Evaluation of Geopolymer Concrete using Non Destructive Techniques

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Abstract- *The present investigation is mainly focused on evaluation of geopolymer concrete (GPC) with respect to M25 grade concrete mix using non-destructive testing (NDT) techniques viz., Schmidt rebound hammer (SRH), ultrasonic pulse velocity (UPV). The NDT techniques were performed to compare the accuracy between the SRH, UPV in estimating the compressive strength of GPC. In this study, the mix of GPC was prepared with Fly ash as replacement to cement , Slag as replacement to fine aggregate and Coal washery rejects as partial replacement to Coarse aggregate (up to 30 % replacement by weight). Combination of sodium hydroxide (6M) and sodium silicate solution was used as an alkaline activator. Prior to compressive strength of test specimens, SRH and UPV methods were recorded after 7, 28, 56 and 112 days of curing at ambient room temperature. From the results, it is revealed that the compressive strength from SRH, UPV was more than M25 grade Mix. This shows that the durability of geopolymer is adequate to be used as replacement to M25 Grade concrete. Different equations were proposed correlating the compressive strength of concrete to SRH, UPV. Statistical analysis includes type of fit, sum of square residuals and standard errors were determined for the proposed equations. The measured compressive strength of all mixes was compared with predicted equations developed by past researchers.*

Keywords- Geopolymer concrete, Coal washery rejects, Compression strength, Non-destructive testing, Schmidt rebound hammer, Ultrasonic Pulse velocity.

I. INTRODUCTION

Approximately it is estimated that the global consumption of cement is more than 2.2 billion tons per year [1], so it releases equal quantity of carbon dioxide [2]. To minimize this affect an alternative binder for the concrete technology was proposed in the year 1978 i.e., geopolymer technology [3]. Heat-cured low-calcium fly ash-based geopolymer concrete has excellent compressive strength, suffers very little drying shrinkage and low creep, excellent resistance to sulfate attack, and good acid resistance as compare to water curing [4]. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, which results in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows [5].

Mn [-(SiO2) z-A1O2] n. wH2O

Where:

M = Cation such as potassium, sodium or calcium; the symbol - indicates the presence of a bond, n is the degree of polycondensation or polymerization; z is l, 2, 3, or higher, up to 32. One of source material granite slurry used as replacement of fine aggregate in the GPC. The typical mix proportions of GPC are evaluated by using non-destructive testing’s. Based on relevant literature, the effect of typical mix proportions of GPC on compressive strength, SRH and UPV has been discussed in the following sections.

1. Compressive strength

The compressive strength of concrete is used as the most basic and important material property when reinforced concrete structures are designed [6].

Most of the researchers concluded that the cube compressive strength has higher strength than the cylinders. The compressive strength of concrete should be influenced by proportion of cement, water cement ratio and curing. Compressive strength should also predict by Non-destructive tests, viz., Schmidt rebound hammer and ultrasonic pulse velocity.

2. Schmidt Rebound Hammer (SRH)

From the code of practice, it is clear that the rebound number reflects only the surface strength of concrete and the number indicates strength of about first 30-mm depth of concrete. The rebound number results obtained are only representative of the outer concrete layer with a thickness of 30-50 mm [7]. The SRH test is affected by various factors, viz.: surface smoothness, size, shape, rigidity, age and internal moisture condition of test specimen. Also it affects by selecting the type of aggregate and type of cement [8].

The calibrated range of the compressive strength of specimens using hammers are ± 15 to ± 20% differ from the actual results [9]. As such, the estimation of strength of concrete by rebound hammer method cannot be held to be very accurate and probable accuracy of prediction of concrete strength in a structure is ± 25 % [10]. The SRH test procedure, data collection and processing of test results are described in respective codes [10-13]. Based on the limited past research, the quality of concrete as a function of the rebound number as shown in Table 1.

Table 1. Quality of concrete by rebound number

Average Rebound Number	Quality of Concrete
> 40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
< 20	Poor concrete
0	Delaminated

3. Ultrasonic Pulse Velocity (UPV)

The UPV test is generally used to estimate quality and homogeneity of the concrete structures. High UPV results are generally indicative of good quality concrete and vice versa. To easily estimate the existence of the flows, cracks and voids in the concrete structures based on pulse velocity [14].

The actual pulse velocity obtained depends primarily upon the materials and mix proportions of concrete. Density and modulus of elasticity of aggregate also significantly affect the pulse velocity. Surface condition, moisture content, path length, shape, size of the specimen may also influence the pulse velocity [10]. The estimated strength obtained from UPV may vary from the actual strength by ± 20 percent.

Based on the placing of transmitter and receiver, there are mainly three different transducer arrangements [15]. There are direct transmission (transducers on opposite faces), semi-direct transmission (transducers are placed either on adjacent faces) and indirect or surface transmission (same face) and the arrangement of transducers are depict in Figure 2. The direct transmission method gives a void detect ability of 100% while the indirect method gives an accuracy of 66 – 99% percent void detect ability. Based on code of practice [10] ; the quality of concrete as a function of the pulse velocity as shown in Table 2.

The principle of the test is that the velocity of sound material, V is a function of the square root of the ratio of its modulus of elasticity (E) to its density (ρ) [16] :

$$V = f(\sqrt{gE/\rho})$$

Where, g = acceleration due to gravity.

In the test, time and the pulse take to travel through concrete is recorded. Then, the velocity is calculated as [10]

$$V = L/T$$

Where, V = pulse velocity (m/sec), L = length (m), T = effective time (sec)

II. EXPERIMENTAL STUDY

1. Experimental program:

Our objective was to evaluate the compressive strength performance of GPC using NDT techniques. In this study, the mix of GPC was prepared with Fly ash,. Slag and. Coal washery rejects up to 30% replacement by weight. Combination of sodium hydroxide (6M) and sodium silicate solution was used as an alkaline activator. The hardened properties that were determined are compressive strength, SRH and UPV method after 7, 28, 56 and 112 days of curing at ambient room temperature and also plot the correlation curves for compressive strength to SRH and UPV. Compressive strength values were also derived from SRH and UPV using the formulae provided in past literatures.

2. Materials

In this investigation, Class F (low calcium) fly ash is used as an additive. The physical and chemical properties of fly ash are presented in Table 2 and Table 3.

Table 2. Physical properties of fly ash and GGBS

Particulars	Specific gravity	Fineness (m^2/Kg)
Fly ash	2.26	360

Table 3. Chemical properties of fly ash and GGBS from X-ray fluorescence analysis (%)

Particulars	Fly ash
SiO_2	65.6
Al_2O_3	28
Fe_2O_3	3
CaO	1
MgO	1
TiO_2	0.5
SO_3	0.2
LOI[a]	0.29

[a]LOI: loss of ignition

Slag is used as a fine aggregate. Coal Washery rejects and Crushed granite stones of size 20mm and 10mm are used as coarse aggregate. The alkaline liquid used was a combination of sodium silicate solution (Na2Sio3) and sodium hydroxide solution (NaOH) in the form of flakes or pellets.

3. Mixture proportions

Based on the limited past research on GPC, the following proportions were selected for the constituents of the mixtures. In the design of GPC mix, coarse and fine aggregates together were taken as 77% of entire mixture by mass [2]. Fine aggregate was taken as 30% of the total aggregates. The density of GPC is taken similar to that of OPC as 2400 kg/m3. The Class F fly ash and was used and the molarity of sodium hydroxide solution was kept at 6M. The details of mix design and its proportions for different mixes of GPC are given in Table 4.3.

III. METHODOLOGY

The compressive strength of GPC is evaluated by using NDT techniques viz., SRH and UPV. The Compressive strength test [12] and Schmidt rebound hammer [10] and ultrasonic pulse velocity of all specimens was evaluated by using their respective codes. These samples were tested at 7, 28, 56 and 112 days of curing at ambient room temperature.

Table 4. Mix proportions of constituent materials (kg/m3 and litres)

Mix type		GPC
Coarse aggregate	**Crushed stone**	903
	Coal Washery rejects	387
Fine aggregate	**Slag**	549
Fly ash		409
Na_2SiO_3		102
NaOH		41 (6M)

IV. EXPERIMENTAL RESULTS AND DISCUSSION

1. Compressive strength

The compressive strength of GPC mix (100:0, at different curing periods are depicted in Table 4. Compressive strength was tested at different curing periods of 7, 28, 56 and 112 days respectively. It was observed that the strength was in proportionate with normal M25 mix at all curing periods. From the results it is concluded that GPC mix can be surely used as replacement to Conventional concrete as it has good dense structure. The experimental values obtained are depicted in Figure 1. The similar type of trend have been seen in the rebound number as well as the ultrasonic pulse velocity results at different curing periods of 7, 28,56 and 112 days respectively.

2. Schmidt Rebound Hammer (SRH)

The rebound numbers of GPC at different curing periods are depicted in Table 4.

The calibration curve for compressive strength versus rebound number of GPC as shown in Figure 1, from the results the best fit line is a straight line which has the following equation, which represents the relationship between the rebound number and the compressive strength of GPC.

$$f'c = 0.8762R + 0.0430$$

Where, f'c and R are the compressive strength and rebound number.

The number of data used in the correlation n = 12. The R2 value is found to be 99.59%, which indicates a significant correlation. The 95% prediction interval is quite narrow (f'c ±1.15 MPa) where most of the data values are within this interval (Figure 2). The standard error are found to be S.E. = 0.7851.

Table 4. Compressive strength, Rebound Number and UPV of GPC

Mix type	Age (days)	Compressive strength, *f'c* (MPa)	Rebound Number, R	Ultrasonic pulse velocity (Km/s)
GPC	28	35.87	42	4.212
	56	43.53	50	4.447
	112	50.12	53	4.545
Conventional concrete	28	31.12	32.3	4.298
	56	35.84	38.1	4.496
	112	39.05	40.2	4.586

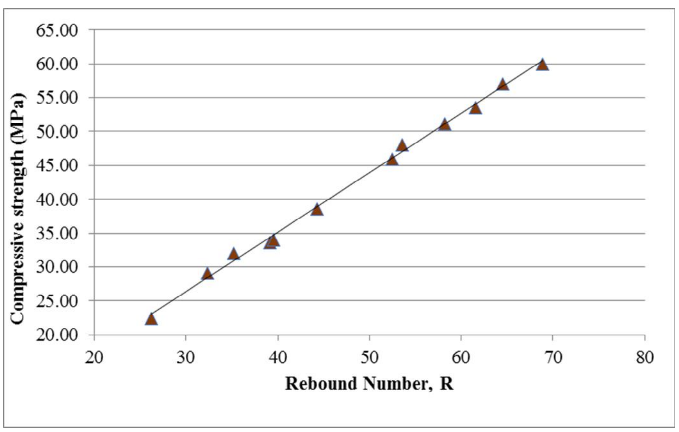

Figure 1. Calibration curve for compressive strength versus SRH

3. Ultrasonic pulse velocity (UPV)

Table 4 shows the ultrasonic pulse velocity of GPC mix at different curing periods, from the results the best fit line is a straight line which has the following equation, which represents the relationship between the compressive strength and the ultrasonic pulse velocity of GPC.

f'c = 26.361V – 50.306

Where, f'c and V are the compressive strength and ultrasonic pulse velocity.

The number of data used in the correlation n = 12. The R2 value is found to be 94.44%, which indicates a significant correlation. The 95% prediction interval is quite narrow (f'c ±4.61 MPa) where most of the data values are within this interval (Figure 2). The standard error are found to be S.E. = 8.707.

4. SRH Vs UPV

Figure 2 shows the relationship between measured SRH and UPV, from the results the best fit line is a straight line and representing the relationship is given by:

R= 0.0317V+1.9862

The R2 value is found to be 95.19%, which indicates a significant correlation, it is clear that the 95% prediction interval is quite narrow. The only conclusion is that there is a general trend for the UPV to increase with the increase in SRH results.

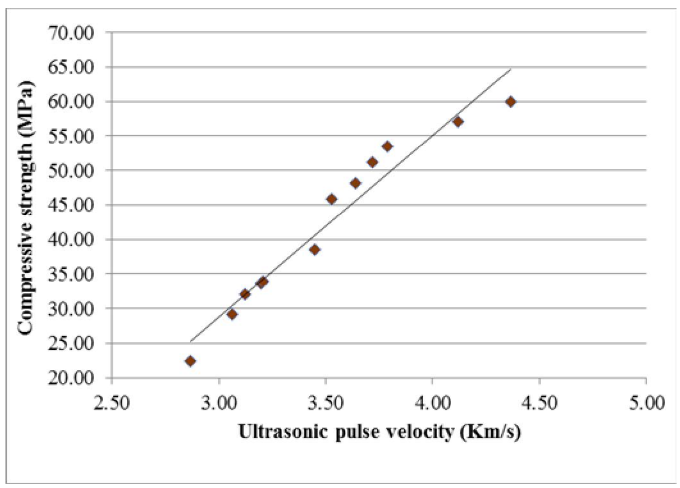

Figure 2. Calibration curve for compressive strength versus UPV

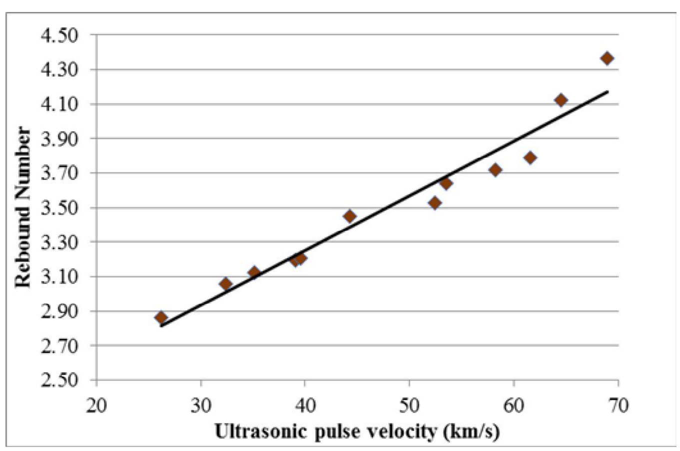

Figure 3. Calibration curve for SRH versus UPV

V. CONCLUSIONS

Based on the investigation, the following conclusions have been drawn.

a. The GPC mix has maintained same confinement compared to conventional concrete at all curing periods
b. The SRH and UPV results are also show that the GPC has good dense structure compared to conventional concrete.
c. The approximate values of compressive strength can be predicted from SRH and UPV.
d. Hence it can be concluded that GPC mix can be proposed to be used in place M25 Concrete Mix.

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