Proportioning of Fly Ash Concrete Mixes A Comprehensive Approach

M. N. Balakrishna, M. C. Nataraja

Abstract- The Concrete as a material synonymous with strength and longevity has emerged as the dominant construction material for the infrastructure needs of the 21st century. In addition to being durable, concrete is easily prepared and fabricated from readily available constituents and is therefore widely used in all types of structural systems. However, the environmental drawbacks of cement production have come under increased scrutiny as expanding industrialization and urbanization fuel the accelerated growth of infrastructure worldwide. As a consequence of that, Fly ash is one such supplementary cementing material which in turn more concern about environmental and cost-effective objectives. In this research investigation, the influencing factors of Fly ash and Cement to arrive at appropriate combinations so to satisfy the requirement of placement, development of strength with age has been examined. Also in this investigation that, the applicability of Generalized Abrams law [1] developed for single cementing materials has been examined to two components like Cement and Fly ash. In addition to that, with the determination of workability and strength of trail mix at different ages, how adjustments can be made in water/cementitious ratio in order to arrive at matching micro-structure in hardened states, so as to result in strength development of Fly ash cement concrete mixes, in turn to obtain identical strength levels are to be investigated. Analysis of experimental data reveals that even with high grade of cement, Fly ash admixture could not be effective despite the fineness requirement is satisfied provided if carbon content is high. On the contrary if Fly ash satisfies fineness consideration without unburnt carbon, the development of strength could not approach as that of normal concrete at later ages provided when the grade of cement is not high enough such as 53 grade of cement. Thus finally in order to achieve judicious combinations of Fly ash and Cement in concrete mixes, its very essential to satisfy the requirement of cementitious materials like grade of cement, fineness of Fly ash with very low unburnt carbon content.

Key words: Fly ash, Mix proportioning; Cementitious materials; Fineness; Grade of concrete; Age of Concrete; Compressive strength.

I. INTRODUCTION

The cement is the most costly and energy intensive component of concrete. The unit cost of concrete can be reduced as much as possible by partial replacement of cement with Fly ash. The disposal of Fly ash is one of the significant issues for environmentalists, as dumping of Fly ash as waste material causes severe environmental problems. The use of Fly ash instead of dumping it as a waste material which can be partly used on economic basis as pozzolana for partial replacement of cement.

The Fly ash were to be partially replaced with cement because of its beneficial effects of lower water demand for similar workability, reduced bleeding and lower evolution of heat. Thus the world today needs an environmentally friendly construction material because of the desire to reduce CO_2 emissions, save nonrenewable energy resources, provide aesthetically pleasing and healthy surroundings and at the same time minimize waste. Fortunately we have just such a material like concrete, and most of the essential research has been done to enable concrete to fill this role. The general use of Fly ash has been at replacement levels of 10% to 25% although higher levels are required for resistance to aggressive environments or AAR. Replacement levels of the order of 30% to 40% of Fly ash would be required for marine, sulphate, acidic and other aggressive conditions, subject to formwork stripping and curing requirements. Replacement levels for AAR would range from 10% to 30% depending on the type of aggregate and the magnitude of potential Reactivity. The replacement of Fly ash as a cementitious component in concrete depends upon several factors like design strength and workability of the concrete, water demand and relative cost of fly ash compared to cement are particularly important in mixture proportioning of concrete. From the literature it is generally found that Fly ash content in the cementitious material varies from 30-80% for low strength (20 MPa) to high strength (100MPa).

The present study investigates the efficiency of using generalized mix proportioning methods for different grades of cement (33 & 53 Grade), fineness of cement and with their chemical composition, age of concrete curing, and water/cement ratio. Other aspects examined in this investigation are the effects of two batches of Fly ash. In turn one of the batches of Fly ash despite being finer than the other had higher carbon content. It's generally known that presence of carbon in Fly ashes inhibit hydration of cement. Thus this can be nullified to a certain extent by use of higher grade of cement has also been examined. Generally the water requirement for workability of Fly ash concrete mixes gets reduced. In turn how far this is true in the case of Fly ashes with two levels of fineness and carbon content has also been examined. This is the method developed at Indian institute of Science, Bangalore. This method is an attempt towards getting the final mix proportions in order to achieve the targeted workability and strength as required. This mix proportioning method was based on Generalization of Abram's law by normalization strength at water/cement ratio of 0.50 which is proposed by Nagaraj et al [2].

Manuscript received on June 2013.

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II. LITERATURE REVIEW

The art of arriving at a proper mixture by suitable combination of cement, coarse and fine aggregate, water, and admixture if necessary to order to satisfy the required workability, strength, and durability is termed as proportioning. Also, apart from satisfying the above said factors, the material mixture should also be an economical one. As such parameters involved in the mixture proportioning are water/cement ratio, type of cement, aggregate/cement ratio with quality of aggregate, of which water/cement ratio plays an important role. The burning of pulverised coal to make steam, to produce electricity and using the Fly ash arising from the process has been established in the UK since the 1950's [3], although in the USA the history of use goes back further [4]. In the USA, dam construction in the 1930's provided the drive to publish the first in-depth technical appraisal of the use of fly ash in concrete by Davis et al [5]. It must be acknowledged, that their work laid down the framework by which the 'quality' of ash is judged to this day, i.e. 45um fineness and loss-on-ignition (LOI). Similally significant independent research into the wider performance of Fly ash in concrete was carried out by centres including the University of Dundee [6-9]. Since then, work at Dundee has covered diverse areas of research such as concrete durability [10-11], high Fly ash content concrete [12] and use of conditioned and lagoon Fly ash [13-14]. Swamy et. al. [15] reported that concrete mixes containing 30 percent by weight of Fly ash (ASTM Class F) could be proportioned to have adequate workability and early one-day strength and elastic modulus for structural applications. As per ACI 116R [16], Fly ash is the finely divided material resulting from combustion of ground or powered coal which is transported from firebox through boiler by flue gas known in UK as pulverized fuel ash. Mukerjee et al. [17] incorporated high volumes of fly ash in concrete through the aid of three different superplasticizers. They reported that satisfactory high-strength concrete can be achieved using large quantities of ASTM Class F fly ash. Langley et. al. [18] reported that maximum fly ash percentage might range between 55 and 60 percent of total cement content in order to produce structural grade concrete.

Table 1:Results of Ordinary Portland cement (ACC 53 Grade)

Sl.No	Properies	Test Results	IS:12269-1987
1	Standard consistency	32.25%	-
2	Initial setting time	60 min	Max of 30 min
3	Final setting time	140 min	Max of 600 min
4	Specific gravity	3.15	-
5	Compressive strength		
	3 Days	26.07 MPa	27 MPa
	7 Days	35.84 MPa	37 MPa
	28 Days	52.11 MPa	53 MPa

III. EXPERIMENTAL WORK

In this investigation, the potentiality of Comprehensive approach which is proposed by Nagaraj et al [2] to reproportion Fly ash Concrete mixes was evaluated in order to achieve required workability and Compressive strength of concrete with different curing period like 7-90 days. For that the following materials are used like Fly ash (partial replacement with cement like 0%, 10%, 20%, 25%, 30%, and 40%), Cement, Fine aggregate, Coarse aggregate, and natural potable water in order to evaluate the above mentioned Comprehensive approach. In the present pilot program, two types of Fly ashes were used. In turn both the Fly ash types were to be sieved through 150 micron sieve in order to remove pebbles, and clods and afterwards passes through 90 micron sieve to remove un-burnt coal particles as per IS:383-1981. An ordinary Portland cement 53 grade and 33 grades have been used in this investigation. The test results are represented as shown below in (Table.1& 2).

Table 2:Results of Ordinary Portland cement (ACC 33 Grade)

Sl.No	Properies	Test Results	IS:12269-1987
1	Standard consistency	29.50%	-
2	Initial setting time	140 min	Max of 30 min
3	Final setting time	255 min	Max of 600 min
4	Specific gravity	3.15	-
5	Compressive strength		
	3 Days	14.51 MPa	16 MPa
	7 Days	21.53 MPa	22 MPa
	28 Days	32.36 MPa	33 MPa

Since locally good quality river sand is available in turn due to that the same sand has been used as fine aggregates. The properties of the sand have been determined by conducting tests in accordance with IS: 2386 (Part-1)-1963. For assessing the grading by sieve analysis, 1000 grams sample has been used and sieved through a set of IS sieve. The specific gravity has been assessed as 2.70 as per IS: 2386 (Part-III)-1963. Similarly crushed stone aggregate obtained from machine crusher was used as Coarse aggregates. In the present investigation aggregate passing through 20 mm sieve was used. The results of various tests conducted as concern to Coarse aggregate as per IS:2386 (Part-III)-1963 are given as viz specific gravity and Bulk density of 2.59 and 1619 Kg/m^3. Finally the compressive strength of concrete with or without Fly ash replacement with cement was evaluated by testes performed on cubic specimens (150x150x150 mm^3) in a controlled universal testing machine

IV. DISCUSSION AND RESULTS

It can be seen from Fig.1, as expected that with (53 and 33 grade) cements have different potential to develop strength with age for the same water/cement ratio of 0.50.Although at 90 day age the strength development of 33 grade of cement is lower by 10 MPa (Fig.1). The characteristics of Type 1 and Type 2 Fly ashes are that, the fineness of each of them are in the same order but Type 2 had higher unburnt carbon than type 1.

With 53 grade as base cement with combination of Fly ash by 10%,20%,30%,40%, the seven day strength drops to as low as 17.4 MPa (Figs.2-5 and Table. 3). Even with age upto 20% addition, the strength development approaches to that of cement concrete at the age of 90 days, although the strength development in the early age viz 7 and 14 days are lesser. Whereas in the case of 33 grade of cement, the addition of Fly ash satisfies the fineness considerations, as a result of that the early strength development at the same age with same water/cementitious material ratio is further reduced. This is attributed to the lower potential to develop compatible microstructure by generation of CSH compounds.

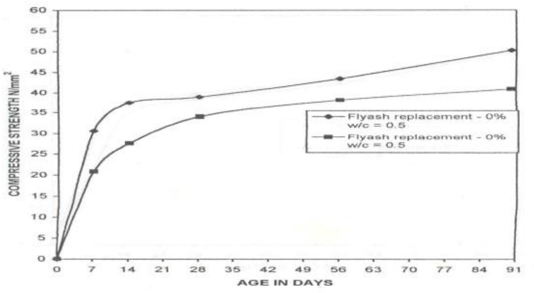

Fig. 1 Variation of Compressive Strength of Concrete Vs. Age containing 53 & 33 Grade Cement

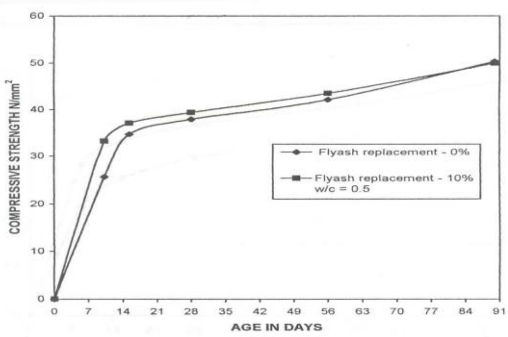

Fig. 2 Variation of Compressive Strength of Concrete Vs. Age containing 53 Grade Cement and Type 1 Flyash

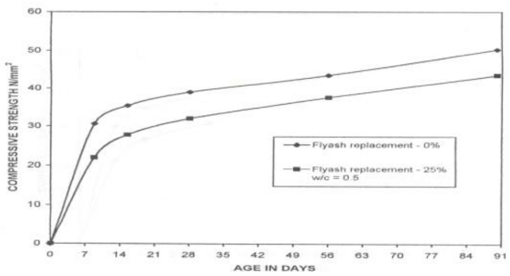

Fig. 3 Variation of Compressive Strength of Concrete Vs. Age containing 53 Grade Cement and Type 1 Flyash

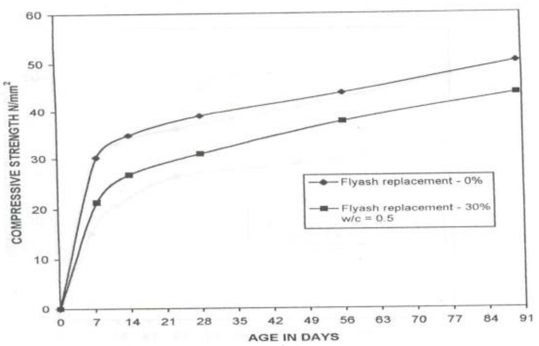

Fig. 4 Variation of Compressive Strength of Concrete Vs. Age containing 53 Grade Cement and Type 1 Flyash

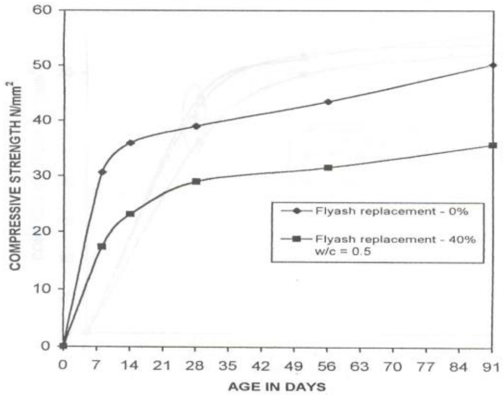

Fig. 5 Variation of Compressive Strength of Concrete Vs. Age containing 53 Grade Cement & Type 1 Flyash

Table 3: Variation of Compressive strength of Concrete with age containing 53 Grade cement and Fly ash type 1

f_c N/mm^2 w/c = 0.50	7 day	14 day	28 day	56 day	90 day	Slump (mm)
0%	30.61	37.49	39.00	43.52	50.28	22-29
10%	25.53	34.71	37.93	41.86	50.00	11-12
20%	25.53	29.97	34.77	39.96	49.75	12-13
25%	22.08	26.54	31.98	37.59	43.51	14-13
30%	21.34	22.21	29.49	39.08	43.74	00-00
40%	17.44	22.95	29.02	31.60	35.76	14-13

Table 4: Variation of Compressive strength of Concrete with age containing 33 Grade cement and Fly ash type 2

f_c N/mm^2 w/c = 0.50	7 day	14 day	28 day	56 day	90 day	Slump (mm)
0%	20.92	27.56	34.04	38.21	40.98	32-31
10%	16.54	21.87	29.21	34.36	34.92	40-42
15%	22.20	25.44	34.57	32.17	34.48	24-26
20%	15.18	22.30	24.53	27.17	30.07	23-24
25%	19.30	25.17	28.32	33.39	36.05	13-16
40%	11.90	18.57	22.33	26.86	28.42	12-14

The possibility of reproportioning Fly ash concrete mixes for matching strengths of OPC mixtures is now discussed. The matching of microstructure in terms of porosity for a specified age is the basis of the approach. The premise is that for a particular level of strength at an age, say 7 or 14 days which is associated with a specific level of porosity. Since the rate of strength development of Fly ash cement concrete mixes was slower at the same age that is strength development is lesser (Table. 3 and 4). For example, the 7 days strength of OPC mix at w/c ratio of 0.5 is 30.60 MPa. With 10% Fly ash, the strength at same water/cement+fly ash ratio of 0.50 its 25.5 MPa. To jack up this value to 30.60 MPa, the available space to fill up by hydrated gel is to be lesser.

Thus by using Generalized Abrams law and data of Fly ash to cement concrete mixes, the calculated water/cementitious material ratio is 0.439 instead of 0.5 (Fig.6). With this reduction at the age of 7 days, the gel space ratio (porosity) would be same as that at 0.50 OPC mixes. The strength obtained by Fly ash (10%) +cement concrete mixture has been 33.4 MPa (Table. 5 and Fig.6). The same principle has been used to match the strength at 14 day (Table.4 and Fig.7). The matching of strengths (both 7 and 14 days) with 30% addition of Fly ash can be seen in Table 5 (Figs.8 and 9).

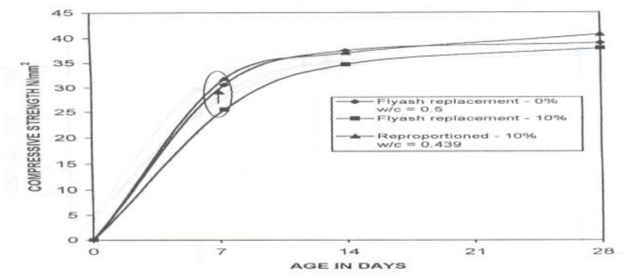

Fig. 6 Reproportioned 7 day strength of FAC to PC containing 53 Grade Cement and Type 1 Flyash

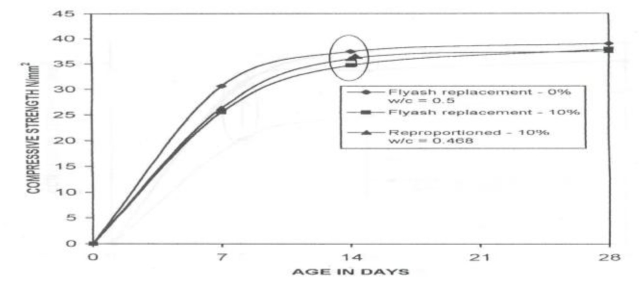

Fig. 7 Reproportioned 14 days strength of FAC to PAC containing 53 Grade Cement and Type 1 Flyash

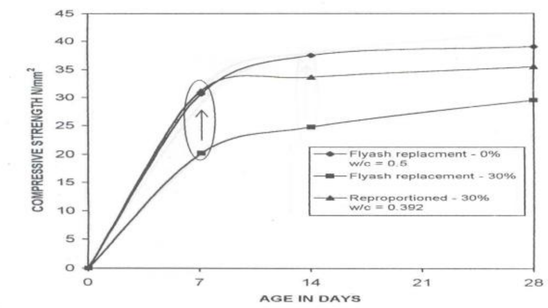

Fig. 8 Reproprotioned 7 day strength of FAC to PC containing 53 Grade Cement and Type 1 Flyash

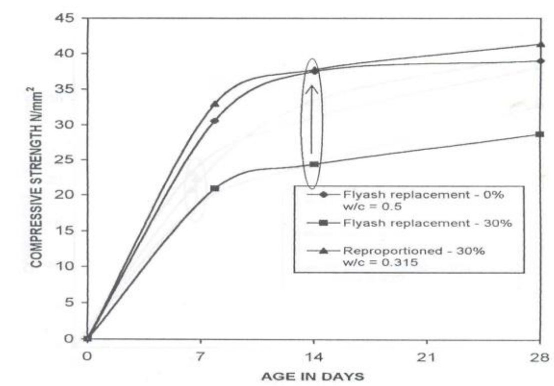

Fig. 9 Reproportioned 14 day strength of FAC to PC containing 53 Grade Cement and Type 1 Flyash

Table 5: Strength results of reproportioned Concrete

f_c N/mm^2 (53 Grade Cement)	**7 day**	**14 day**	**28 day**	**w/c**	**Slump (mm)**	**Mix**
0%	30.61	37.49	39.00	0.50	22-29	1:2.09:2.55
Based on 10% 7 day strength of FAC to 7 day strength of PC	33.41	36.61	40.67	0.439	37-38	1:1.14:1.89
14 day strength of FAC to 14 day strength of PC	26.35	36.04	37.54	0.468	54-55	1:1.27:2.02
Based on 30% 7 day strength of FAC to 7 day strength of PC	31.21	33.69	35.51	0.392	48-50	1:0.93:1.68
14 day strength of FAC to 14 day strength of PC	33.04	37.75	41.36	0.315	45-48	1:0.58:1.35
f_c N/mm^2 (33 Grade Cement)	**7 day**	**14 day**	**28 day**	**w/c**	**Slump (mm)**	**Mix**
0%	20.92	27.56	34.04	0.50	32-31	1:2.09:2.55

Based on 10% 7 day strength of FAC to 7 day strength of PC 14 day strength of FAC to 14 day strength of PC	27.60 19.00	33.42 29.75	37.37 35.00	0.432 0.435	45-47 43-46	1:1.64:2.17 1:1.65:2.19

The strength levels that can be obtained in the case of 33 grade cement by using another type of Fly ashes are also lesser (Table. 4), due to reduced intrinsic potential of grade of cement (Figs.12-14). By proportioning, it has been possible to obtain matching strengths for 33 grades of OPC mixes for 7 and 14 days, the levels of strengths are lower than that of 53 grade of cement (Fig.10 & Fig.11). It can thus infer that both the grade of cement and characteristics of Fly ash (fineness and unburnt carbon) are equally important to obtain optimal results.

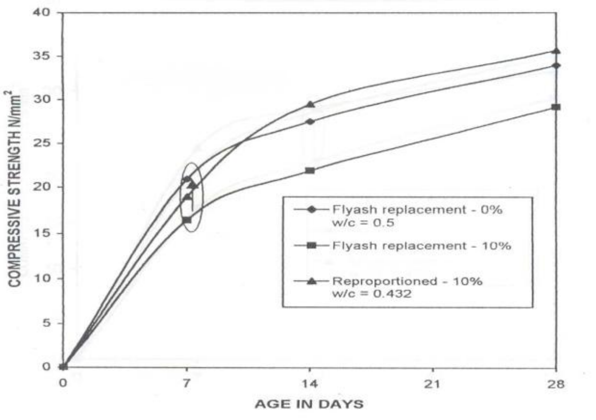

Fig. 10 Reproportioned 7 day strength of FAC to PC containing 33 Grade Cement and Type 2 Flyash

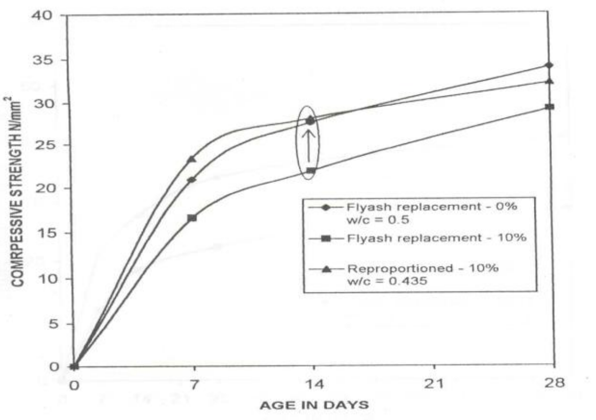

Fig. 11 Reproportioned 14 day strength of FAC to PC containing 33 Grade Cement and Type 2 Flyash

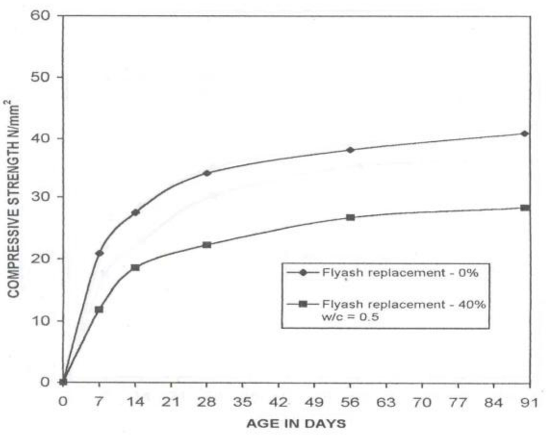

Fig. 12 Variation of Compressive Strength of Concrete Vs. Age containing 33 Grade Cement and Type 2 Flyash

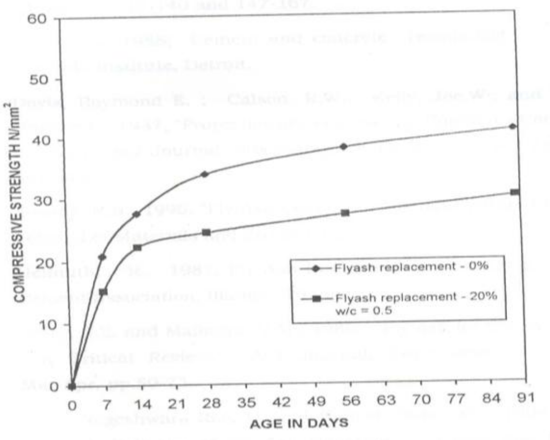

Fig. 14 Variation of Compressive Strength of Concrete Vs. Age containing 33 Grade Cement and Type 2 Flyash

V. CONCLUSION

The following concluding remarks arise out of this investigation:

1) The Portland cement and Fly ashes are interacting particulate materials. Hence it's possible to account for its combined interaction by Generalized Abrams law instead of water/cement ratio, water/cementious material (Cement+Fly ash) ratio. Since the strength development rate is not at the same rate hence it is not possible to expect same strength development at same age.
2) In order to obtain the same strength ratios both in the case of Portland cement and Fly ash cement concrete mixes, the water/cement and water/cementitious material ratios can be readjusted. For each of the mixes, appropriate strength data of trial mixes are to be used. By appropriate reductions in water/cementitious material ratios, the strength development at a particular age can be matched in turn such reductions would result in identical residual porosities.
3) This investigation indicates that, the grade of cement is as important as the characteristics of Fly ashes (fineness and unburnt carbon content) to have optimal strength development with age.

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