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ISSN 0974-5904, Volume 08, No. 02

International Journal of Earth Sciences and Engineering

April 2015, P.P.279-284

Determination of Mechanical Properties of EOF Steel Slag Replaced Concrete Using NDT

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Abstract: The objective of the paper is to determine the mechanical properties of concrete by Destructive Testing and Non – Destructive Testing method. Investigation is carried out for M20 grade concrete; specimens are cast from 0% to 100% partial replacement of fine aggregate with Energy Optimized Furnace (EOF) Steel Slag with an increment of 10%. Destructive testing method is carried out by crushing of concrete and NDT method is done by Ultrasonic Pulse Velocity (UPV) and Rebound Hammer (RHT) tests. The relationship between the result of the non-destructive tests (RHT & UPV) and compressive strength (compression) is arrived at. Further, more parameters such as Modulus of Elasticity and Poison's Ratio were determined. The accuracy of interpretation of results depends directly on the correlation between strength of the material and measured velocity. The compressive strength of concrete is carried out and the result shows that optimum value is arrived at 40% replacement of EOF steel slag in both destructive and non-destructive testing. Correlation between bulk density and UPV, Dynamic Modulus of Elasticity and Rebound Number, Velocity and Compressive Strength, UPV2 and Dynamic Modulus of Elasticity are arrived and compared with earlier findings.

Keywords: *Non Destructive Testing (NDT); Rebound Hammer Test (RHT); Ultrasonic Pulse Velocity (UPV); EOF Steel Slag*

1. Introduction

Concrete, as a composite material, is generally composed of cement, sand, aggregate, water, admixtures and chemical admixtures. It is necessary to test structures to determine whether the structure is suitable for its designated use. This paper deals with two NDT methods viz, Ultra Sonic Pulse Velocity (UPV) method [IS: 13311, Part 10: 1992] and Rebound Hammer Test (RHT) .The UPV method have been followed to evaluate the quality of concrete for more than 60 years successfully which gives results on detecting internal cracking and other defects as well as changes in concrete structure such as deterioration due to aggressive chemical environment and freezing and thawing. The ultrasonic pulse generated by an electro acoustical transducer is induced into the concrete, which undergoes multiple reflections at the boundaries differ and material phases within the concrete. A complex system of stress waves are developed which includes longitudinal (compression), shear (transverse) and surface (Rayleigh) waves. The receiving transducer detects the onset of the longitudinal waves, which is the fastest. Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic properties, pulse velocity method is a convenient technique for investigating structural concrete. By using the pulse velocity method it is also possible to estimate the strength of concrete test specimens and in-place concrete. The pulse velocity method is a truly non-destructive testing method, as the technique uses mechanical waves resulting in no damage to the concrete element being tested.

1.1. UPV (Direct Measurement Technique)

In this paper direct measurement technique is carried out for the entire specimen. When an ultrasonic pulse travelling through concrete it meets a concrete-air interface, there is a negligible transmission of energy across this interface. So that any air-filled crack or void lying directly between the transducers, will obstruct the direct beam of ultrasound when the void has a projected area larger than the area of the transducer faces. The first pulse to arrive at the receiving transducer will have been diffracted around the periphery of the defect and the transit time will be longer than in similar concrete with no defect. The arrangement for direct method is as shown in Figure 1, where it requires access to two surfaces. The transmitting and receiving transducers are placed on opposite surfaces of the concrete slab. This will give maximum sensitivity and provide a well-defined path length.

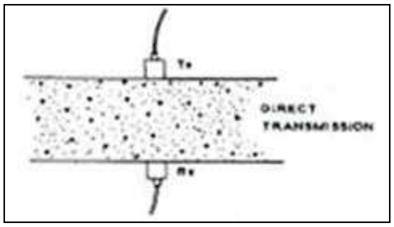

Figure1. *Direct Measurement Technique*

1.2. Rebound Hammer Test

The Rebound Hammer measures the surface hardness of the concrete. This is accomplished by placing the rebound hammer plunger against the concrete surface and releasing a spring loaded weight. The amount the plunger rebounds is measured. This rebound number is shown on a scale and will be between 10 and 100. The Impact Hammer is another name for Schmidt Hammer. The surface of concrete gets harder as concrete gains strength; thus, we have a method of estimating the strength of concrete. A low rebound number indicates that the surface of the concrete is soft and the concrete is weak. A high rebound number indicates that the concrete is hard and strong. Unfortunately, there is no theoretical relationship between surface hardness and the strength of concrete. Hence nondestructive testing plays an important role in assessing and assuring that structural and mechanical component perform their function in safe and reliable and cost effective manner. By reference to the conversion chart, the rebound value can be used to determine the compressive strength.

2. Background

Dallshad et al[1] using combined method of non-destructive testing estimated for SCC. Hassan and Hajjeh [2] discussed the Correlation between Destructive and Non-Destructive Strengths of Concrete Cubes. JedidiMalek and MachtaKaouther[3] Using Combined method of Non-Destructive Testing of Concrete Structures is estimated. Kheder et al [4] Using Combined method of Non-Destructive Testing insitu concrete structure is evaluated.Kheder et al [5]determined strength of concrete using Non Destructive Testing. Mohammed Salman et al [6] discussed static and dynamic modulus of Elasticity for high strength concrete. Nash'tand Sadoon [7] relationship between crushing strength of concrete. Nada Mahdi et al [8] predicted strength on concrete using Non Destructive Testing. Omer Arioz.et al [9] by using combined method of Non-Destructive Testing strength of concrete is determined. Rio et al [10] discussed the hardening of concrete with ultrasonic testing. Samia Hannach[11] by using combined evaluates the compressive strength of concrete. Turgut and Kucuk[12] studied the combined relationship of Non-Destructive Testing for concrete.

3. Materials and Experimental Details

3.1. Cement

Ordinary Portland cement (Ultratech43 Grade) confirming to IS: 269-1976 was used throughout the investigation.

3.2. Coarse Aggregates [Natural]

Locally available basal stone chips were used for preparation of concrete. Machines crushed locally available hard basalt, well graded 20 mm and down size were used.

3.3. Natural Sand (Fine Aggregate)

Locally available river sand passing through 4.75mm sieve as per IS: 383 provisions were used as fine aggregates. Table I depicts the physical properties of fine and coarse aggregate.

Table 1: *Physical Properties of Fine and Coarse Aggregate*

Description	Fine Aggregate	Coarse Aggregate
Specific gravity	2.6	2.75
Water absorption	1.57%	2.3%
Fineness modulus	3.1(zone II)	6.4
Surface moisture	Nil	Nil
Bulk density	1450 kg/m^3	1765kg/m^3

3.4. EOF Steel Slag

Steel slag is a by-product obtained either from conversion of iron to steel in a Basic Oxygen Furnace (BOF), or by the melting of scrap to make steel in the Electric Arc Furnace (EAF). In JSW Steel Ltd., Salem Works (JSWS), steel is produced in Energy Optimized Furnace (EOF). 200,000 m^3 – 300,000 m^3 EOF slag is produced annually. Table II& III give the properties of EOF steel slag.

Table2.*Physical Properties of EOF Steel Slag*

Properties	Result
Specific gravity	2.8
Bulk density	1455 kg/m^3
Finess modulus	2.9(zone I)
Water absorption	1.87%

Table 3.*Chemical Properties of EOF Steel Slag*

Parameter	Steel Slag (%)
CaO	35.28
MgO	9.27
SiO_2	16.69
Al_2O_3	6.20
MnO	1.88
FeO	26.91

P_2O_5	1.43
Na_2O	0.16
K_2O	0.03
SO_3	0.56

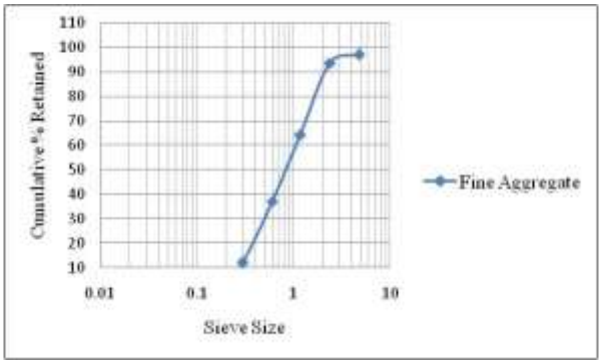

Figure2. *Particle size distribution curve for natural aggregate (river sand)*

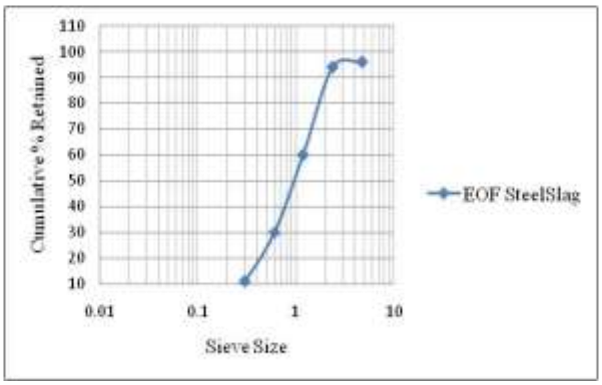

Figure3.*Particle size distribution of EOF steel slag*

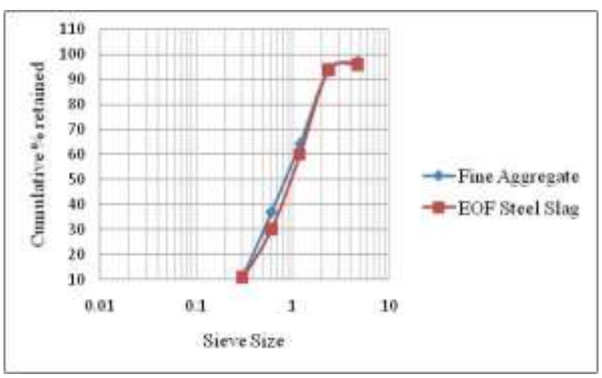

Figure4.*Particle size distribution of natural sand (river sand) and EOF steel slag*

From Table I and II, it is observed that the specific gravity of steel slag is more than the natural sand. From table III, it is inferred that there is no harmful chemicals present in slag. Since CaO content is more, it may contribute for strength increment, otherwise when steel slag is exposed to atmosphere for 3-6 months, there will not be any leaching in concrete.

From figure 2 and 3 shows the particle size distribution of natural sand (river sand) and EOF steel slag which conformed to zone II and zone I. From figure 4 it is inferred that, the particle size distribution of steel slag is almost matches with the natural sand. The natural sand confirms with zone II and steel slag is in between zone I and zone II.

3.5. Mix Design

The mix design for concrete M20 grade is arrived based on the code IS 10262:2009, and the obtained mix proportion is given in figure 4.

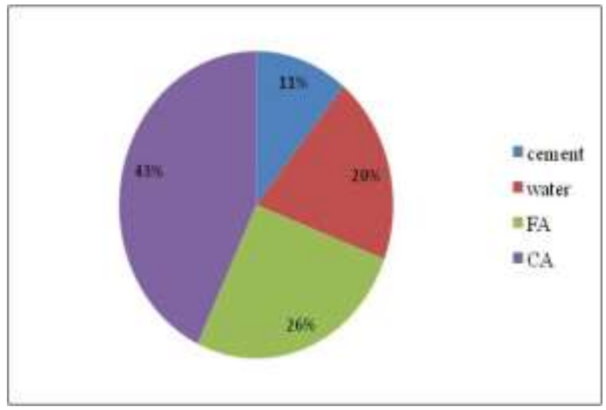

Figure5. *Percentage of M20 concrete*

4. Experimental Program

Compressive strength is measured using Destructive Testing and NDT. In destructive testing using compression testing machine 28 days compressive strength is obtained .Using NDT the 28 days Strength is calculated by Rebound Hammer and by generating Ultrasonic Pulse Velocity Waves into concrete. Indirectly strength is calculated in terms of Velocity and Rebound Strength by feeding to a Pundit Link.

5. Results and Discussion

5.1. Strength Properties

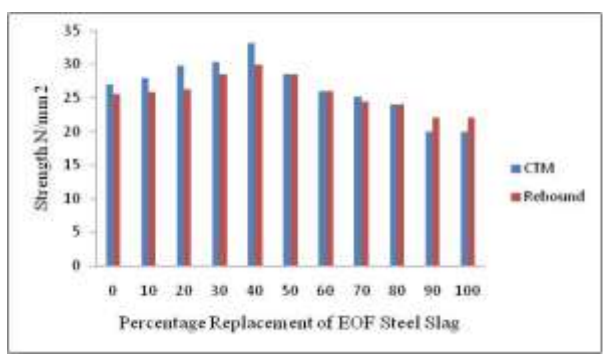

Figure6.*UPV and CTM compressive strength*

Fig 6 shows comparative bar chart between percentage replacement of slag and Non-Destructive testing (RHT), Destructive testing (CTM) compressive strength .Both Destructive and Non-destructive testing shows incremental pattern from 0% to 40%, and shows decrement beyond 40%.Hence optimum percentage replacement is 40%.

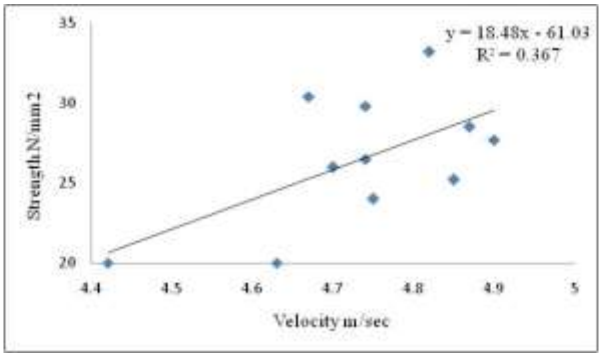

Figure 7 *Correlation between UPV and compressive strength*

Fig.7 represents the relationship between UPV and Strength of concrete as partial replacement of EOF Steel Slag and the equation is found that S=18.48Vp -61.03 and it is shown in Fig.7.

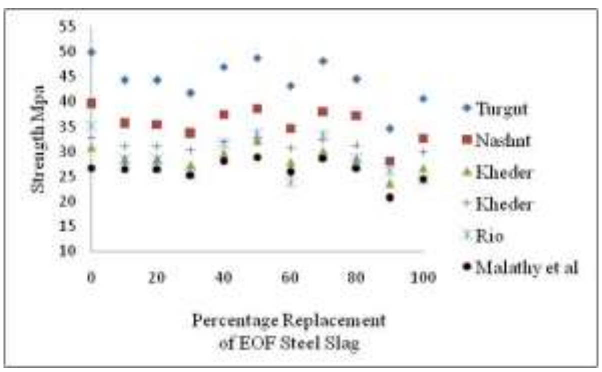

Figure 8.*Relationship between Percentage replacement of Slag and Strength by Theoretical Equation*

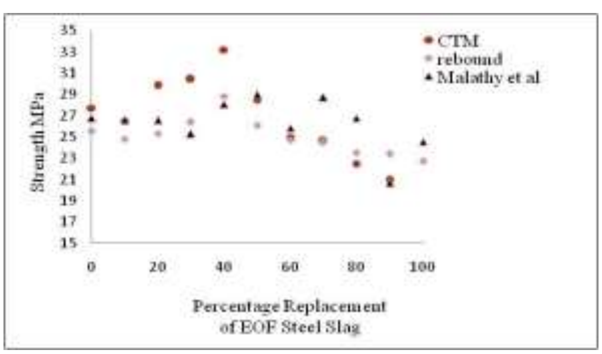

Figure 9.*Relationship between Percentage replacement of Slag and Strength by Destructive and Non-Destructive Tests*

Earlier researchers have developed correlation between strength and UPV and equation are shown in Table IV. As per those equations, the strength has been calculated and the graph has been plotted for different replacement of steel slag as shown in Fig.8 and Fig.9.From the Fig .9, it is observed that the strength obtained is almost matching with actual strength obtained from CTM and RH.

Table IV: *Relationship between Compressive Strength and Ultrasonic Velocity*

EQUATION	REFERENCES
$S= 1.146\exp(0.77\ V_p)$	Turgut (2004) (1)
$S = 1.19\exp(0.715Vp)$	Nashn't et.al (2005)(2)
$S = 8.4 \times 10^{-9}(V_p \times 10^3)^{2.5921}$	Kheder (1994)^A(3)
$S = 1.2 \times 10^{-5}(V_p \times 10^3)^{1.7447}$	Kheder (1999)^B(4)
$S=\exp[(3.3+0.0014 \times V_p \times 10^3)]$	Rio et.al(2004) (5)
$S= 18.48V_p-61.03$	Malathy et.al(2015)

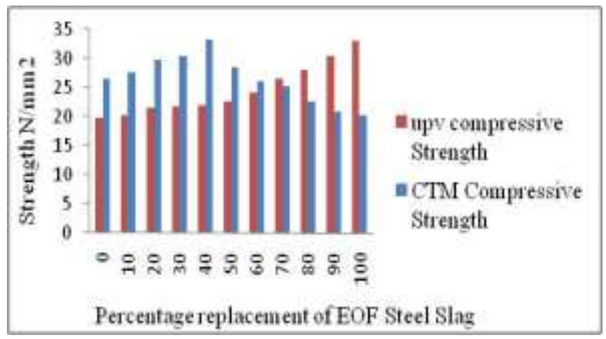

Figure 10 *UPV and CTM Compressive Strength*

Fig.10 shows that comparative bar chart between Compressive Strength obtained from destructive testing (CTM) and Non-destructive testing (UPV) by feeding Rebound Hammer number and CTM results in Pundit Link .From the figure it is observed that the destructive testing strength increased up to 40% replacement of EOF Steel Slag and it is decreasing beyond 40% replacement of EOF Steel Slag. But in UPV test strength is increased from 0% to 100% replacement that means replacing of slag as Fine Aggregate is giving good quality concrete. Hence the slag can be replaced up to 100% for natural sand to attain M20 grade concrete.

5.2. Density of Concrete

Fig.11 shows ,the linear correlation between Density and Ultrasonic Pulse Velocity and the equation is formed as $y=1391\rho+1190$ ($R^2= 0.643$).From the figure11 it is observed that density increases as Ultrasonic Pulse Velocity increases .Therefore replacement of EOF Steel Slag as Fine Aggregate is increasing the density of concrete and corresponding strength of concrete.

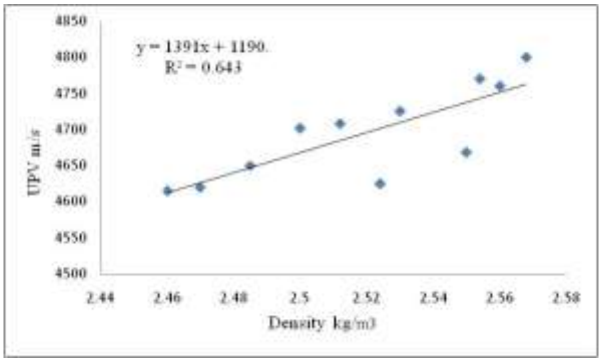

Figure 11.*Relationship between Density of Concrete and UPV*

5.3. Modulus of Elasticity

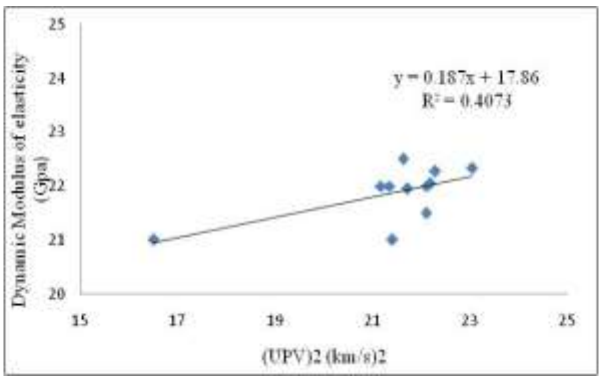

Figure 12*.Relationship between UPV ^{2} and Dynamic Modulus of Elasticity*

The fig.12, shows the dynamic modulus of elasticity can be determined from UPV test by measuring longitudinal and shear waves from Pundit Link .The obtained modulus of elasticity is plotted against UPV^2 values and shown in fig.12 From that the equation is arrived and shown below and equation is arrived as $E_d = 0.187V_P+17.86$ ($R^2 = 0.4073$).Also the obtained modulus of elasticity is plotted against RN and shown in fig.13

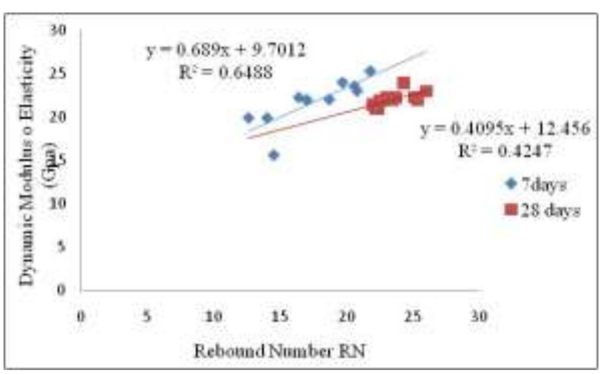

Figure 13.*Relationship between Rebound Number and Dynamic Modulus of Elastiсity*

Figure 13 shows that Rebound Number is measured at 7 and 28 days and it is related with Dynamic Modulus of Elasticity were the linear equation for 7 days is $y = 0.689 R_N +9.701$($R^2 = 0.648$) and 28 days as$y=0.409R_N +12.45$(R^2=0.424).Both the equation and correlation of 7 days and 28 days are nearer.

6. Conclusion

By conducting destructive and non-destructive testing on M20 concrete replacing steel slag for natural sand from 0% to 100%, the strength, density and modulus of elasticity of concrete are arrived and the following conclusion were drawn.

UPV and RH results can be very well used to determine the mechanical properties of concrete

The correlation between strength and UPV arrived by earlier researchers are compared with the equation developed for slag replaced concrete

The correlation between UPV and density, UPV and modulus of elasticity for slag replaced concrete were obtained.

7. Acknowledgement

Authors thank JSW steels, Mecheri and Management and Principal, Sona College of Technology, Salem for their support and encouragement.

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