse aggregates and another set of sample with 40% fly ash concrete made with manufactured sand and artificial light weight fly ash coarse aggregates are prepared.

5. Upto 30% replacement desired strengths are achieved for made with river sand and natural crushed stone coarse aggregates.
6. Fly ash aggregates are prepared using cold bond technique where high quantities of fly ash is mixed with alkaline activators 14 M NaOH and Na2SiO3 for polymerization process.
7. Fly ash produced through this method has less density and high water absorption is little higher but within permissible limits of usage for structures other than pavements as per IS 2386. But this limitation can be overcome using manufactured sand as fine aggregate.
8. It was established from experimental results that use of manufactured sand enhanced compressive, tensile and flexural strengths by 6-8% only. Even permeation properties such as water absorbtion and porosity of fly ash concrete made with manufactured sand and artificial light weight fly ash coarse aggregates is almost similar to that of fly ash concrete made with made with river sand and natural crushed stone coarse aggregates.

So it can be concluded that fly ash aggregates can be used as coarse aggregate in combination with manufactured sand as fine aggregate for sustainability.

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