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Experimental study of concrete with Blended Cement with Accelerated Curing & Formation of Mathematical Model

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Abstract: *Traditionally, strength of concrete in construction work is evaluated in terms of its 28 days strength of cubes. This procedure requires 28 days of moist curing before testing as per IS: 516-1959[9]. This time duration may be considered as a long period. Hence, needs for an accelerated curing technique has arisen, where 28 days strength of concrete can be easily predicted. The main objective of this paper is to develop mathematical model, which gives relation between accelerated curing strength and normal curing strength for 7 and 28 days compressive strength. Boiling water curing at 100˚ 3˚ C is applied to accelerate the strength gain of concrete for the early prediction of 7 days and 28 days compressive strength. Various concrete mixes in terms of cement (OPC), cement replacing materials likes activated fly ash, Metakaolin were considered to prepared cubes.*

Keywords: *Accelerated curing, Activated fly ash, Concrete compressive strength, Flexural strength, Metakaolin*

I. Introduction

Recent trend in engineering technology is to develop economic concrete and complete the project within time limit. To develop the economic concrete, mix design is to be developed and to complete project within time limit, the compressive strength of concrete cubes for selected mix design should be determined earlier in the laboratory.

The compressive strength of hardened concrete is most common property required for the structural use. The prediction of 28 days strength at early age is needed for different purpose such as,

- The fast trend of construction progress and its economic benefits attained from accelerating construction schedule.
- Testing for quality control purposes
- To check the suitability of concrete mixes much earlier than 28 days test.

The rate of strength gain mainly depends upon the rate of hydration and the rate of hydration depends on the surrounding temperature. The strength gain could be accelerated at early age and related to 7days, 28 days and 56 days compressive strength.

Blended cements are produced by intimately and uniformly intergrinding or blending Ordinary Portland Cement (OPC) with one or more supplementary cementitious materials (SCMs). Most SCMs, such as ground granulated blast-furnace slag (GGBFS) or fly ash (FA), are industrial by-products. These materials are generally not used as cements by themselves, but when blended with OPC, they make a significant cementing contribution to the properties of hardened concrete through hydraulic or pozzolanic activity. Today, fly ash and bottom ash are being widely used in the construction industry. The use of fly ash is a well-established practice. The judicious use of fly ash results in reduced heat of hydration, increased later age concrete strengths. Coal fly ash is an abundant industrial waste product that happens to be high in reactive silica, and thus an excellent pozzolan. For this simple reason it is rapidly becoming a common ingredient in concrete all over the world; it is already present to some degree in half the concrete poured in the US. Particular interest to the industry is the idea of not just adding fly ash to known concrete mixes, but using large quantities to replace 30%, 50%, or more of the portland cement-the glue-in a concrete mix. Most of the reasons for using fly ash in any proportion are practical, such as increasing strength and durability, decreasing heat of hydration.

Many reports published over the past decades, confirm the effectiveness of use of fly ash as replacement material in concrete. Fly ash used in concrete to reduce the heat of hydration of concrete but due to this resultantly there is reduction in early strength of concrete i.e. it requires more time to set also the use of fly ash has great influence on the mechanical properties of concrete. The great number of parameters that affect the concrete strength. These parameters are volume of fly ash used, presence of binder material, aggregate size, curing conditions, chemical effect, grade of concrete used and mixing proportions also. It is necessary to know the exact effect of different additive volume fraction and different curing conditions on mechanical properties of concrete. Such an evaluation is needed for developing the mathematical model of strength of concrete which will give us guidance of use of blended cement concrete and use accelerated curing methods.

II. Materials

2.1 Cement

Ordinary Portland Cement (53 grade) confirming to IS: 12269-1987 was used for the experimental investigation. The cement was tested as per IS: 4031-1988.

2.2 Fly Ash

Fly Ash comprise of the non- combustible mineral portion of coal. Fly ash particles are glassy spherical shaped, ball bearings, finer than cement particles, which helps to reduce amount of water and improve workability. It also reduces heat of hydration and improves durability.

2.3 Metakaolin

It is highly pozzolanic material. It is obtained by calcinations of Algerian kaolin at 700˚ C for 7 hours. The silica and alumina contained in the metakaolin are active and react with free lime to form C-S-H and alumina-silicates which greatly improve the strength.

III. Figures And Tables

3.1 Composition of Cement

Table 1: Composition of different types of cement

Type	Composition
A	OPC
B	90% OPC + 10% Fly Ash
C	80% OPC + 10% Fly Ash + 10% Metakaolin
D	70% OPC + 20% Fly Ash + 10% Metakaolin
E	60% OPC + 30% Fly Ash + 10% Metakaolin

3.2 Compressive strength test on concrete cube

Total 45 concrete cubes were casted with five different mixes of cement. Then after 15 cubes were cured method of accelerated curing i.e. in boiling water for 3hr at 100 ^{0}C and 30 concrete cubes were cured by normal curing method i.e. 7 days and 28 days curing. The cubes are then tested to failure under gradually increasing load in CTM of capacity 1000 KN.

Fig. 1. shows compressive testing machine used to determine the compressive strength of plain concrete.
The compressive strength of specimen will be calculated by following formula,

$$f_{ck} = P/A$$

Where,
P = Failure load in compression, KN
A = Loaded area of cube, mm^2

Table 2 : Compressive strength test values

Type Of Cement	Compressive Strength (N/mm^2)				Accelerated Compressive Strength (N/mm^2)	
	Failure Load (KN)	7 Days	Failure Load (KN)	28 Days	Failure Load (KN)	Compressive strength
A	485	21.56	756	33.6	868	38.57
	523	22.24	774	34.4	905	40.22
	492	21.87	767	34.08	900	40
B	441	19.6	684	30.4	801	35.6
	450	20	715	31.77	819	36.4
	468	20.8	724	32.17	828	36.8
C	372	16.53	571	25.37	761	33.82
	390	17.33	603	26.8	790	35.11
	372	16.53	578	25.68	772	34.31
D	352	15.64	497	22.08	688	30.57
	346	15.37	481	21.37	680	30.22
	362	16.08	504	22.4	706	31.37
E	297	13.2	434	19.28	594	26.4
	318	14.13	454	20.17	612	27.2
	306	13.6	448	19.91	621	27.6

3.2.1 The Mathematical model developed to show the relation between accelerated curing compressive strength and 7 days normal curing compressive strength for Type A (i.e. only OPC) is derived from following graph.

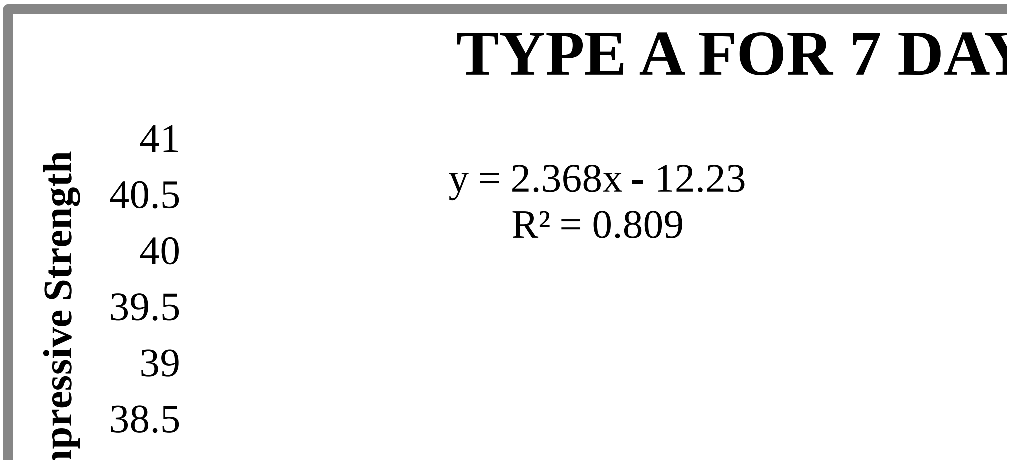

Fig 2 Mathematical Model of 7 Day Normal Compressive strength & Accelerated Compressive strength

3.2.2 The Mathematical model developed to show the relation between accelerated curing compressive strength and 28 days normal curing compressive strength for Type A (i.e. only OPC) is derived from following graph.

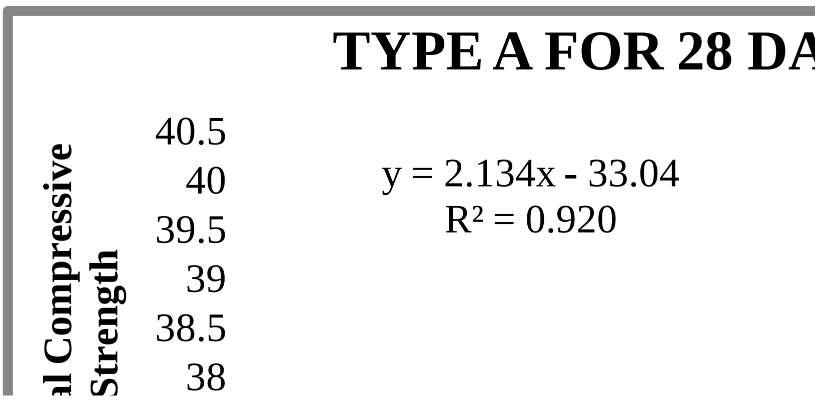

Fig 3 Mathematical Model of 28 Day Normal Compressive strength & Accelerated Compressive strength

3.2.3 The Mathematical model developed to show the relation between accelerated curing compressive strength and 7 days normal curing compressive strength for Type B cement is derived from following graph.

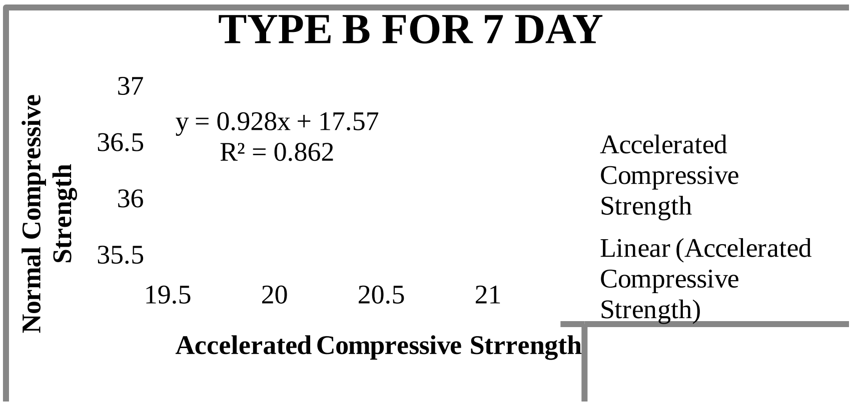

Fig 4 Mathematical Model of 7 Day Normal Compressive strength & Accelerated Compressive strength

3.2.4 The Mathematical model developed to show the relation between accelerated curing compressive strength and 28 days normal curing compressive strength for Type B cement is derived from following graph.

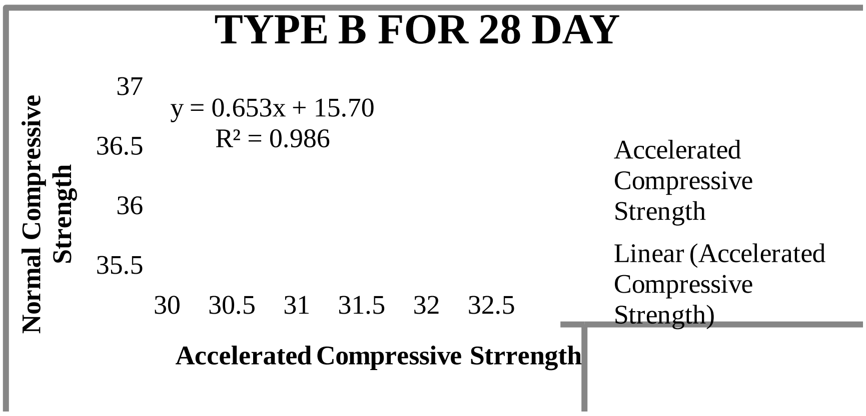

Fig 5 Mathematical Model of 28 Day Normal Compressive strength & Accelerated Compressive strength

3.2.5 The Mathematical model developed to show the relation between accelerated curing compressive strength and 7 days normal curing compressive strength for Type C cement is derived from following graph.

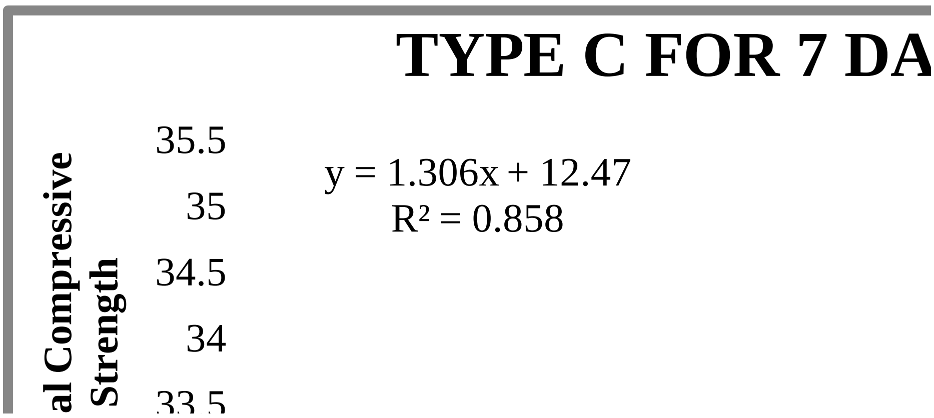

Fig 5 Mathematical Model of 7 Day Normal Compressive strength & Accelerated Compressive strength

3.2.6 The Mathematical model developed to show the relation between accelerated curing compressive strength and 28 days normal curing compressive strength for Type C cement is derived from following graph.

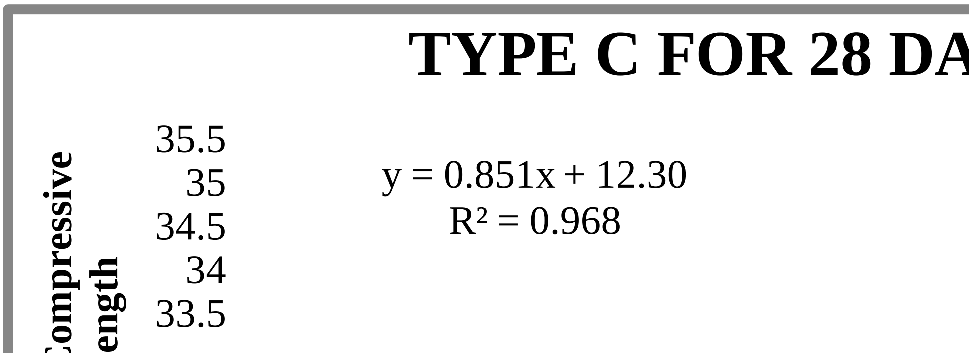

Fig 6 Mathematical Model of 28 Day Normal Compressive strength & Accelerated Compressive strength

3.2.7 The Mathematical model developed to show the relation between accelerated curing compressive strength and 7 days normal curing compressive strength for Type D cement is derived from following graph.

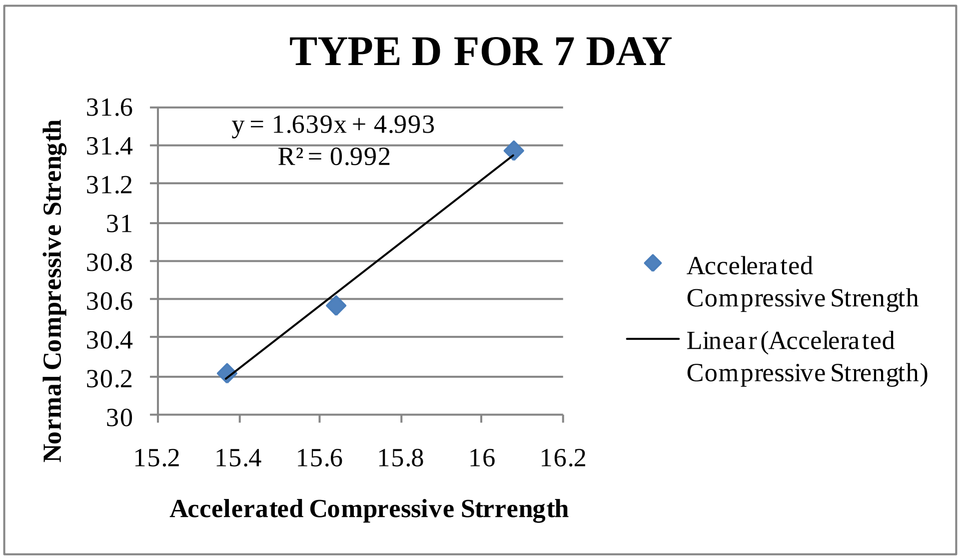

Fig 7 Mathematical Model of 7 Day Normal Compressive strength & Accelerated Compressive strength

3.2.8 The Mathematical model developed to show the relation between accelerated curing compressive strength and 28 days normal curing compressive strength for Type D cement is derived from following graph.

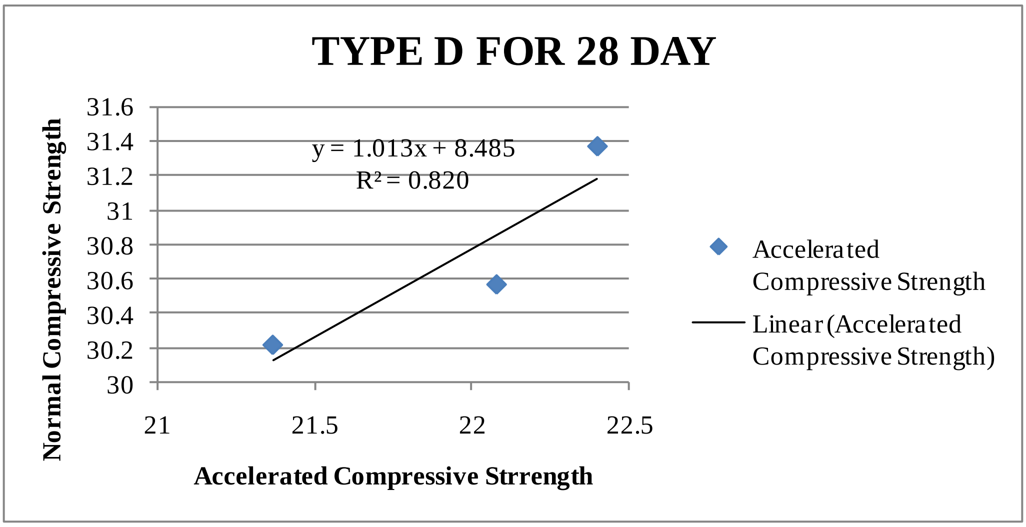

Fig 8 Mathematical Model of 28 Day Normal Compressive strength & Accelerated Compressive strength

3.2.9 The Mathematical model developed to show the relation between accelerated curing compressive strength and 7 days normal curing compressive strength for Type E cement is derived from following graph.

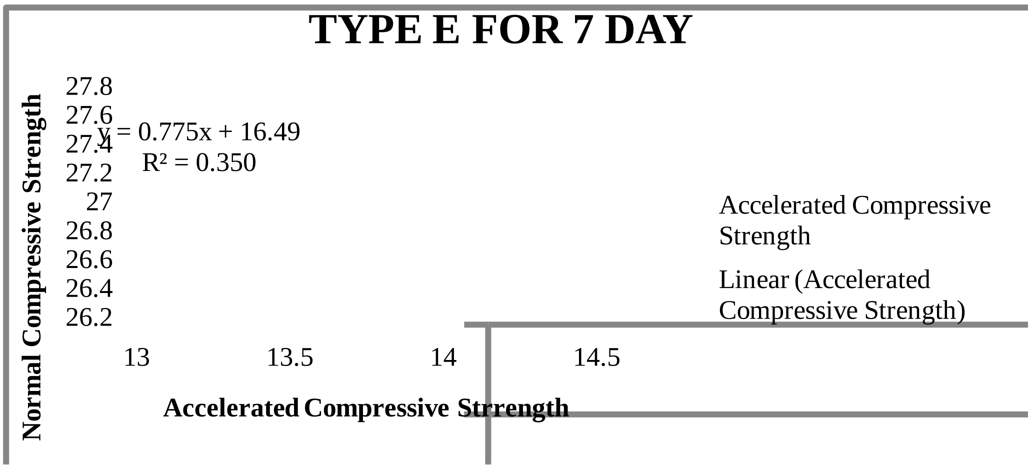

Fig 9 Mathematical Model of 7 Day Normal Compressive strength & Accelerated Compressive strength

3.2.10 The Mathematical model developed to show the relation between accelerated curing compressive strength and 28 days normal curing compressive strength for Type E cement is derived from following graph.

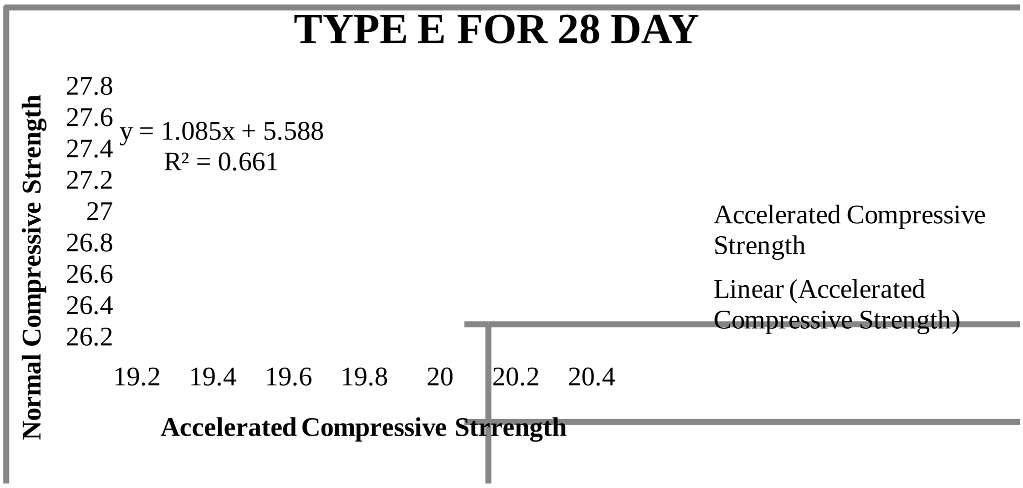

Fig 10 Mathematical Model of 28 Day Normal Compressive strength & Accelerated Compressive strength

3.2.11 Relation between accelerated strength and normal curing strength at 7 days

Table 3 : Relation between accelerated strength and normal curing strength @ 7 days

Type of Cement	Relation between accelerated strength and normal curing strength at 7 days
A	$F_7 = 2.368\ F_{acc} – 12.23$
B	$F_7 = 0.928\ F_{acc} + 17.57$
C	$F_7 = 1.306\ F_{acc} + 12.42$
D	$F_7 = 1.639\ F_{acc} + 4.993$
E	$F_7 = 0.775F_{acc} + 16.49$

3.2.12 Relation between accelerated strength and normal curing strength at 28 days

Table 4 : Relation between accelerated strength and normal curing strength @ 28 days

Type of Cement	Relation between accelerated strength and normal curing strength at 7 days
A	$F_{28} = 2.134\ F_{acc} – 33.04$
B	$F_{28} = 0.653\ F_{acc} + 15.70$
C	$F_{28} = 0.851\ F_{acc} + 12.30$
D	$F_{28} = 1.013\ F_{acc} + 8.485$
E	$F_{28} = 1.085\ F_{acc} + 5.588$

3.2.13 The Mathematical model developed to show the relation between accelerated curing compressive strength and 7 days normal curing compressive strength for all types of blended cement is derived from following graph.

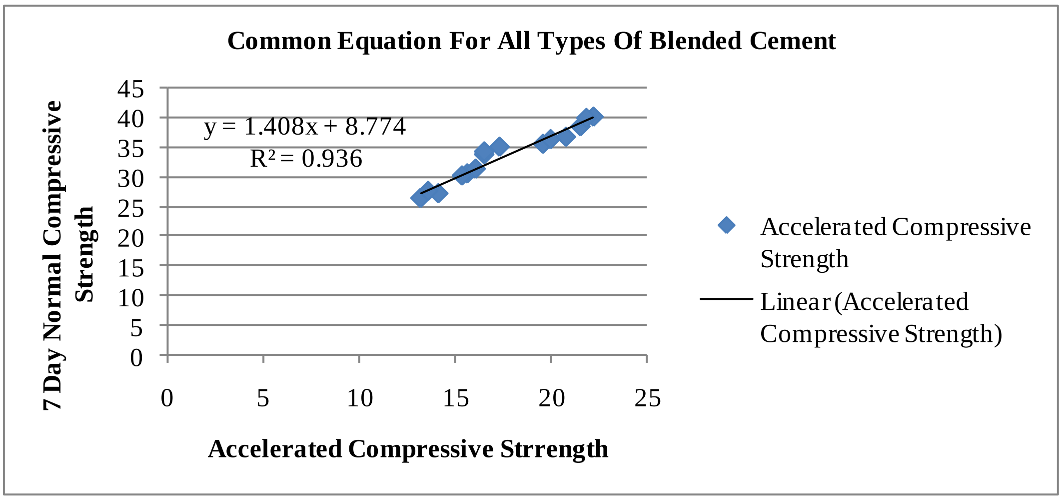

Fig 11 Mathematical Model of 7 Day Normal Compressive strength & Accelerated Compressive strength

3.2.11 Relation between accelerated strength and normal curing strength at 7 days

Table 5 : Relation between accelerated strength and normal curing strength @ 7 days

For all types of blended cement	$F_7 = 1.408\ F_{acc} + 8.774$

3.2.14 The Mathematical model developed to show the relation between accelerated curing compressive strength and 28 days normal curing compressive strength for all types of blended cement is derived from following graph.

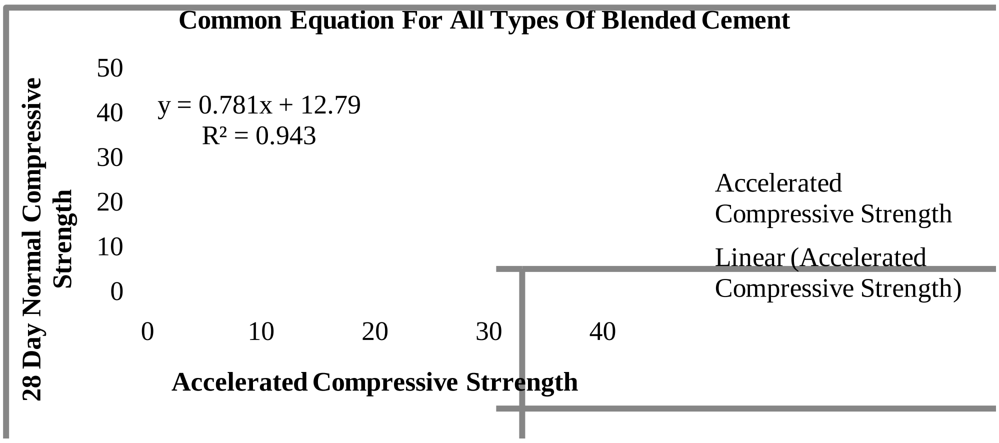

Fig 12 Mathematical Model of 28 Day Normal Compressive strength & Accelerated Compressive strength

3.2.11 Relation between accelerated strength and normal curing strength at 28 days

Table 6 : Relation between accelerated strength and normal curing strength @ 28 days

For all types of blended cement	$F_{28} = 0.781\ F_{acc} + 12.79$

3.3 Flexural Strength of Beam Specimen

After 28 days curing period, and accelerated curing period the two type test beam specimens were removed from the curing tank and both sides of the beam were white-washed to aid observations of the crack development during testing. The beams were tested to failure under gradually increasing load in a Universal Testing Machine (UTM). The capacity of Universal Testing Machine (UTM) is of 1000 KN.

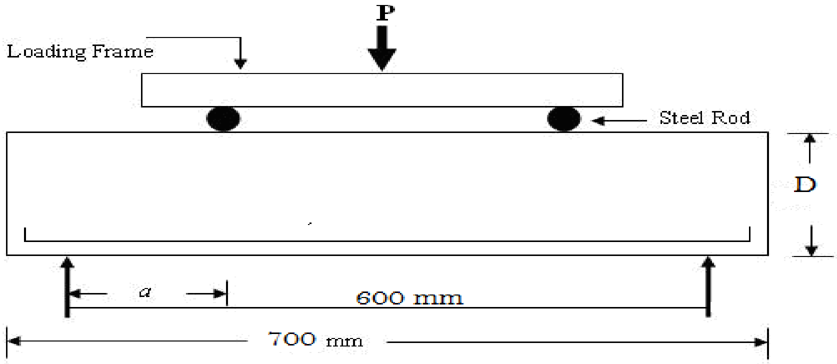

Fig. 13 Schematic representation of beam under four point loading

3.4 Beam design

Total 10 simply supported beams of normal size were tested up to failure. All specimens were of rectangular cross-section 150mm breadth, 150mm width & 700mm span. Two bars of 6mm diameter were provided as longitudinal reinforcement. Grade of longitudinal reinforcement is Fe-500. Clear span of beam is 600mm with clear cover 25mm.

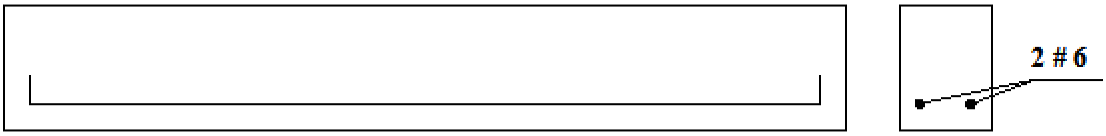

Fig 3 Beam specimen under UTM with four point loading

3.5 Flexural strength test results

Table 7 : Flexural strength test values

Type of cement	Normal 28 days curing				Accelerated curing			
	Fracture load (KN)			Flexural strength (N/mm^2)	Fracture load (KN)			Flexural strength (N/mm^2)
	Trial - 1	Trial - 2	Avg.		Trial - 1	Trial - 2	Avg.	
A	25.5	25	25.25	4.48	27	27.5	27.25	4.84
B	27.5	27	27.25	4.84	29.5	29.5	29.5	5.24
C	28	28.5	28.25	5.02	31.5	31	31.25	5.55
D	23.5	23	23.25	4.13	25.5	25	25.25	4.48
E	18.5	18	18.25	3.24	21.5	21	21.25	3.77

3.5.1 The graph developed to show the variation of 28 days flexural strength depending on types of mixtures

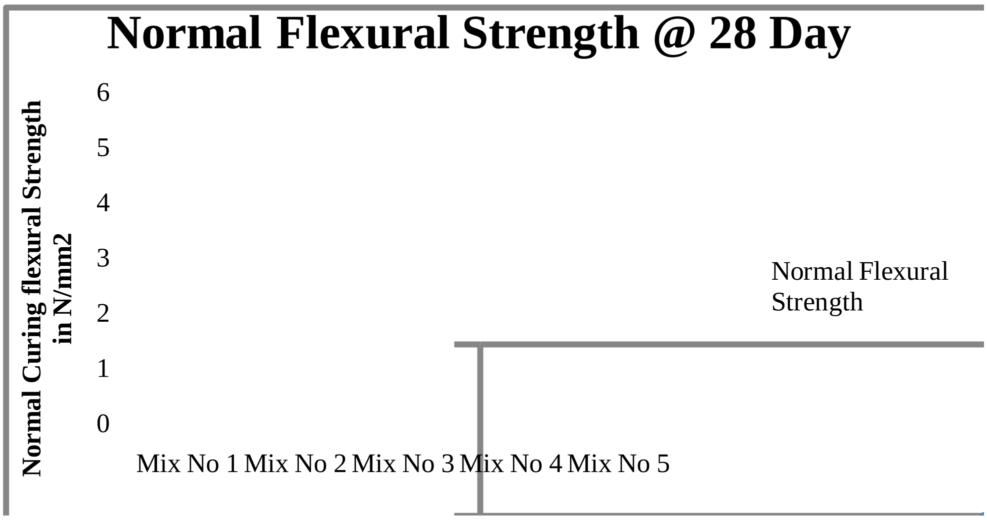

Fig 13 Variation of flexural strength with types of mixture @ 28 days normal curing

From Table 7 and Fig 13, it is observed that, the maximum value of flexural strength for 28 days normal curing 5.02 N/mm^2 is observed at Mixture No. 3 i.e. 10 % Fly ash & 10 % Metakaolin and further it goes on decreasing

3.5.2 The graph developed to show the variation of accelerated curing flexural strength depending on types of mixtures

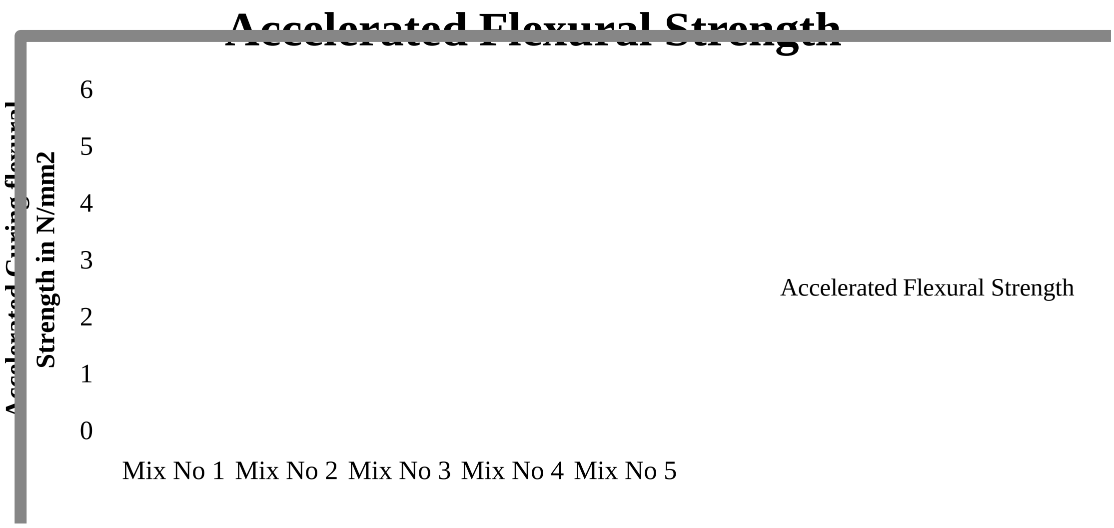

Fig 14 Variation of flexural strength with types of mixture with accelerated curing

From Table 7 and Fig 14, it is observed that, the maximum value of flexural strength for accelerated curing 5.55 N/mm^2 is observed at Mixture No. 3 i.e. 10 % Fly ash & 10 % Metakaolin and further it goes on decreasing .

Also from the test results of flexural strength of concrete increased by accelerated curing as compared to 28 days normal curing but it is also noticed that accelerated curing has a very little effect on flexural strength of concrete.

IV. Conclusion

The present research focused on studying the effect of fly ash and metakaolin in concrete mix and on strength of concrete and to determine how curing conditions affects concrete strength. Based on the results obtained the following conclusions can be drawn:

- It is seen that with accelerated curing concrete compressive strength increased with desirable amount and also higher than target strength of concrete.
- It is also seen that fly ash and metakaolin addition in cement has noticeable effect on compressive strength of concrete.
- In case of flexural strength of concrete it is increased upto addition of fly ash 10% and addition of 10 % Metakaolin in mixture i.e. Mixture No. 3 after that it is considerably start to decrease.
- Early prediction of 7 days and 28 days compressive strength results through simple prediction factor is not possible for concrete mix containing cement replacement materials due to their physical and chemical properties on the rate of strength gain.
- Mathematical model for early prediction of 7 days and 28 days compressive strength of cubes are proposed for OPC cement and blended cement individually. Due to this relation, this method will also helpful for Precast Manufactures.
- It can also be concluded that increase in curing temperature has more favorable effect on the strength gain of concrete with cement and cement replacing material.

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