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EXPERIMENTAL STUDIES IN ULTRASONIC PULSE VELOCITY OF ROLLER COMPACTED CONCRETE CONTAINING GGBS AND M-SAND

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ABSTRACT

This paper presents the experimental investigation results of Ultrasonic Pulse Velocity (UPV) testing conducted on Roller Compacted Concrete (RCC) containing Ground Granulated Blast furnace Slag (GGBS) as mineral admixture and manufactured sand (M-sand) as partial replacement of fine aggregate (50%). The UPV was determined at the age of 24 hours, 3 days, 7 days, 14 days, 28 days and 90 days for seven RCC mixtures using cube specimens of plain and GGBS Roller Compacted Concrete (GRCC). The amount of OPC replaced by GGBS was varying from 0% to 60%. The UPV of GRCC was found to be lower for all mixtures at 24 hours in comparison with control mix concrete. But at 3, 7,28and 90 days the Ultrasonic pulse velocities were significantly improved for all the mixes. Relationships between compressive strength of GRCC and UPV and Dynamic Elastic Modulus were proposed. A new model is proposed to determine the Dynamic Elastic Modulus of GRCC as a function of age of concrete and percent replacement of GGBS by Ultrasonic Method.

Keywords: roller compacted concrete, ultrasonic pulse velocity, ggbs, compressive strength, dynamic elastic modulus, m-sand.

1. INTRODUCTION

The American Concrete Institute (ACI) defines roller compacted concrete (RCC) as the concrete compacted by roller compaction [1]. RCC is a stiff and extremely dry concrete and has a consistency 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[3]. The main advantage of RCC over conventional concrete pavement is speed in construction and cost savings. RCC needs no formwork, dowels and no finishing [4].

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 becomes one of the ingredients of concrete [5,6,7,19,20,21,22,26,27,30,32,34]. The GGBS is a mineral admixture which is obtained from the pig-iron in blast furnaces as a by- product and it derives from the minerals contained in iron ore, flux ashes and foundry coke. It consists of mainly Calcium alumina- Silicates and is essential for producing hydraulic binder. It is used as partial replacement of cement in concrete for reducing the heat of hydration, improving mechanical properties and reduces the permeability of concrete [5, 31]

Ultrasonic Pulse Velocity (UPV) is the main destructive method of testing of concrete quality, homogeneity and compressive strength of existing structures. This method is also useful tool in evaluating dynamic modulus of elasticity of concrete [12, 16]. The Dynamic modulus of Elasticity (Ed) is an essential and important factor when assessing the quality and performance of structural concrete. 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 [25].

Wen Shi –You, Li Xi -Bing [35] conducted experimental study on Young's Modulus of concrete through P-Wave velocity measurements. They proposed two empirical equations for obtaining static Yung's Modulus and Dynamic Young' Modulus when dynamic Poisson ratio varies around 0.20. Hisham Y. Qasrawi(2000) [24] proposed an empirical equation between UPV and Cube Compressive strength of Concrete and its R^2 value was found to be 0.9562. Subramanian V. Kolluru *et al*(2000) [17] was proposed a technique for evaluating the elastic material constants of a concrete specimen using longitudinal resonance frequencies using Rayleigh- Ritz method.

Ismail OzgurYaman *et al.* (2001) [36] investigated the use of indirect UPVs in Concrete slabs and found similarity between direct and indirect UPVs. Their significant conclusion is that the indirect UPV is statistically similar to direct UPV. N.K.Choudhari *et al* (2002) [8] proposed a methodology to determine the elastic modulus of concrete by Ultrasonic method.

M.Conrad *et al*(2003) [9] investigated stress-strain behaviour and modulus of elasticity of young Roller Compacted concrete from the ages of 6 hours to 365 days. They found that the Young's Modulus for the early ages for aged low cementitious RCC can be by an exponential type function. This function can be written as:

$$E_c(t) = E_{c,\alpha}\exp(a.t^b) \quad (1)$$

$E_c(t)$ = Time dependent Modulus [GPa]

$E_{c,\alpha} =$ Final modulus of elasticity [GPa]
t= Concrete age [days], *a, b* are model parameters

Glenn Washer *et al* (2004) [34] conducted extensive research on Ultrasonic Testing of Reactive powder concrete. Ultrasonic pulses were generated using high power ultrasonic instrument in three different geometric shapes (Cube, Cylinder and Prism). Average P-wave velocity and average S- Wave velocity were found.

RESEARCH SIGNIFICANCE

There were many studies carried out in relation with UPV, but the relationship between UPV and the Elastic and Mechanical properties of GGBS Roller Compacted Concrete has not been investigated. Also the effect of M-sand as partial replacement of river sand has not been reported by any researcher, when GGBS was used in RCC. The GGBS 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 where the wheel loads are moderate and speed of travel is medium. The findings of this experimental investigation will be useful in predicting the quality and behaviours of RCC made with GGBS intended for lean concrete base and cement concrete surface courses and similar applications and utilize the M-sand effectively in pavement construction. This research work was focused on the relationship between Elastic properties, strength properties and UPV of GGBS based roller compacted concrete with partial replacement of M-sand as fine aggregate in combination of River Sand.

2. EXPERIMENTAL WORK

2.1 Materials

Ordinary Portland Cement (OPC) of 53 Grade was used in the present experimental investigation. Cement was tested as IS 4031[14]. Ground Granulated Blast furnace Slag (GGBS) used in this research project was collected from the TOSHALI CEMENTS PVT LTD located at Visakhapatnam District, Andhra Pradesh, India. The GGBS was ground in a laboratory mill to a Blaine fineness of 4222 cm^2/g. The properties of cement and GGBS are given in Table-1.Local aggregate available in the area were used in the study, namely river sand and manufactured sand (M-sand) as fine aggregate and coarse aggregate of Nominal Maximum size of 19mm were used. Some of the physical properties of aggregates are shown in Table-2 and Table-3. The particle size distribution curves of fine, coarse and combine aggregate were shown in fig.1and Figure-2 respectively. The fine aggregate and course aggregate were conforming to BIS:383-1970 [13]. Potable drinking water is used in the preparation of all RCC mixtures.

Table-1. Properties of cement and GGBS.

Cement and GGBS characteristics		
Component (%)	**Cement**	**GGBS**
Chemical analysis		
Loss Ignition	1.8	1.01
SiO_2	20.4	34.4
Fe_2O_3	3.2	2.65
Al_2O_3	3.9	15.6
CaO	63	33.1
MgO	2.4	8.9
Na_2O	-	0.62
K_2O	-	0.6
SO_3	3	2.46
Physical properties		
Fineness (Blaine), m^2/kg	285	422.2
% of passing 45µm	88.5	98.0
Compressive Strength, MPa		
3 Days	29.00	-
7 Days	40.00	-
28 Days	58.00	-
Specific Gravity	3.15	2.82
Color (Figure-1)	Grey	Whitish

Table-2. Properties of fine aggregate.

S. No.	Property	Test value
1	Specific Gravity	2.68
2	Sieve Analysis Test results	Particle Size Distribution Curve shown in Figure-1

Table-3. Properties of coarse aggregate.

S. No.	Property	Test value
1	Specific Gravity	2.88
2	Water absorption	0.5%
3	Sieve Analysis Test results	Particle Size Distribution Curve shown in Figure-2
4	Aggregate Impact Value, %	21.50
5	Aggregate crushing value, %	20.40
6	Combined Flakiness & Elongation Value, %	21.90

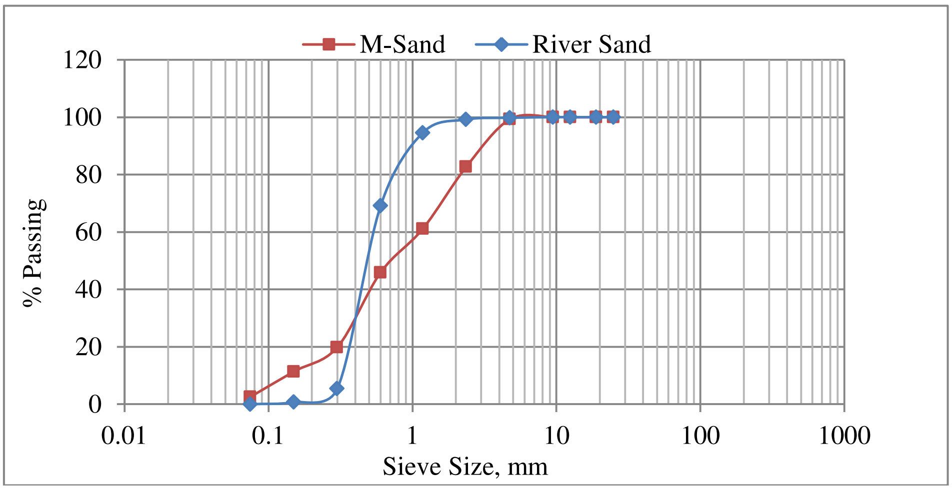

Figure-1. Particle size distribution curve for fine aggregate.

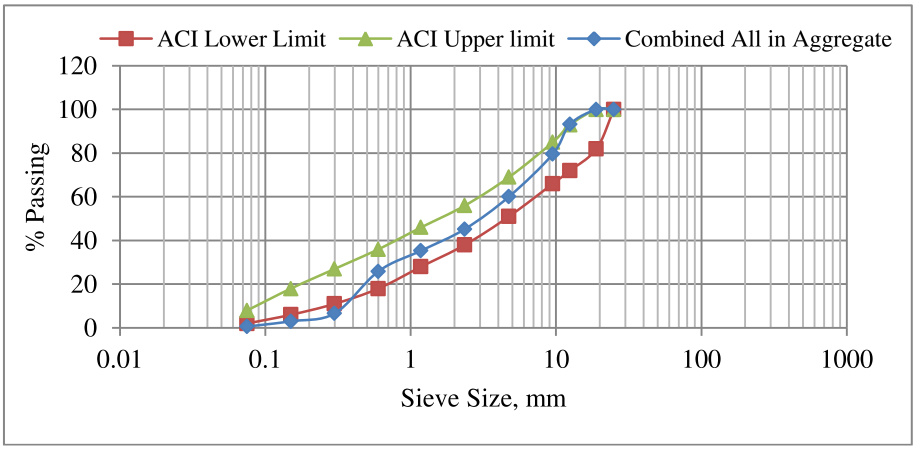

Figure-2. Particle size distribution curve for combined aggregate.

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2.2 Mixture

Seven mixtures prepared the details of mix proportions were shown in Table-4. The concretes produced are designated as G0, G10, G20, G30, G40, G50 and G60 on the basis of percent replacement of GGBS into it. All the mixes were designed for a specified flexural strength of 5.0 MPa. [18, 26, 27, 28, 29]. The mix design was based on soil compaction principles and ACI211.3R [2] guidelines. The combination of fine aggregates used in the investigation was 50% river sand and 50% M-sand (based on the authors work[18,26]. And the same was used in the production of all seven mixtures. The cement content of control mix of RCC was 295kg/m^3. In six RCC mixtures 10, 20, 30, 40, 50 and 60% by weight of cement were replaced with mineral admixture i.e. GGBS. The coarse aggregate of NMSA of 19mm was used in the RCC mixtures. The identification of mix proportions and quantity of material are given in Table-4.

Table-4. Quantities of materials per one m^3 of RCCP of 5 N/mm^2 flexural strength.

Concrete mix	Mix proportion (Kg/m^3)					
	Cement	GGBS	CA	River sand	M-sand	Water
G0	295	0	1209	400.5	400.5	114
G10	265	30	1209	400.5	400.5	117
G20	235	60	1209	400.5	400.5	119
G30	205	90	1209	400.5	400.5	126
G40	175	120	1209	400.5	400.5	130
G50	145	150	1209	400.5	400.5	147
G60	115	180	1209	400.5	400.5	155

2.3 Test methods

2.3.1Compressive strength

The compressive strength test was conducted on 150mm x 150mmx 150mm cubes in accordance with BIS: 516-1959[15] specifications. The cube specimens were cast and were covered with plastic sheet to reduce the moisture loss and cured for 24 hours in air. After 24 hours, all specimens were removed from moulds. Some of the specimens were tested for compressive strength at 24 hours. Remaining specimens were kept in clear water for curing. All the specimens were casted at prevailed room temperature. Compressive strength of roller compacted concrete specimens was measured at 1,3, 7, 14,28 and 90 days of curing age as per IS 516 [15]. They were tested in compression testing machine of 3000 KN capacity by applying load at the rate of 4.5 KN/sec until the resistance of the cube to the applied load breaks down (Figure-5). The test results are presented in Table-5.

Figure-3. Compression test on GRCC.

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Table-5. Compressive strength test results of 150mm x 150mm cube.

Concrete mix	Compressive strength of GRCC, N/mm^2					
	24 hours	3 days	7 days	14 days	28 days	90 days
G0	18.66	28.11	32.7	41.22	48.14	52.3
G10	14.76	24.52	45.30	53.22	57.71	62.36
G20	12.88	21.37	47.41	55.73	58.12	65.78
G30	10.45	18.66	49.15	56.56	59.88	68.49
G40	8.67	17.10	52.22	57.22	61.38	70.25
G50	8.23	16.14	48.64	56.17	58.11	67.18
G60	7.65	14.43	45.22	53.44	56.43	64.23

2.3.2 Ultrasonic pulse velocity

The UPV test was conducted on 150mmx 150mm x 150mm cubes in accordance with BIS: 13311(Part1):1992 [12] specifications. This method consists of measuring the time taken by a pulse to travel a measured distance. The apparatus consists of transducers which are kept in contact with cube specimens of concrete, a pulse generator with 10 to 150 KHz frequency, one amplifier, a time measuring circuit and a digital display of the time taken by the pulse and the velocity of longitudinal wave (Figure-4) between the transducers through the concrete. Test data was generated for all seven mixtures of GRCC at the ages of 24 hours, 3days, 7 days, 14 days, 28 days and 90 days. For each mix and age, an average of three cubes was reported. The total number of cube specimens tested were 7 x 3x 6(ages) = 126. The setup for measuring was shown in Figure-6 and Figure-7 the UPV of RCC was taken as the average of three specimens. For the purpose of calculations in this experimental work, ρ= 2450 KN/m^3 and μ= 0.2 have been assumed [23].

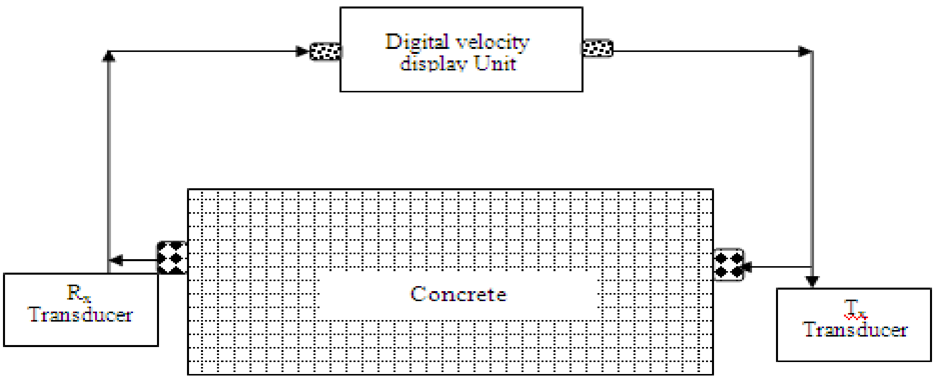

Figure-4. Direct transmission (T_x= emitter; R_x = Receiver).

Figure-5. Cube specimen under UPV Test and ultrasonic pulse velocity tester.

The following formula is used for calculating the dynamic modulus of elasticity of Roller compacted concrete [32].

$$E_d = \frac{\rho(UPV)^2\,(1+\mu)(1-2\mu)}{(1-\mu)} \quad (2)$$

E_d = Dynamic Modulus of elasticity in MPa

ρ= Density of concrete in KN/m^3

UPV=Ultrasonic Pulse velocity in Km/s

μ=Poisson's Ratio of concrete

Table-6 gives the quality of concrete on the basis of UPV obtained from the test as per BIS:13311(Part-1)-1992 [12]. And the UPV test results were presented in Table-7.

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Table-6. Quality of concrete as a function of UPV.

S. No.	Pulse velocity cross probing, Km/Sec	Concrete quality grading
1	> 4.5	Excellent
2	3.5 – 4.5	Good
3	3.0 – 3.5	Medium
4	< 3.0	Doubtful

Table-7. Ultrasonic pulse velocity test results (1,3,7,14,28 and 90 Days).

Concrete mix	UPV, Km/s					
	24 hours	3 days	7 days	14 days	28 days	90 days
G0	4.41	4.63	4.77	4.95	5.26	5.55
G10	4.56	4.81	4.95	5.11	5.38	5.71
G20	4.61	4.94	5.13	5.31	5.42	5.77
G30	4.84	5.12	5.22	5.44	5.55	5.83
G40	4.99	5.2	5.31	5.52	5.71	5.9
G50	4.71	4.96	5.15	5.28	5.41	5.67
G60	4.43	4.71	4.88	5.12	5.3	5.45

3. RESULTS AND DISCUSSIONS

3.1 Effect of GGBS on ultrasonic pulse velocity of RCC with time

The experimental progression of UPV of Control Mix and GGBS Roller Compacted Concrete (GRCC) with the age was shown in Figure-6 and Table-7 for RCC Mixes from G0 to G60 (Total seven mixtures). The ultrasonic pulse velocity of GRCC mixes increases with increase in curing age of roller compacted concrete for all the mixes as expected. Also the UPV of GRCC mixes was found to be higher than the control mix (G0) for all replacement levels up to 40% replacement at all ages for all mixes. The increase in UPV from 24 hours to 3 days is at slower rate, but beyond 3 days to 90 days the UPV increases rapidly. This is due to the fact that the hydration rate is slow at initial ages with GGBS and faster at later ages.

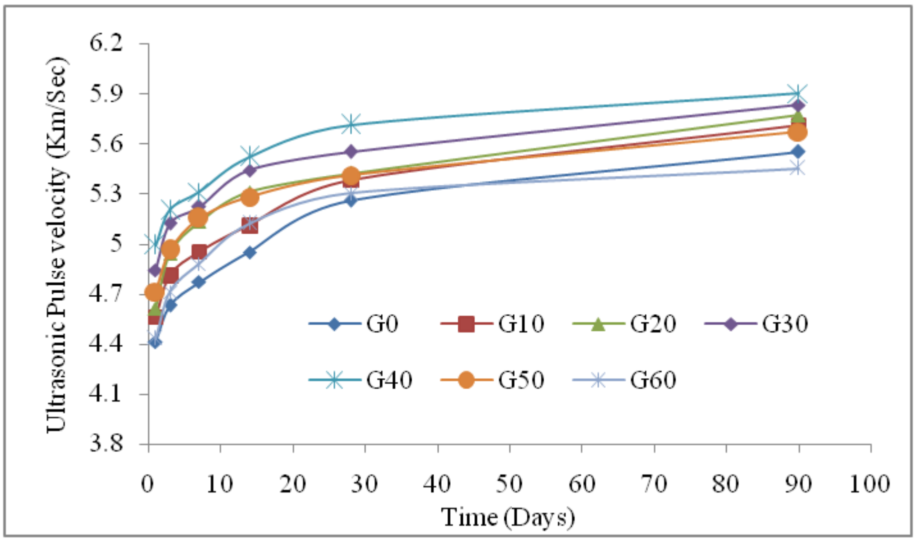

Figure-6. Progression of UPV with time for GRCC mixes.

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3.2 Effect of GGBS on quality of roller compacted concrete and UPV with age

Table-6 give the range of UPV qualitative rating as per IS: 13311(Part 1): 1992 [12]. A value of above 4.5 Km/s shows the concrete with excellent quality. For good concrete the UPV shall be varying between 3.5- 4.5 Km/s; for medium quality concrete the UPV shall be between 3.0 - 3.5 Km/s. The effect of GGBS on the quality of RCC mixtures with curing age for all mixes was shown in Table-8.

The quality assessment of RCC of control mix with age shows that the quality of RCC is found to be good at early ages of 1 and 3 days. However, as the time increases from 3 days to 90 days the quality of concrete changes from good to excellent for control mix (G0). Similar trend has been observed for mixtures G10 to G60, when cement was partially replaced with GGBs from 10 % to 60 %.

Amongst the GRCC mixtures from G0 to G60, G40 mix shows good to excellent quality and higher UPV values in comparison with other mixes. Hence 40 % GGBS replacement has been considered as optimum replacement level in GRC mixtures.

Table-8. Effect of GGBS on quality of RCC mixtures with age.

Time (Days)	**Quality of RCC mixes for all replacement levels** (from 0% to 60%)						
	G0	**G10**	**G20**	**G30**	**G40**	**G50**	**G60**
1	G	E	E	E	E	E	G
3	E	E	E	E	E	E	E
7	E	E	E	E	E	E	E
14	E	E	E	E	E	E	E
28	E	E	E	E	E	E	E
90	E	E	E	E	E	E	E

E= Excellent; G= Good

3.3 Relationship between compressive strength and UPV of RCC mixes

From the literature review, it was concluded that there is no definite relationship was existing between UPV and compressive strength of Concrete. Hence a relationship between compressive strength of RCC mixtures with different replacement levels of GGBS and UPV has been developed. Figure-7 and Figure-8shows the relationship between compressive strength of GRCC mixtures (G0, G10,G20, G30,G40, G50 and G60) and UPV at all ages. Figure-7 and Figure-8 can be used to assess the compressive strength of control mix (G0) and GRCC (G10,G20, G30,G40, G50 and G60) at any age of concrete. From the experimental results, exponential relationship between cube compressive strength and UPV of control mix (G0) and GRCC mixtures containing 10%,20%,30%,40%,50% and 60 % GGBS respectively has been proposed as under:

a. $f_c = 0.466e^{0.915(UPV)}$, R^2 = 0.959 for 0% GGBS (3)

b. $f_c = 0.053e^{1.360(UPV)}$, R^2 = 0.829 for 10%GGBS (4)

c. $f_c = 0.017e^{1.546(UPV)}$, R^2 = 0.809 for 20%GGBS (5)

d. $f_c = 0.014e^{1.571(UPV)}$, R^2 = 0.915 for 30% GGBS (6)

e. $f_c = 0.015e^{1.535(UPV)}$, R^2 = 0.936 for 40%GGBS (7)

f) $f_c = 0.0005e^{2.240(UPV)}$, R^2 = 0.936 for 50% GGBS (8)

g) $f_c = 0.002e^{1.998(UPV)}$, R^2 =0.967for60% GGBS (9)

Where
f_c= Cube Compressive strength of RCC in MPa
UPV= Ultrasonic Pulse Velocity in Km/s

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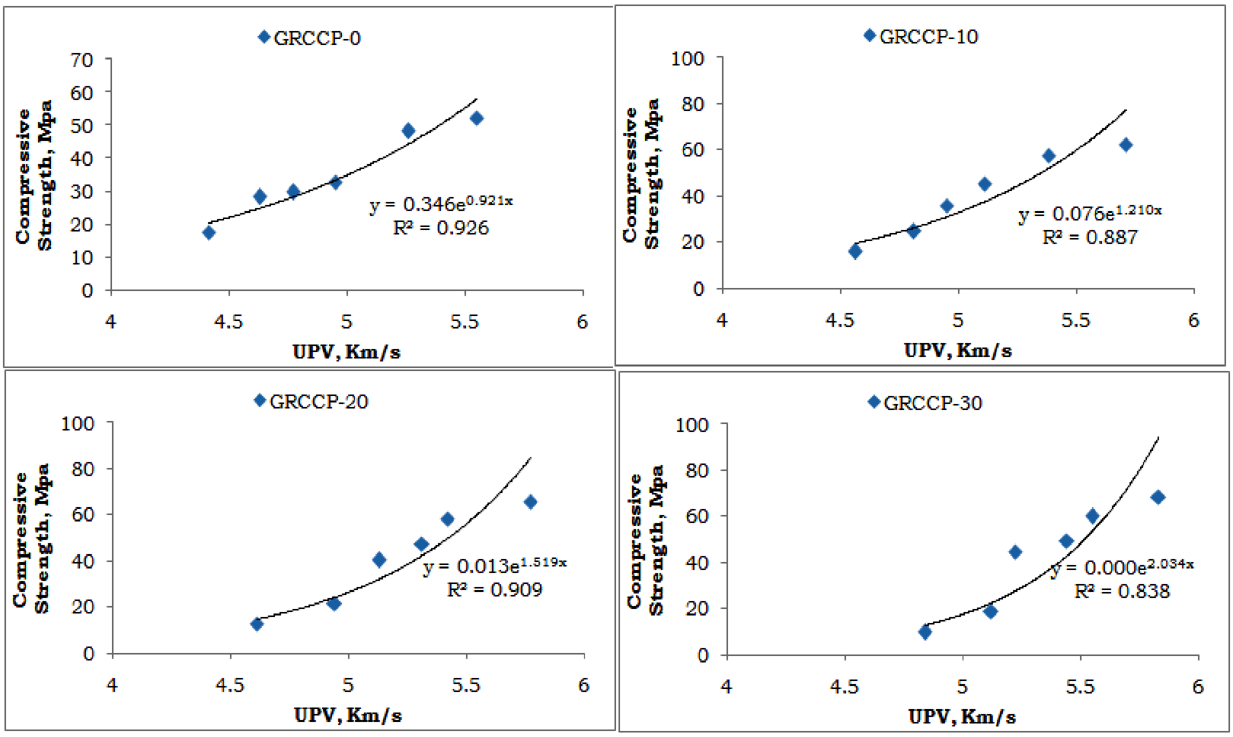

Figure-7. Relationship between compressive strength of RCC and UPV.

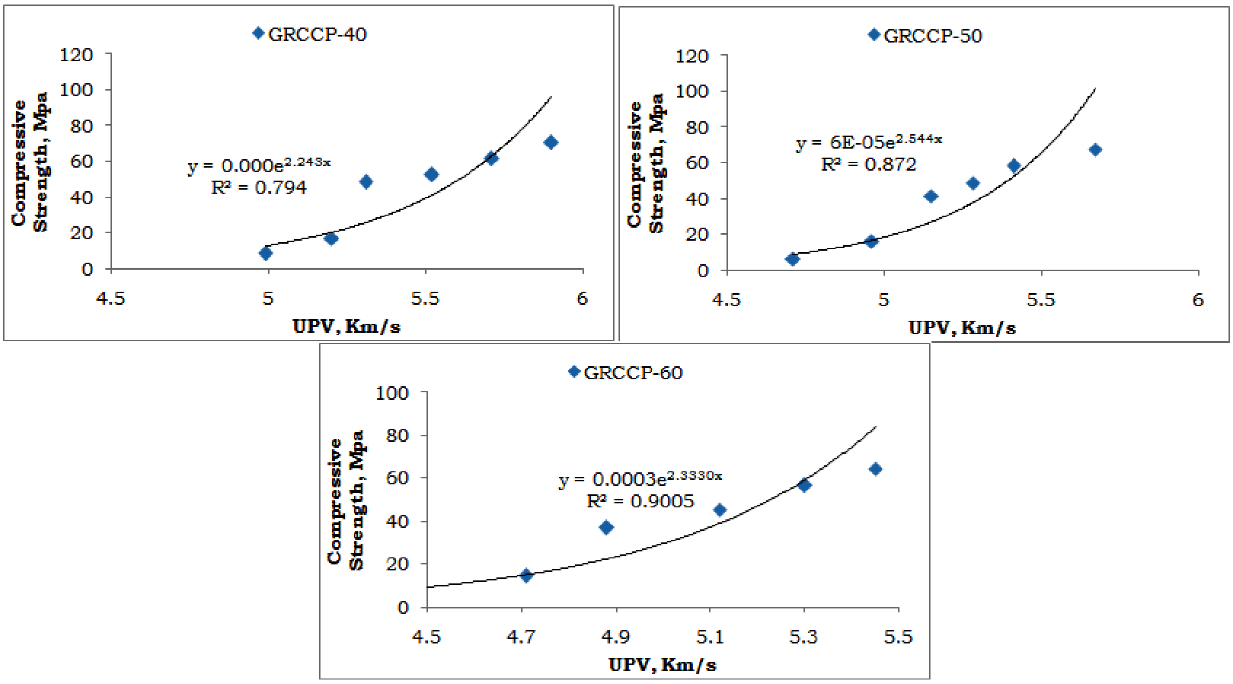

Figure-8. Relationship between compressive strength of RCC and UPV.

3.4 Dynamic modulus of elasticity of GRCC Mixes

Figure-9 show that the variation of dynamic modulus of elasticity of RCC mixtures with age of curing for control mix (G0) and GRCC mixtures (G10 to G60). Figure-8 shows that the dynamic modulus of elasticity of RCC is lower for control mix concrete in comparison with the GRCC mixtures with GGBS contents of 10 % to 60% at the all ages of curing. The 28 days dynamic modulus of elasticity control mix(G0) has been attained by the RCC mixture of G20, G30, G40 and G50 at 14 days of curing. Similarly the same value has been attained by the RCC

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mix of G 40 at 7 days; this is due to the fact that the hydration of GGBS has been started from the age of 7 days to 28 days at faster rate. This trend has also seen in the attainment of UPV from 7 days to 28 days of curing. Amongst the various RCC mixtures, at early age of concrete, the dynamic modulus of elasticity decreased with increase in the percent of GGBS. After 28 days, dynamic modulus of elasticity GRCC is observed to be higher for 40 % GGBS content that other replacements i.e. 10,20,30,50 and 60% respectively.

The dynamic modulus of elasticity development with age of concrete from 7 days to 28 days is 22% for Control mix (G0), where as it is 18%, 12%,13%, 16%, 10% and 18% for 10%,20%,30%,40%,50% and 60 % respectively for all GRCC mixtures. At the age of 28 days, the variation of dynamic modulus of elasticity for 10%,20%, 30%, 40%, 50% and 60% GGBS replacement is 105%,106%,111%,118%,106% and 102% respectively in comparison with the control mix(G0). At the age of 90 days, there is slight variation observed as 106%, 108%, 110%, 113%, 104% and 96% in 10%, 20%, 30%, 40%, 50% and 60%, respectively.

From the above points, it has been observed that, the variation of dynamic modulus of elasticity with age of concrete for GRCC mixes (G10 to G60) is higher than control mix (G0) concrete dynamic modulus of elasticity. Also the development of dynamic modulus of elasticity increases as the percent replacement of cement with GGBS increases. The cement replacement of 40% by GGBS was found to be the optimum for Roller Compacted Concrete.

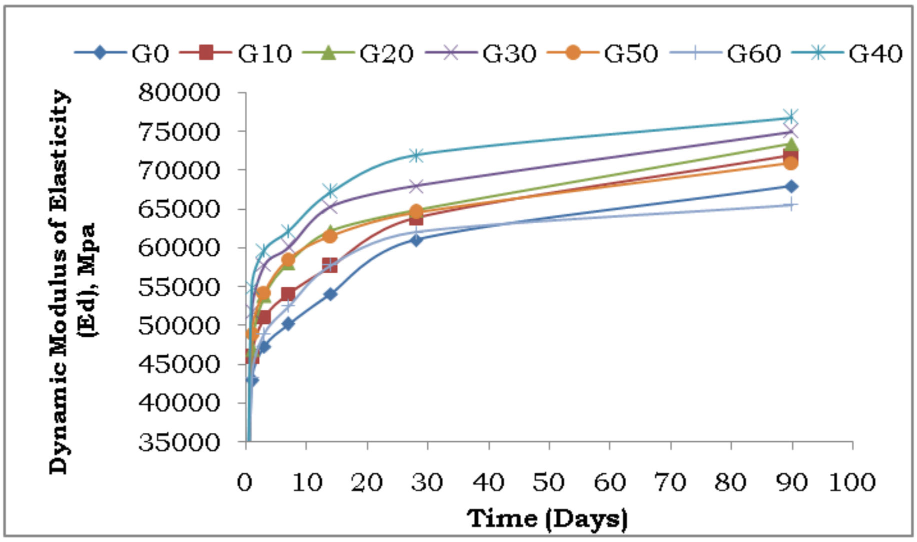

Figure-9. Progression of dynamic modulus of elasticity of RCC with age.

3.5 Relationship between dynamic modulus of elasticity and compressive strength of GRCC

Figure-10 show that the relationship between the dynamic modulus of elasticity and the compressive strength of cube which increases with increase in the Roller Compacted Concrete strength. The best fit equation was found with the observed test results are shown in Figure-10.

The relation can best express as:

$$E_d = 24.24(f_c)^{0.229} \qquad R^2 = 0.825 \qquad (10)$$

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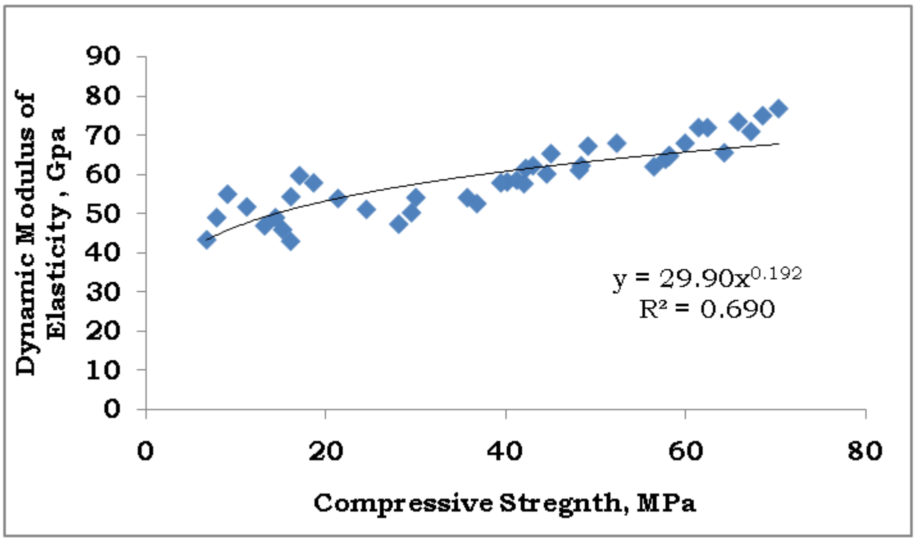

Figure-10. The relationship between the dynamic modulus of elasticity with compressive strength of GRCC.

3.6 Proposed model for dynamic modulus of elasticity with age of RCC

From the experimental results obtained in investigations on RCC mixtures, there is a relationship exists among dynamic modulus of concrete, age of concrete and GGBS content. Hence a model has been proposed for the prediction of dynamic modulus of elasticity of roller compacted concrete at any age of concrete and percent replacement of GGBS. The best - fit multiple regressions equation was proposed based on the test data:

$$(E_d)_t = 88.52(t)^{0.55} + 0.0467(p_g) - 48.66 \qquad (11)$$

Where,

$(E_d)_t$ = dynamic modulus of elasticity at the age of t days in M Pa

p_g= % of replacement of cement by GGBS

The prediction of dynamic modulus of elasticity from the above expression was compared with the experimental data obtained from the test results and it is graphically shown in Figure-11. From Figure-11, it shows that the measured and predicted values are in good relation.

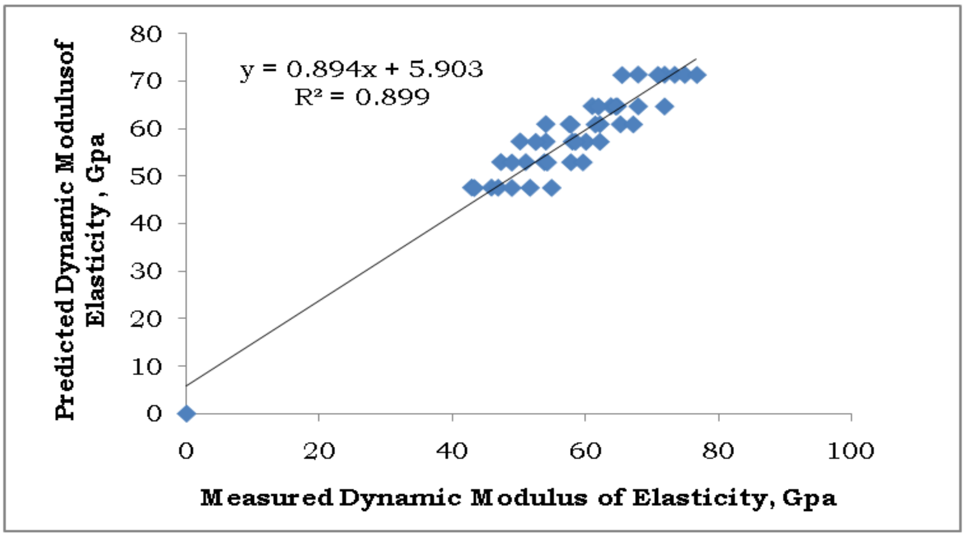

Figure-11. Comparison of predicted and measured values of dynamic modulus of roller compacted concrete with GGBS using proposed model.

4. CONCLUSIONS

From the experimental work conducted on the Roller Compacted Concrete with GGBS as mineral admixture and M-sand as partial replacement of River sand by 50%, following conclusions were drawn:

a) Amongst the GRCC mixtures made with 50% M-sand and 50% river sand, after the age of 28 days for the roller compacted concrete with cement replacement of 40 % by GGBS, the UPV was observed to be higher than the concrete in comparison with 10%, 20%, 30%, 50% and 60 % respectively. Therefore 40 % GGBS as cement replacement was found to be optimum.

b) The quality of Roller Compacted Concrete with GGBS at early ages is found to be good for all concrete mixtures, but at later ages i.e from 3 days to 90 days, quality of RCC has been improved from good to excellent. Also it has been found that at 40% GGBS replacement, the quality of RCC was found to be excellent beyond 7 days.

c) Utilization of UPV measurements is quite adequate to evaluate the compressive strength and dynamic modulus of elasticity of roller compacted concrete from day 1to day 90 for known replacement level of GGBS.

d) A new model has been proposed for time dependent dynamic modulus of elasticity of roller compacted concrete containing GGBS and M-sand at 50% replacement level, and it was found to be in good agreement with experimental test results.

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