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An Experimental Investigation on Dynamic Modulus of Elasticity of Fly Ash Based Normal Strength Concrete

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Abstract : Use of industrial by-products such as Fly Ash (FA) as one of the raw materials used in Normal Strength Concrete is appropriate to deal with the sustainability of concrete and industrial growth. The present experimental investigation assesses the potential of FA in normal strength concrete for Industrial applications. The fine aggregate used in the investigation was natural river sand. The Ultrasonic Pulse Velocities (UPV) was determined at various ages varying from 1 day to 90 days of curing. The Fly Ash is used as partial replacement of Cement at the range varying from 10% to 35% by volume. The ultrasonic pulse velocities of Fly Ash based Normal Strength Concrete was lower for all mixtures at 1 day when compared to control mix concrete. However as the age of concrete increases the ultrasonic pulse velocities were appreciably improved for all the mixes. Empirical relationships between strength, UPV and Dynamic Elastic Modulus were proposed.
Keywords : Fly Ash, Compressive Strength, Ultra sonic Pulse Velocity and Dynamic Elastic Modulus.

1. Introduction

1.1 Preamble

Various industries produce numerous solid waste materials. The disposal of these solid waste materials is an environment hazard for the surrounding living beings. Now a day's increasing environmental concerns and sustainable issues, the utilization of solid waste materials is the need of the hour. The productive use of solid waste materials is the best way to alleviate the problems associated with their disposal. The construction industry has enormous potential for the use of solid waste materials as construction material. Based upon their properties, the solid waste materials can either be used as supplementary cementitious materials or as replacement of fine/coarse aggregate in concrete or mortars. Based on the research reports some solid waste materials such as fly ash, silica fume, grounded blast furnace slag etc. have been put in use in manufacturing of either cement or concrete.

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1.2 Fly Ash

Fly ash is finely divided waste by product obtained from the combustion of pulverized coal in suspension fired furnaces of thermal power plants. It is collected by electrical or mechanical precipitators including cyclone precipitators or bag houses. It is generally finer than cement and consists of mostly spherical glassy particles of complex chemical as well as mineralogical composition.

During the combustion of coal, the products formed are fly ash, bottom ash and gases and/or vapours. Fly Ash is the fine part of the ash which is entrained in the flue gases, whereas the bottom ash is the residue consisting of coarser discrete or fused particles heavy enough to drop out of the combustion zone (furnace chamber) onto the bottom of the furnace. See Fig.1.1 the vapour and gases form the volatilized fraction of the carbonaceous material which are partly discharged into the atmosphere and partly condense onto the surface of the fly ash particles. Pollution control devices such as scrubbers using limestone slurry or powder are employed to capture the SO, content of the flue gases before being released into the atmosphere, particularly when high sulfur coals are burned. It may be pointed that depending on the type of precipitator used the majority of incombustible mineral present in coal, about 85 to 99.9 percent is retrieved in the form of fly and bottom ash while the remainder is discharged into the atmosphere. Fly ash makes up 75 to 85 percent of the total ash and the remaining is bottom ash or boiler slag.

2. Literature Review

The River sand obtained from river beds has been used primarily as fine aggregate in the concrete production. In the recent past, there has been enormous increase in the usage of mineral admixtures in concrete such as Fly ash and Ground Granulated Blast Furnace Slag (GGBS) and it has become one of the ingredients of concrete [1-12]. The American Concrete Institute (ACI) defines roller compacted concrete (RCC) as the concrete compacted by roller compaction [24]. RCC is a stiff and extremely dry concrete and has a consistency as that of wet granular material or wet moist soil. The use of RCC as paving material was developed from the use of soil cement as base material. The first use of RCC pavement was in the construction of Runway at Yakima, WA in 1942[25]. The main advantage of RCC over conventional concrete pavement is the speed in construction and cost savings. RCC needs no formwork, dowels and no finishing [26].Concrete Pavements addition of active mineral admixtures like fly ash has great scientific significance. Fly Ash (FA) consists of SiO2 and Al2O3, and has high potential activity. The main useful and significant effects of FA can be of three folds: Morphologic effect, pozzolanic effect, and Micro aggregate effect. [49]. Research in India regarding the utilization of Fly ash has shown that the quality of fly ash produced at National thermal power Corporation (NTPC) plants is extremely good with respect to fineness, low un-burnt carbon, high pozzolanic activity and conforms to the requirements of IS: 3812 - 2003-Pulverized Fuel Ash for use as Pozzolana in cement, cement mortar and concrete. The fly ash generated at NTPC stations is ideal for use in the manufacture of concrete [50] Assessing the quality of concrete used for paving applications has become essential for control operations during and after construction. Concrete pavement is gaining importance due to numerous advantageous. Fly Ash has become an essential mineral admixture for producing good pavement quality concrete and the same can be used in the design and construction of low volume rural roads. Ultrasonic Pulse Velocity (UPV) is a non-destructive method of testing of concrete quality, homogeneity and compressive strength of existing structures. This method is also a useful tool in evaluating dynamic modulus of elasticity of concrete [14, 15]. The Dynamic modulus of Elasticity (Ed) is an essential and important factor when assessing the quality and performance of structural concrete [42, 43]. The UPV is a useful parameter for estimation of static modulus of elasticity, dynamic modulus of elasticity, static Poisson's ration and dynamic Poisson's ratio [16]. Yıldırım, H., &Sengul, O [4] conducted experimental investigation on the modulus of elasticity of concrete. A total of 60 mixtures are prepared, in which the effects of water/cement ratio, maximum size of the aggregate, aggregate type, and fly ash content are investigated. Modulus of elasticity of the concretes was obtained besides compressive strength and ultrasound pulse velocities of the concrete. A model is also proposed to predict the dynamic modulus of concrete. The predicted model has close association with experimental test results. Wen, S.Y., & Li, X.B (2015) [17] conducted experimental study on Young's Modulus of concrete through P-Wave velocity measurements. Two empirical equations for obtaining static Young's Modulus and Dynamic Young' Modulus when dynamic Poisson ratio varies around 0.20. Qasrawi, H. Y.(2000) [18] proposed an empirical equation between UPV and Cube Compressive strength of Concrete and its R2 value was found to be 0.9562. Subramanian Kolluru, S.V., et al (2000) [19] was proposed a technique for evaluating the elastic material constants of a concrete specimen using longitudinal resonance frequencies using Rayleigh- Ritz method. A simple, accurate and more reliable method is developed for determining dynamic elastic constants of concrete. Yaman, I.O., et al. (2001) [20] investigated the use of indirect UPVs in Concrete slabs and found similarity between direct and indirect UPVs. A significant conclusion is drawn that the indirect UPV is statistically similar to direct UPV. Choudhari, N.K., et al (2002) [21] proposed a methodology to determine the elastic modulus of concrete by Ultrasonic method. M.Conrad et al (2003) [22] investigated stress-strain behaviour and modulus of elasticity of concrete from the ages of 6 hours to 365 days. The Young's Modulus for the early ages and aged low cementitious RCC can be an exponential type function. Washer, G., et al (2004) [23] conducted extensive research on Ultrasonic testing of Reactive powder concrete. Demirboga, R., et al(2004) [34] found a relationship between ultrasonic velocity and compressive strength of concrete using different mineral admixtures such as Fly ash(high volume), Blast Furnace Slag and combination of FA in replacement of Portland Cement. Compressive strength, UPV values are determined at 3,7,28 and 90 days curing period. An exponential relationship between compressive strength and UPV was reported. Atici, U.(2011) [35] estimated the compressive strength of concrete containing various amounts of blast furnace slag and fly ash through non-destructive tests like rebound hammer and ultrasonic pulse velocity tests at different curing ages of 1, 3,7,28, and 90 days. Two different methods like artificial neural network and multivariable regression analysis adopted for estimation of concrete strength and concluded that the application of an artificial neural network had more potential in predicting the compressive strength of concrete than multivariable regression analysis. Trtnik, G., et al (2009) [36] proposed a numerical model for predicting the compressive strength of concrete based on Ultrasonic Pulse Velocity and some concrete mix characteristics. Panzera, T. H., et al. (2011) [37] published a paper on Ultrasonic pulse velocity evaluation of cementitious materials and emphasized the significance of UPV as an important non-destructive technique and provides reliable results on the basis of rapid measurements. Turgut, P. (2004) proposed a relationship between concrete strength and UPV. Hannachi, S., et al.(2012) [39] studied the use of UPV and Rebound Hammer tests on the compressive strength of concrete and proposed three equations for rebound hammer, UPV and combined methods for predicting the compressive strength of concrete. From the above literature survey it is observed that, many researchers studied the relationship between compressive strength in relation with UPV, but the relationships between UPV and the Elastic and Mechanical properties of Fly Ash Concrete pavement mixes have not been investigated. Also the use of Manufactured sand on the strength and elastic modulus of Fly ash Roller compacted Concrete Pavement has not yet been investigated. Hence an experimental investigation has been planned to predict the quality and behaviour of RCC made with Fly Ash intended for lean concrete bases and cement concrete surface courses and similar applications. This research work was focused on the relationship between Elastic properties, Compressive strength properties and UPV.1.1

3. Experimental Programme

3.1 Materials

Constituent materials used to make concrete can have a significant influence on the properties of the concrete. The following sections discuss constituent materials used for manufacturing of both conventional concrete (CC) and Fly Ash (FA) based concrete with different replacement levels of Fly Ash i.e. 10% (F 10), 15% (F 15), 20% (F 20), 25% (F 25), 30% (F 30) and 35% (F 35) . Chemical and physical properties of the constituent materials are presented in this section.

3.1.1 Cement

Ordinary Portland Cement 53 grade was used corresponding to IS 12269 (1987). The chemical and physical properties of the cement as obtained by the manufacturer are presented in the Table 3.1 and 3.2 respectively.

Table: 3.1 Chemical Composition of Ordinary Portland cement

Oxide	Common Name	Approx. Amount (%)
CaO	Lime	60 – 67
SiO_2	Silica	17-25
Al_2O_3	Alumina	3 – 8
Fe_2O_3	Iron Oxide	0.5 - 6
MgO	Magnesia	0.1 - 4
Na_2O	Soda	0.2 – 1.3
K_2O	Potassa	
SO_3	Sulphuric Anhydride	1 – 3

Table 3.2 Physical Properties of Ordinary Portland Cement

Physical properties	Test result
Specific gravity	3.06
Fineness (m^2/Kg)	311.5
Normal consistency	30%
Initial setting time (min)	90
Final setting time (min)	220
Soundness Lechatelier Expansion (mm) Autoclave Expansion (%)	 0.8 0.01

3.1.2 Fine Aggregate

The sand used for the experimental programmed was locally procured (Indian Standard Specifications IS: 383-1970). The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and then was washed to remove the dust. The aggregates were sieved through a set of sieves of 4.75 mm, 2.36 mm, l.l8 mm, 0.6 mm, 0.3 mm, 0.150 mm, 0.75 mm and pan to obtain sieve analysis.

Natural river sand was used as fine aggregate. The bulk specific gravity in oven dry condition and water absorption of the sand as per IS 2386 (Part III) 1963 were 2.62 and 1% respectively. The gradation of the sand was determined by sieve analysis as per IS: 383-1970. Fineness modulus of sand was 2.69.

Table: 3.3 Sieve Analysis of Fine Aggregate

Sieve No.	Cumulative Percent Passing	
	Fine Aggregate	Requirements as per IS 383 – 1970 (ZONE II)
10 mm	100	100
4.75 mm	98.8	90 – 100
2.36 mm	96.8	75 – 100
1.18 mm	70.8	55 – 90
0.600 mm	48.2	35 – 59
0.300 mm	14.4	8 – 30
0.150 mm	2.0	0 - 10

3.1.3 Coarse Aggregate

Crushed granite stones of size 20 mm used as coarse aggregate. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate 20 mm per IS 2386 (Part III, 1963) are 2.6 and 0.3%

respectively. The bulk density, impact strength and crushing strength values of 20 mm aggregate are 1580 kg/m3, 17.9% and 22.8% respectively.

Table 3.4 Sieve analysis of 20 mm coarse aggregate

Sieve size	Cumulative percent passing	
	20 mm	
20 mm	100	20 mm
16 mm	56.17	16 mm
12.5 mm	22.32	12.5 mm
10 mm	5.29	10 mm
4.75 mm	0	4.75 mm

3.1.4 Water

Generally, water that is suitable for drinking is satisfactory for use in concrete. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided.

3.1.5 Fly Ash

Fly ash is a by-product produced from the combustion of coal in an electrical generation station. According to design and control of concrete mixtures. Fly ash is a natural pozzolana, which means that it is a siliceous or siliceous-and-aluminous material which chemically reacts with calcium hydroxide (CH) to form composites having cementitious properties.

The physical and chemical properties of fly ash shown in Table 3.5

Table 3.5 Physical and Chemical Properties of Fly Ash

Physical Properties		
S. No	**Property**	**Value**
1	Specific Gravity	2.2
Chemical Properties		
1	Silica (Si O2)	57.00
2	Alumina (Al2 O3)	23.00
3	Ferric oxide (Fe2 O3)	8.32
4	Sulfur trioxide(So_3)	5.00
5	Moisture content	3.00
6	Titanium Oxide(Tio_2)	0.23
7	Loss on ignition	3.55

3.2 Test Methods

This section describes the test methods that are used for testing the hardened properties of concrete

3.2.1 Compressive Strength Test

Compressive strength test was conducted on the cubical specimens for all the mixes at different curing periods as per IS 516 (1991). Three cubical specimens of size 150 mm x 150 mm were cast and tested for each age and each mix. The compressive strength (f'c) of the specimen was calculated by dividing the maximum load applied to the specimen by the cross-sectional area of the specimen.

Fig.3.1 compressive strength of cubes

3.2.2 Pulse Velocity

The test involves determination of pulse velocity through concrete as per procedure give in ASTM C 597-02. Battery operated Portable Ultrasonic Non-destructive Digital Indicating Tester was used to measure the pulse velocity through concrete. Pulses of longitudinal stress waves are generated by an electro acoustical transducer held in contact with one face of concrete and are received by another transducer held in contact with other face of concrete specimen. The time (T) taken by pulse to pass through specimen of length (L) is known as transit time. The pulse velocity (V) is calculated by dividing the length of specimen (L) by transit time (T). Average value of three specimens was considered as the pulse velocity of concrete mix. The apparatus set for the test is shown in Fig 3.4 and values of pulse velocity for grading concrete as per BIS 13311-92 (Part-I) are given in Table 3.6.

Table 3.6 Concrete quality grading as per BIS 13311-92 (Part-I)

Pulse velocity (m/s)	Concrete quality grading
Above 4500	Excellent
3500 – 4500	Good
3000 - 3500	Medium
Less than 3000	Doubtful

Fig.3.2 Ultrasonic Pulse Velocity test of cubes

3.2.3 Dynamic Modulus of Elasticity:

The following formula is used for calculating the dynamic modulus of elasticity of Concrete as per BIS 13311-92 (Part-I)

Ed= (ρ (UPV) ^2 (1+μ) (1-2μ))/ ((1-μ))

Where, Ed = dynamic modulus of elasticity

ρ = Density of Concrete in kg/m3 (2450 kg/m3)

UPV = Ultrasonic Pulse Velocity in km/Sec

μ = Poisson's Ratio (0.2)

3.3 Mix Design of M 30 Grade Conventional Concrete

The following Table is shows the Mix design of M 30 grade concrete with different replacement levels of Fly ash as per BIS 10262 - 2019

Table 3.7 Mix Proportions of CC or F 0, F 10, F 15, F 20, F 25, F 30 and F 35

Mix Type	Cement Kg/m3	Fly Ash Kg/m3	Water l/m3	20mm kg/m3	Sand kg/m3
F 0	427	0	202	1133	606
F 10	384.3	29.23	202	1133	606
F 15	362.9	44.73	202	1133	606
F 20	341.6	59.64	202	1133	606
F 25	320.3	74.56	202	1133	606
F 30	298.9	89.47	202	1133	606
F 35	277.5	104.4	202	1133	606

4. Results and Discussion

4.1 Introduction:

In this Chapter, the test results are presented and discussed. The test results cover the performance of Conventional Concrete (M 30) (CC or F0) and Fly Ash blended Concrete (F10, F15, F20, F25, F30 & F35) at different curing periods (1, 3, 7, 14, 28 & 90 days). The hardened properties of CC and FC viz. compressive strength, ultrasonic pulse velocity (UPV) and dynamic modulus of elasticity were determined at different curing periods. Empirical relationships between compressive strength, ultrasonic pulse velocity and dynamic modulus of elasticity were proposed.

4.2 Compressive Strength:

Table 4.1 shows the compressive strength values of concrete with partial replacement of Fly Ash. Compressive strength of Fly Ash blended concrete specimens was measured at 1, 3, 7, 14, 28 and 90 days of curing as per IS 516.

4.3 Ultrasonic Pulse Velocity Test:

Table 4.2 shows the ultrasonic pulse velocity values of concrete with partial replacement of Fly Ash. Ultrasonic pulse velocity of Fly Ash blended concrete specimens was measured at 1, 3, 7, 14, 28 and 90 days of curing as per IS 13311 (Part 1).

4.3.1 Effect of Fly Ash on UPV of Fly Ash Blended Concrete With Age:

The experimental progression of UPV of control mix and fly ash based concrete with the age was shown in Fig 4.1 and Table 4.2 (a, b & c) for fly ash mixes from F0 to F35. The ultrasonic pulse velocity of fly ash mixes increases with increase in curing age. Also the UPV of fly ash blended mixes was found to be higher than the control mix (F0) for all replacements up to 35% at all ages. The increase in UPV from 1 day to 3 days is at slower rate, but beyond 3 days to 90 days the UPV increases rapidly. This is due to the pozzolanic reactions of fly ash are slow at initial age and faster at later ages.

Table 4.1 Compressive strength of concrete

Mix	Compressive Strength of Concrete (MPa)					
	1 day	3 days	7 days	14 days	28 days	90 days
F 0	10.02	20.54	24.44	31.93	37.79	45.2
F 10	8.67	16.61	31.52	39.44	44.61	48.37
F 15	7.76	16.12	33.11	41.23	46.02	49.66
F 20	7.33	14.60	34.58	44.37	46.86	50.87
F 25	6.00	13.98	36.76	47.91	48.12	51.91
F 30	6.31	13.46	35.23	44.44	45.41	50.11
F 35	5.63	12.90	35.06	41.33	43.32	49.34

Table 4.2.a. Ultrasonic Pulse Velocity of concrete (1 day & 3 days)

Mix	Ultrasonic Pulse Velocity (km/Sec)							
	1 day				3 days			
	F1	F2	F3	Avg	F1	F2	F3	Avg
F 0	3.93	4.01	4.12	4.02	4.22	4.39	4.42	4.34
F 10	4.16	4.28	4.31	4.25	4.28	4.47	4.49	4.41
F 15	4.17	4.48	4.58	4.41	4.32	4.55	4.58	4.48
F 20	3.92	4.4	4.31	4.21	4.41	4.57	4.59	4.52
F 25	3.72	4.2	4.14	4.02	4.47	4.66	4.71	4.61
F 30	4.17	4.29	4.35	4.27	4.43	4.59	4.61	4.54
F 35	3.69	4.22	4.12	4.01	4.29	4.46	4.49	4.41

Table 4.2.b. Ultrasonic Pulse Velocity of concrete (7 days & 14 days)

Mix	Ultrasonic Pulse Velocity (km/Sec)							
	7 days				14 days			
	F1	F2	F3	Avg	F1	F2	F3	Avg
F 0	4.4	4.52	4.61	4.51	4.69	4.72	4.72	4.71
F 10	4.58	4.63	4.63	4.61	4.82	4.84	4.85	4.84
F 15	4.68	4.82	4.83	4.78	5.00	5.03	5.02	5.02
F 20	4.79	4.82	4.83	4.81	5.13	5.15	5.16	5.15
F 25	4.89	4.9	4.93	4.91	5.21	5.24	5.25	5.23
F 30	4.8	4.82	4.83	4.82	5.02	5.03	5.04	5.03
F 35	4.77	4.78	4.78	4.78	4.91	4.92	4.92	4.92

Table 4.2.c. Ultrasonic Pulse Velocity of concrete (28 days & 90 days)

Mix	Ultrasonic Pulse Velocity (km/Sec)							
	28 days				90 days			
	F1	F2	F3	Avg	F1	F2	F3	Avg
F 0	4.87	4.89	4.9	4.89	5.14	5.16	5.16	5.15
F 10	5.02	5.04	5.04	5.03	5.23	5.25	5.25	5.24
F 15	5.17	5.18	5.19	5.18	5.31	5.33	5.33	5.32
F 20	5.25	5.27	5.27	5.26	5.38	5.4	5.4	5.39
F 25	5.32	5.34	5.34	5.33	5.41	5.43	5.43	5.42
F 30	5.12	5.14	5.14	5.13	5.18	5.2	5.21	5.20
F 35	5.02	5.04	5.04	5.03	5.12	5.14	5.14	5.13

Table 4.3. Effect of Fly Ash on Quality of Concrete with Age

Mix	Quality of Concrete Mixes for all replacements levels (from 0 to 35%)					
	1 day	3 days	7 days	14 days	28 days	90 days
F 0	G	G	E	E	E	E
F 10	G	G	E	E	E	E
F 15	G	G	E	E	E	E
F 20	G	E	E	E	E	E
F 25	G	E	E	E	E	E
F 30	G	E	E	E	E	E
F 35	G	G	E	E	E	E

E = Excellent; G = Good

The effect of fly ash on the quality of fly ash based mixtures with curing age for all mixes was shown in Table 4.3. The quality assessment of control mix (G0) with age shows that is found to be good at early ages of 1 and 3 days. However, as the time increases from 3 to 90 days, the quality of concrete changes from good to excellent. Similar trend has been observed for mixtures F10 to F35. Amongst the Fly Ash based mixtures from F0 to F35, F25 mix shows good to excellent quality and higher UPV values in comparison with other mixes. Hence 25% Fly Ash replacement has been considered as an optimum replacement level.

4.3.2 Relationship Between Compressive Strength And UPV of Fly Ash Mixes:

From the literature review, it was concluded that there is no definite relationship was existing between UPV and Compressive strength of Fly Ash blended concrete. Hence a relationship between compressive strength of Fly Ash blended concrete and UPV has been developed.

Fig 4.1 (a, b, c, d, e, f & g) shows the relationship between compressive strength of fly ash mixtures (F0, F10, F15, F20, F25, F30 & F35) and UPV at all ages.

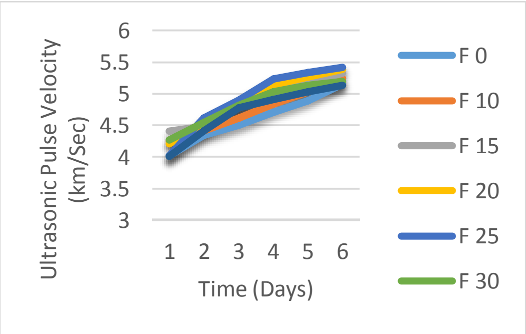

Fig 4.1. Progression of UPV with Time for FA mixes

From the experimental results, exponential relationship between cube compressive strength and UPV has been proposed under:

y = 0.0636 e1.3017 (UPV), R2 = 0.9448 for control mix (F0)
y = 0.011 e1.6495 (UPV), R2 = 0.8464 for 10% FA (F10)
y = 0.0039 e1.8153 (UPV), R2 = 0.8464 for 15% FA (F15)
y = 0.0087 e1.6444 (UPV), R2 = 0.9284 for 20% FA (F20)
y = 0.0096 e1.6116 (UPV), R2 = 0.9548 for 25% FA (F25)
y = 0.0004 e2.2779 (UPV), R2 = 0.9515 for 30% FA (F30)
y = 0.0016 e2.0519 (UPV), R2 = 0.9802 for 35% FA (F35)
Where, y = Cube compressive strength in MPa

UPV = Ultrasonic Pulse Velocity in km/sec

The above equations were useful in predicting the compressive strength of fly ash based concrete for different conditions in terms of UPV at any age and any dosage of Fly Ash.

4.4 Dynamic Modulus of Elasticity Of Fa Based Concrete:

Table 4.4 shows that the variation of dynamic modulus of elasticity of CC and FA based mixes with age of curing. Fig 4.2 shows that the dynamic modulus of elasticity is lower for CC in comparison with all FA based mixes. The 28 days dynamic modulus of elasticity of CC (F 0) (i.e. 52.65 GPa) has been attain by the FA based mixes of F 10 to F 35 at 14 days curing.

From the below table is has been observed that the variation of dynamic modulus of elasticity with age of concrete for FA based mixes is higher than control mix concrete dynamic modulus of elasticity. Also the development of dynamic modulus of elasticity increases as the percentage replacement of cement with Fly Ash increases due to fact of Pozzolana reaction of Fly Ash.

4.5 Relation Between Dynamic Modulus of Elasticity and Compressive Strength:

Fig 4.3 shows that relation between the dynamic modulus of elasticity and compressive strength of cube is increases with increase in the FA based concrete. The equation was found with the observed test results is shown below.

The relation can be expressed as

y = 0.5078 e 0.0774x, R2 = 0.8392

Where, y = Dynamic Modulus of Elasticity (GPa)

x = Compressive Strength of Concrete (MPa)

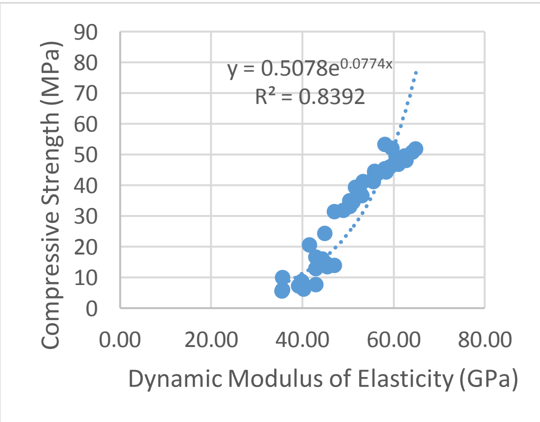

Fig 4.2. Dynamic Modulus of Elasticity Vs Compressive Strength of concrete

Table 4.4. Effect of Fly Ash on Dynamic Modulus of Elasticity with Age

Dynamic Modulus of Elasticity (GPa)						
Mix	1 day	3 days	7 days	14 days	28 days	90 days
F 0	35.63	41.60	44.85	48.92	52.65	58.56
F 10	39.83	42.95	46.93	51.58	55.86	60.62
F 15	42.88	44.32	50.31	55.49	59.17	62.49
F 20	39.08	45.12	51.09	58.41	61.08	64.14
F 25	35.63	46.93	53.09	60.39	62.72	64.85
F 30	40.20	45.52	51.16	55.79	58.10	59.55
F 35	35.46	42.95	50.31	53.30	55.86	58.10

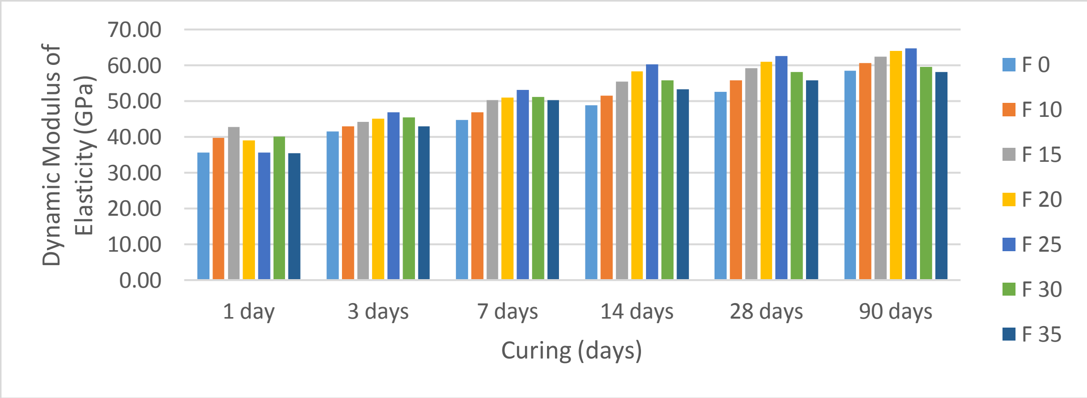

Fig 4.2. Progression of Dynamic Modulus of Elasticity with Time for FA mixes

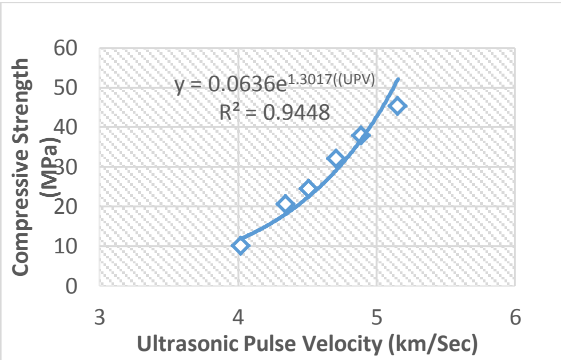

Fig 4.1.a. F0 Vs UPV

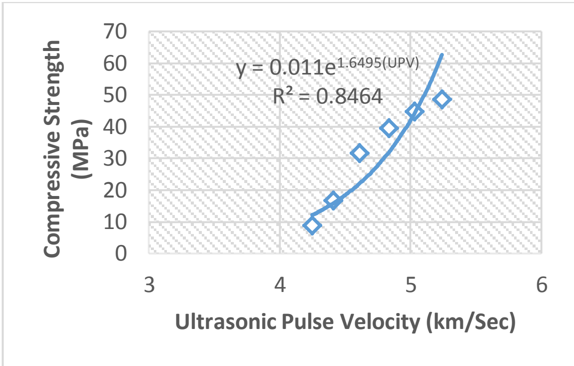

Fig 4.1.b. F10 Vs UPV

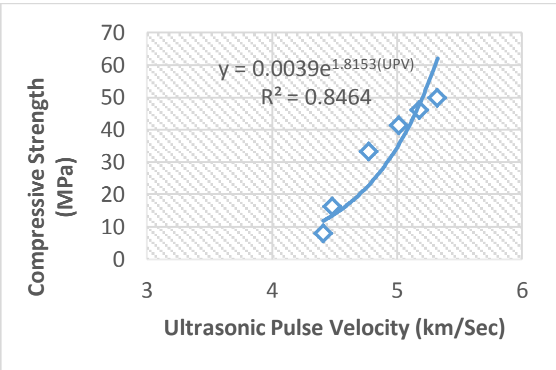

Fig 4.1.c. F15 Vs UPV

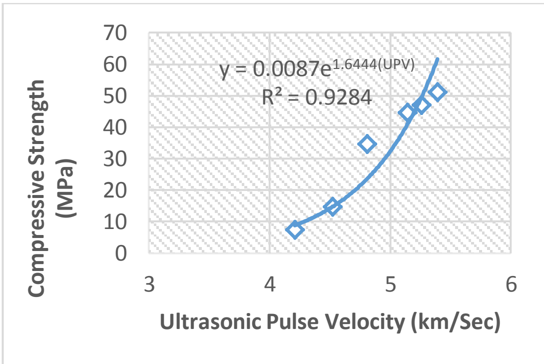

Fig 4.1.d. F20 Vs UPV

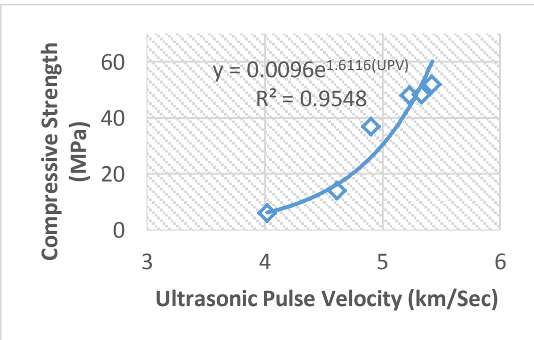

Fig 4.1.e. F25 Vs UPV

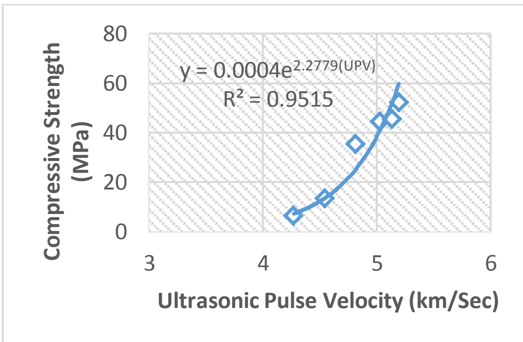

Fig 4.1.f. F30 Vs UPV

5. Conclusion

From the experimental work conducted on the FA based concrete, following conclusions were drawn:

1. The UPV values are higher at 28 days and beyond 28 days for mixtures with 25% Fly Ash content.
2. At the one day hydration, the quality of RCC with Fly Ash is found to be good for all mixes. However, from the ages of 3 to 90 days the quality was improved from good to excellent due to the contribution of Pozzolanic reactions of Fly Ah.
3. Use of UPV measurements is adequate to evaluate the compressive strength and dynamic modulus of elasticity of Fly Ash based concretes from different replacement levels of Fly Ash. Also a model was proposed for time dependent dynamic modulus of elasticity of Fly Ash based concrete.

Future Scope:

This work shall be extended to study the effect of other mineral admixtures like Silica Fume, Rice Husk Ash and Meta Kaolin etc.

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