



Predicting compressive strength of geopolymer concrete using NDT techniques

C. Sreenivasulu¹ · J. Guru Jawahar² · C. Sashidhar¹

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Abstract

The present investigation is mainly focused on predicting compressive strength of geopolymer concrete (GPC) using non-destructive testing (NDT) techniques viz., Schmidt rebound hammer (SRH), ultrasonic pulse velocity (UPV) and combined method. The NDT techniques were performed to compare the accuracy between the SRH, UPV and combined method in estimating the compressive strength of GPC. In this study, four mixes of GPC were prepared with different fine aggregate blending. Sand and granite slurry or granite fines (GF) are blended in different proportions (100:0, 80:20, 60:40 and 40:60). Coarse aggregates of size 20 and 10 mm are blended in proportions 60:40. Ground granulated blast furnace slag (GGBS) and fly ash (class F) were used at 50:50 ratio as geopolymer binders. Combination of sodium hydroxide (8M) and sodium silicate solution was used as an alkaline activator. Prior to compressive strength of test specimens, SRH, UPV and combined method were recorded after 7, 28 and 90 days of curing at ambient room temperature. From the results, it is revealed that the compressive strength, SRH, UPV and combined method results were increased up to fine aggregate blending of 60:40. Different equations were proposed correlating the compressive strength of concrete to SRH, UPV and combined method. 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.

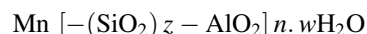
Keywords Geopolymer concrete · Compression strength · Non-destructive testing · Schmidt rebound hammer · Ultrasonic pulse velocity · Combined method

Introduction

Approximately, it is estimated that the global consumption of cement is more than 2.2 billion tons per year (Malhotra 1999), so it releases equal quantity of carbon dioxide (Hardjito & Wallah 2002). To minimize this affect, an alternative binder for the concrete technology was proposed in the year 1978, i.e., geopolymer technology (Abhishek et al. 2015). GPC is mainly influenced by fly ash (Rangan 2008), ground granulated blast furnace slag, molarities of NaOH (Supraja & Kanta Rao 2011),

superplasticizer (Aminul & Rajan 2012), and temperature (Kong & Sanjayan 2012). 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 compared to water curing (Sumajouw & Rangan 2006).

The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline (Xu & Van Deventer 2000). The polymerisation 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 (Davidovits 1999).



✉ C. Sreenivasulu
chitralasreenivas@gmail.com

¹ Department of Civil Engineering, Jawaharlal Nehru Technological University, Anantapur, India

² Department of Civil Engineering, Annamacharya Institute of Technology and Sciences, Tirupati, India

where M indicates cation such as potassium, sodium or calcium; the symbol $-$ indicates the presence of a bond; n indicates the degree of polycondensation or polymerization; z indicates 1, 2, 3, or higher, up to 32.

In this study, granite fines were used as a partial replacement of fine aggregate in the GPC. The compressive strength of GPC was evaluated using non-destructive testing. 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.

Compressive strength

The compressive strength of concrete was used as the most basic and important material property, when designing the reinforced concrete structures (Seong-Tae et al. 2006). Most of the researchers concluded that the cube's compressive strength has higher strength than the cylinders (Gonnerman 1925; Gyengo 1938; Murdock & Kesler 1957). The compressive strength of concrete should be influenced by proportion of cement, water–cement ratio and curing (Hacene et al. 2009). Split tensile strength, flexural strength and bond strength of concrete can be predicted using its compressive strength (Guru Jawahar et al. 2013). Modulus of elasticity of concrete can also be predicted using compressive strength and unit weight of concrete (Noguchi et al. 2009).

The fine aggregate in concrete also influences the characteristic strength of concrete (Sreenivasulu et al. 2016). From the past results, it can be concluded that there was significant increase in compressive strength with the increase in percentage of GF up to some extent and then drastic fall has been evidenced in all curing periods (Sreenivasulu et al. 2015).

Compressive strength can also be predicted by non-destructive tests such as Schmidt rebound hammer and ultrasonic pulse velocity.

Schmidt rebound hammer (SRH)

From the code of practice (BS 1881-202 1986), it is clear that the Schmidt rebound number reflects 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 (Teodoru 1988). The SRH test is affected by various factors, viz.: surface smoothness, size, shape, rigidity, age and internal moisture condition of test specimen. Also, it is affected by selecting the type of aggregate and type of cement (Hannachi & Nacer Guetteche 2014).

The rebound hammer calibrated compressive strength range differs from ± 15 to $\pm 20\%$ with the actual values (Malhotra & carino 2004). 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 $\pm 25\%$ (IS 13311-2 1992). The SRH test procedure, data collection and processing of test results are described in respective codes (IS 13311-1 1992). Based on the limited past research, the quality of concrete as a function of the rebound number is as shown in Table 1.

Ultrasonic pulse velocity

The ultrasonic pulse velocity (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. The cracks and voids of concrete structures can be easily estimated using UPV values (Kaplan 1958).

The actual pulse velocity obtained depends primarily upon the materials and mixed 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 (IS 13311-1 1992). The estimated strength obtained from UPV may vary from the actual strength by $\pm 20\%$.

Based on the placing of transmitter and receiver, there are mainly three different transducer arrangements (Karaiskos et al. 2015). 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). The direct transmission method gives a void detect ability of 100%, while the indirect method gives an accuracy of 66–99% void detect ability (Sutan & Meganathan 2003). Based on code of practice (IS 13311-1 1992), the quality of concrete as a function of the pulse velocity is 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) (Qasrawi 2000):

Table 1 Quality of concrete by rebound number

Average rebound number	Quality of concrete
> 40	Very good hard layer
30–40	Good layer
20–30	Fair
< 20	Poor concrete
0	Delaminated

Table 2 Quality of concrete by pulse velocity

Pulse velocity (Km/s)	Quality of concrete
> 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
< 3.0	Doubtful ^a

^aDoubtful means it is very poor or poor quality of concrete

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

where, g acceleration due to gravity.

In the test, the time that the pulse takes to travel through concrete is recorded. Then, the velocity is calculated as follows (IS 13311-1 1992):

$$V = L/T,$$

where, V pulse velocity (m/sec), L length (m), T effective time (s).

Combined methods

The use of one method alone would not be adequate to examine and evaluate the required property (Qasrawi 2000). The variation of proportions in concrete may affect both the UPV and rebound number values. Therefore, the use of more than one method yields more reliable results. For example, the increase in moisture content of concrete increases the ultrasonic pulse velocity, but decreases the rebound number (Neville 1995).

Hence, using both methods together will reduce the errors produced using one method alone to evaluate concrete (Qasrawi 2000).

Experimental study

Experimental program

The objective of the study is to determine the effect of fine aggregate blended (100:0, 80:20, 60:40 and 40:60) on compressive strength of GPC and NDT techniques. In this study, four mixes of GPC were prepared with different fine aggregate blending. Sand and granite fines (GF) are blended in different proportions (100:0, 80:20, 60:40 and 40:60). Coarse aggregates of size 20 and 10 mm are blended in proportions 60:40. Ground granulated blast furnace slag (GGBS) and fly ash (class F) were used at 50:50 ratio as geopolymer binders. Combination of sodium hydroxide (8M) and sodium silicate solution was used as an alkaline activator. The hardened properties that were determined are compressive strength, SRH, UPV after 7, 28 and 90 days of curing at ambient room temperature. The

correlation curves for compressive strength with respect to SRH, UPV and combined methods are represented and these results are validated with the existing models given by past literature.

Materials

In this investigation, Class F (low calcium) fly ash is used as an additive (ASTM C 618-03 2003) and GGBS is used for manufacturing of GPC. The physical and chemical properties of fly ash and GGBS are presented in Tables 3 and 4. Crushed granite stones of size 20 and 10 mm are used as coarse aggregate. Sand and granite fines are used as a fine aggregate. The bulk specific gravity in over dry condition, water absorption and fineness modulus of aggregates are presented in Table 5.

In this study, conplast SP430 is used as a chemical admixture. It acts as a High Range Water Reducer (HRWR) SP for the GPC. The alkaline liquid used was a combination of sodium silicate solution (Na_2SiO_3) and sodium hydroxide solution (NaOH) in the form of flakes or pellets (Somna et al. 2011).

Mixture proportions

Based on the limited past research on GPC (Hardjito & Rangan 2005), 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 (Hardjito & Wallah 2002). 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 (Hardjito & Wallah 2002).

The Class F fly ash and GGBS were taken as 50–50% and the molarity of sodium hydroxide solution was kept at 8M. The details of mix design and its proportions for different mixes of GPC are given in Table 6.

Methodology

The compressive strength of GPC is evaluated using NDT techniques, viz., SRH, UPV and combined method. The Compressive strength test (IS 516 1959), Schmidt rebound hammer (IS 13311-2 1992) and ultrasonic pulse velocity (IS 13311-1 1992) of all specimens were evaluated using

Table 3 Physical properties of fly ash and GGBS

Particulars	Specific gravity	Fineness (m ² /Kg)
Fly ash	2.26	360
GGBS	2.84	400

Table 4 Chemical properties of fly ash and GGBS (%)

Particulars	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	TiO ₂	SO ₃	LOI ^a
Fly ash	65.6	28.0	3.0	1.0	1.0	0.5	0.2	0.29
GGBS	30.61	16.24	0.584	34.48	6.79	–	1.85	2.1

^aLOI loss of ignition**Table 5** Physical properties of aggregates

Particulars	Coarse aggregate		Fine aggregate	
	20 mm	10 mm	Sand	GF
Bulk specific gravity	2.58	2.54	2.62	2.86
Water absorption (%)	0.3	0.3	1	1.2
Fineness modulus	7.35	5.89	2.59	2.34

respective codes. The compressive strength was found on the cube specimens of size 150 mm × 150 mm × 150 mm after 7, 28 and 90 days of ambient curing. Three cubes were cast for each period and each mix and average of three specimen results gives compressive strength of cube. Prior to the compressive strength test, SRH test was conducted horizontally on vertical surface of the each specimen (held at right angles to the surface) (Fig. 1). Totally, nine readings were taken on each specimen and average of such twenty-seven readings of three cubes at each age gives SRH value for each GPC mix proportion. As per code (IS 13311-2 1992), at least six readings should be taken for each point of testing for the rebound number. The UPV test also carried out before commencement of the compressive strength of cube and the transducers are arranged in direct transmission (transducers on opposite faces) (Fig. 2). The average value of three specimen readings at age give UPV values of each proportion.

Results and discussions

Compressive strength

The compressive strength of GPC mixes (100:0, 20:80, 40:60 and 60:40) at different curing periods are depicted in

Table 6 Mix proportions of constituent materials (kg/m³)

Mix type	Coarse aggregate		Fine aggregate		Fly ash	GGBS	Na ₂ SiO ₃	NaOH	Extra water	SP
	20 mm	10 mm	Sand	GF						
100:0 ^a	774	516	549	0	204.5	204.5	102	41 (8M)	92.5	2.86
80:20	774	516	439.2	109.8	204.5	204.5	102	41 (8M)	92.5	2.86
60:40	774	516	329.4	219.6	204.5	204.5	102	41 (8M)	92.5	2.86
40:60	774	516	219.6	329.4	204.5	204.5	102	41 (8M)	92.5	2.86

^a100:0 where 100 is the percentage of fine aggregate (sand) and 0 is the percentage of GF by weight

Table 7 and detailed test results of all tests are presented in Table 9 in “Appendix A”.

Compressive strength was tested for all mix proportions, i.e., 100:0, 80:20, 60:40 and 40:60 at different curing periods of 7, 28 and 90 days, respectively. It was observed that there was a significant increase in compressive strength with the increase in percentage of GF from 0 to 40% in all curing periods. After 7 days of curing, 60:40 sample exhibited a compressive strength of 33.97 MPa, whereas after 28 days of curing, it was 51.14 MPa and after 90 days of curing, it was 59.93 MPa. It is to be noted that the significant improvement in compressive strength is mainly due to the filling of voids with GF.

From the results, it is concluded that GF acts as filling material which fills the voids of the concrete and hence makes the concrete dense. However, when the percentage GF was increased to 60% (40:60), a drastic fall in compressive strength was evidenced irrespective of the time of curing. The compressive strength values of the mix 40:60 were found to be 22.39, 33.63 and 38.55 MPa, respectively, after 7, 28 and 90 days of curing. The fall in the compressive strength at 60% GF can be explained presumably due to the excessive content of fine material in concrete.

The experimental values obtained are depicted in Fig. 3. The similar type of trend have been seen in the rebound number as well as the ultrasonic pulse velocity results, which shows peak value at mix proportion of 60:40 at different curing periods of 7, 28 and 90 days, respectively.

Schmidt rebound hammer (SRH)

To assess the quality and surface hardness of GPC, the SRH test was done before the cube compressive strength test. The SRH results of GPC mixes (100:0, 20:80, 40:60

Fig. 1 SRH equipment and test setup

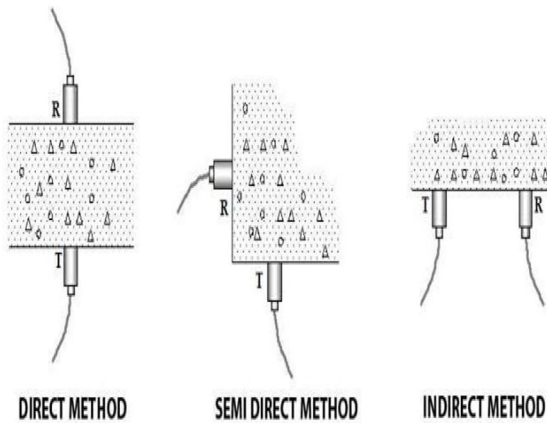
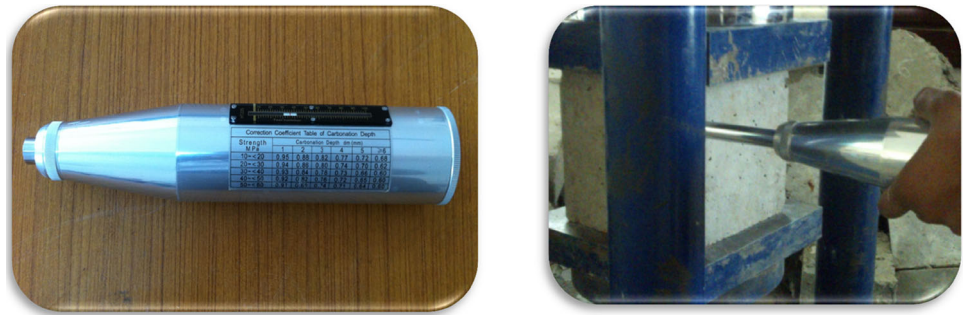


Fig. 2 Arrangement of transducers and UPV test setup

Table 7 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)
100:0	7	29.08	30.07	3.06
	28	45.87	42.26	3.25
	90	53.53	44.19	3.66
80:20	7	31.97	32.15	3.12
	28	48.07	44.22	3.44
	90	57.02	46.26	4.12
60:40	7	33.97	32.96	3.21
	28	51.14	46.44	3.51
	90	59.93	47.07	4.36
40:60	7	22.39	25.26	3.04
	28	33.63	29.15	3.20
	90	38.55	31.74	3.45

and 60:40) at different curing periods are depicted in Table 7 and detailed test results of each specimen are presented in Table 9 in “Appendix A”.

From the results, it is noticed that there was a significant increase in SRH value with the increase in percentage of GF from 0 to 40% in GPC, irrespective of age. After 7 days of ambient curing, 60:40 sample exhibited a SRH value of 32.96, whereas after 28 days and 90 days of ambient

curing, it was found to be 46.44 and 47.07, respectively. This indicates surface strength of GPC increases with increase in percentage of GF from 0 to 40% and it also leads to improvement in the compressive strength.

The calibration curve for compressive strength versus rebound number of GPC is shown in Fig. 4, from the results, it can be seen that the best fit line is a straight line which has the following equation (Eq. 1), which represents

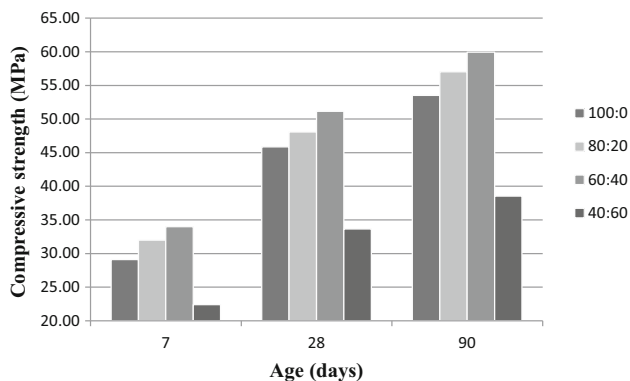


Fig. 3 Compressive strength vs age

the relationship between the rebound number and the compressive strength of GPC.

$$f'_c = 1.471R - 13.32 \tag{1}$$

where, f'_c and R are the compressive strength and rebound number.

The number of data used in the correlation $n = 12$. The R^2 value is found to be 96.36%, which indicates a significant correlation. The 95% prediction interval is quite narrow ($f'_c \pm 1.15$ MPa), where most of the data values are within this interval (Fig. 4). The standard error is found to be $SE = 2.425$.

Ultrasonic pulse velocity (UPV)

Figure 5 and Table 7 shows the ultrasonic pulse velocity of GPC mixes at different curing periods, viz., 7, 28 and 90 days, respectively, and detailed test results of UPV for each specimen are presented in Table 9 in “Appendix A”. From Table 7, it can be observed that the studied

UPV results lay between 3.04 and 3.21; 3.20 and 3.51; 3.45 and 4.36 km/s for 7, 28 and 90 days of curing. From the UPV results, it is observed that the GPC mix 60:40 sample exhibited higher values than the GPC mix 100:0 in all curing periods. Hence, it can be concluded that the improvement in UPV is mainly due to the filling of voids with GF. Based on the test results, the suitable proposed model is a straight line which has the following equation (Eq. 2), which represents the relationship between the compressive strength and the UPV of GPC.

$$f'_c = 26.764V - 50.306 \tag{2}$$

where, f'_c and V are the compressive strength and ultrasonic pulse velocity.

The coefficient of determination (R^2) was found to be 82.24% with a standard error of 5.351. The 95% prediction interval is quite narrow ($f'_c \pm 4.61$ MPa), where most of the data values are within this interval (Fig. 5).

SRH vs UPV

Figure 6 shows the relationship between measured SRH and UPV, and from the results, it can be seen that the best fit line is a straight line which represents the relationship as follows (Eq. 3):

$$R = 16.327V - 18.708. \tag{3}$$

The R^2 value is found to be 71.09%, 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.

Fig. 4 Calibration curve for compressive strength vs SRH

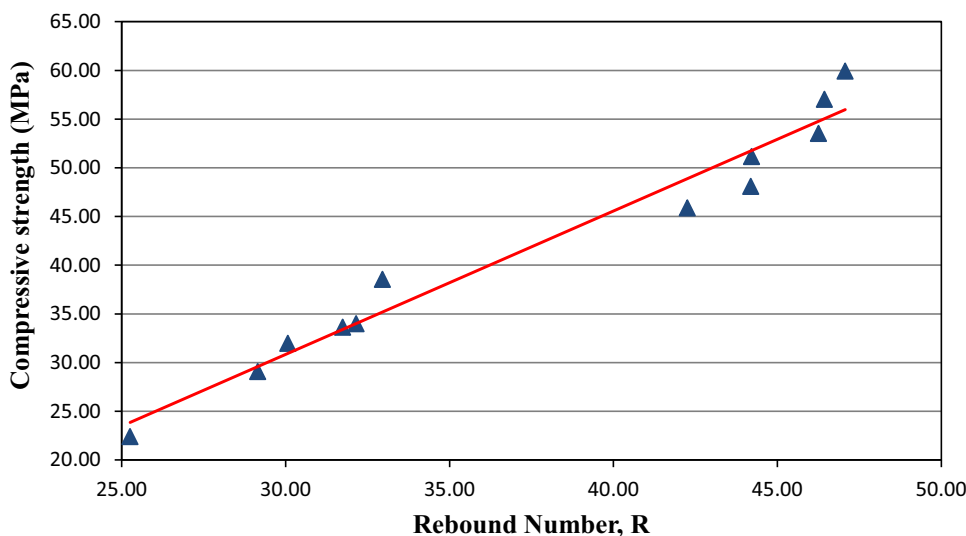


Fig. 5 Calibration curve for compressive strength vs UPV

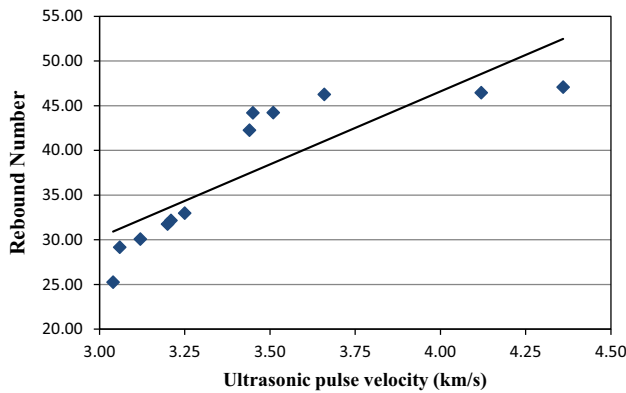
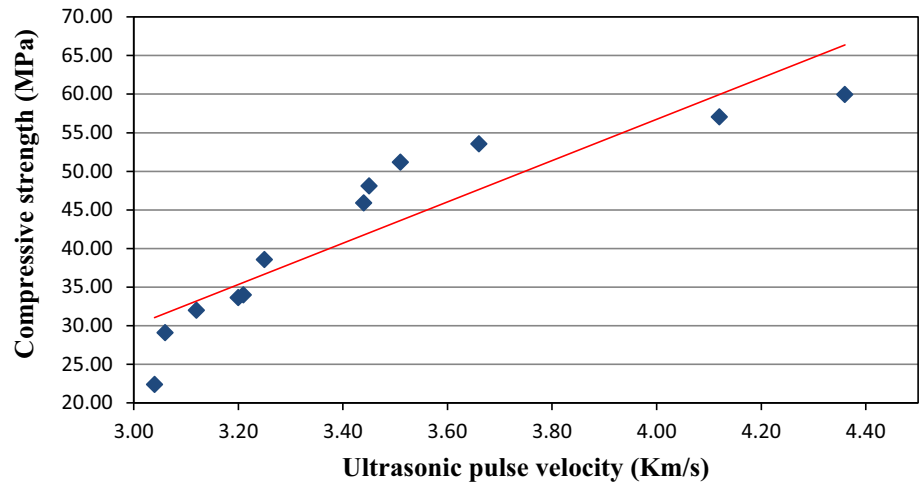


Fig. 6 Calibration curve for SRH vs UPV

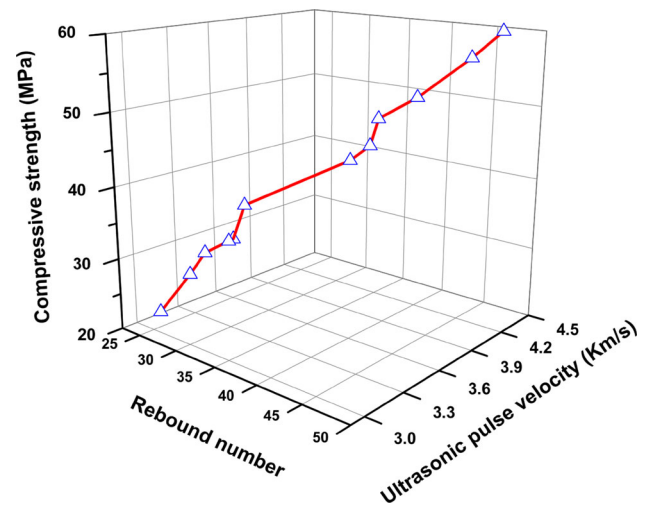


Fig. 7 Calibration curve for compressive strength vs SRH and UPV

Combined analysis

Dependability of results was enhanced while the combination of two NDT methods was used together. To analyze the combined method, a multiple regression was used to predict the concrete compressive strength. The proposed model for predicting the compressive strength of GPC using multiple regression is shown in Eq. 4.

$$f'_c = 7.966V + 1.125R - 27.759. \tag{4}$$

Consequently, the results showed a significant correlation between compression strength, SRH and UPV together. The compressive strength can be predicted from the combined SRH and UPV using equation as shown above with $R^2 = 98.20\%$, where $n = 12$ and $SE = 6.984$ and the 95% prediction interval is quite narrow ($f'_c \pm 1.12$ MPa). The correlation curve for compressive strength to SRH and UPV is depicted in Fig. 7.

Comparison with other published works

The measured compressive strength of GPC after 7, 28 and 90 days of curing have been compared with predicted equations developed by the past researchers as shown in Figs. 8, 9 and 10. The models developed by the past literature are presented in Table 8. From Fig. 8, it is seen that Hassan (2012) equation using SRH predicted the compressive strength values slightly lower than those of experimental values for all the mixes at 7, 28 and 90 days. Whereas, the experimental compressive strength values are closely similar to the values predicted by past literature using SRH (Jain et al. 2013; Kheder 1998; Qasrawi 2000) as shown in Fig. 8. Hence, it is observed that the present study model follows the similar trend of the existing models in predicting the compressive strength using SRH.

From Fig. 9, it can be noticed that the experimental values of compressive strength using UPV results are

Fig. 8 Comparison of compressive strength by SRH with past literature

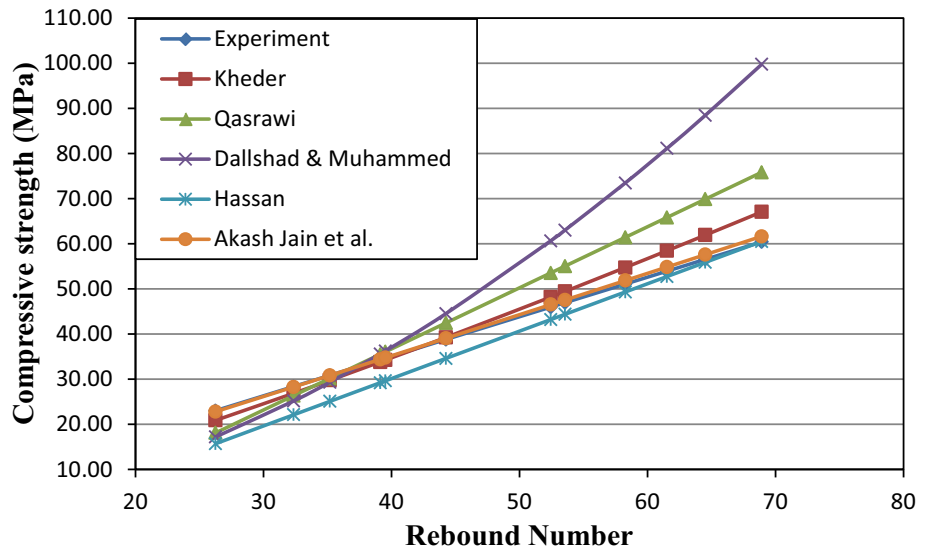


Fig. 9 Comparison of compressive strength by UPV with past literature

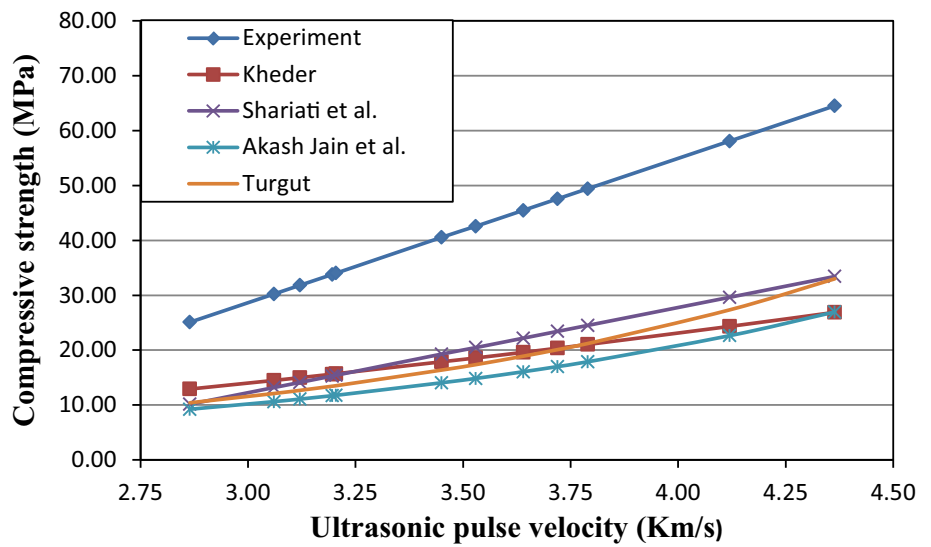


Fig. 10 Comparison of compressive strength by SRH and UPV with past literature

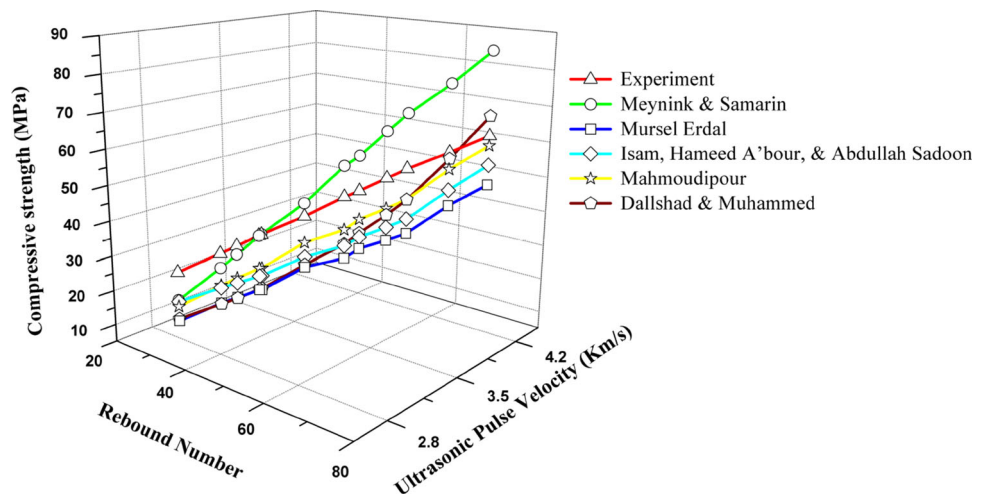


Table 8 Expressions for compressive strength

Expression for f'_c (MPa)	Literatures
$f'_c = 0.4030 \times R^{1.2083}$	Kheder (1998)
$f'_c = 1.353 \times R - 17.393$	Qasrawi (2000)
$f'_c = 0.045 \times R^{1.82}$	Dallshad & Muhammed (2004)
$f'_c = 1.050 \times R - 11.840$	Hassan (2012)
$f'_c = 0.788 \times R^{1.03}$	Jain et al. (2013)
$f'_c = 1.2 \times 10^{-5} \times V^{1.7447}$	Kheder (1998)
$f'_c = 0.1414 \times e^{1.5V}$	Gul et al. (2006)
$f'_c = 15.533 \times V - 34.358$	Shariati et al. (2011)
$f'_c = 1.19 \times e^{0.715V}$	Jain et al. (2013)
$f'_c = 1.146 \times e^{0.77V}$	Turgut (2004)
$f'_c = -24.668 + 0.0294 \times V^4 + 1.427R$	Meynink & Samarin (1979)
$f'_c = 0.42R + 13.166 \times V - 40.255$	Mursel Erdal (2009)
$f'_c = 0.356 \times R^{0.866} \times e^{0.302V}$	Isam, Hameed A'bour, & Abdullah Sadoon (2005)
$f'_c = 14.8 \times V + 0.5285 \times R - 43.32$	Mahmoudipour (2008)
$f'_c = 0.025 \times R^{1.48} \times e^{0.37V}$	Dallshad & Muhammed (2004)

higher than that of the results came from predicted equations developed by past literature (Jain et al. 2013; Kheder 1998; Shariati et al. 2011; Turgut 2004). This is due to fact that past researchers developed the model for conventional concrete (CC), whose compressive strength values are approximately ranging from 10 to 30 MPa. Whereas the present model was developed for GPC, whose compressive strength values are approximately ranging from 22 to 60 MPa. It is already known that the estimated compressive strength obtained from UPV may also vary from the actual strength by $\pm 20\%$ (IS 13311-1 1992). Hence, it is observed that the present study model follows the similar trend of the existing models in predicting the compressive strength using UPV. It can be said that the compressive strength values increase with the increased values of UPV for specific mix proportions.

Similar type of trend has also been observed in the combined analysis using SRH and UPV as shown in Fig. 10.

Conclusions

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

1. The compressive strength results were increased up to fine aggregate blending of 60:40 at all curing periods, because GF acts as filling material which fills the voids of the concrete and hence makes the concrete dense.
2. At 40:60, drastic fall in compressive strength was evidenced due to the excessive content of fine material in concrete.
3. The SRH results increased with increase in GF up to 40% at all ages; this is because hardness of GPC increases with addition of GF.
4. The UPV results also increased with increase in GF up to 40% at all curing periods, but the change is very small. The reason behind it is that the voids in the concrete will be minimized by GF.
5. The approximate values of compressive strength can be predicted from SRH, UPV and combined correlations graphs.
6. The optimum percentage of GF used as fine aggregate is 40%.

Appendix A

See Table 9.

Table 9 Detailed test results of GPC mixes

Mix type	Age (days)	Compressive strength of each specimen (MPa)	Rebound number of each specimen			UPV of each specimen (km/s)	
100:0	7	30.89	30	32	29	3.10	
			29	31	32		
			31	32	29		
		27.78		31	29	28	3.02
				28	28	29	
				32	34	29	
		28.58		28	29	30	3.07
				32	34	29	
				31	29	27	
100:0	28	45.33	41	32	36	3.26	
			36	42	44		
			48	46	45		
		48.40		48	46	46	3.27
				45	49	47	
				44	48	38	
		43.87		39	42	43	3.22
				42	39	38	
				35	37	45	
100:0	90	51.47	39	41	42	3.62	
			40	46	43		
			48	44	48		
		55.91		48	49	45	3.69
				46	47	44	
				41	48	40	
		53.20		45	47	42	3.68
				43	45	44	
				42	43	43	
80:20	7	32.58	28	31	32	3.13	
			31	32	29		
			34	35	32		
		31.29		34	35	31	3.09
				28	33	30	
				32	37	31	
		32.04		34	33	30	3.15
				30	32	34	
				32	33	35	
80:20	28	50.00	40	42	45	3.44	
			45	44	46		
			46	48	44		
		46.22		42	49	42	3.41
				44	45	41	
				49	46	41	
		48.00		48	41	40	3.47
				45	48	42	
				44	47	40	

Table 9 (continued)

Mix type	Age (days)	Compressive strength of each specimen (MPa)	Rebound number of each specimen			UPV of each specimen (km/s)
80:20	90	55.73	47	49	51	4.08
			48	45	49	
			46	43	47	
		57.11	41	47	46	4.16
			43	48	47	
			48	47	45	
		58.22	49	45	44	4.12
			46	46	43	
			48	49	42	
60:40	7	32.62	32	32	33	3.20
			31	33	34	
			32	34	31	
		34.22	30	34	33	3.22
			31	33	36	
			33	34	31	
		35.07	34	35	33	3.23
			32	33	35	
			31	34	36	
60:40	28	54.00	45	46	50	3.55
			48	45	49	
			46	44	47	
		51.42	45	47	46	3.52
			46	45	47	
			51	47	45	
		48.00	49	46	44	3.47
			46	48	43	
			48	49	42	
60:40	90	58.04	48	48	49	4.35
			47	45	50	
			46	44	48	
		58.40	45	47	46	4.37
			46	48	47	
			51	50	48	
		63.33	49	46	47	4.37
			46	48	43	
			48	49	42	
40:60	7	20.84	24	23	24	3.01
			26	24	26	
			27	26	21	
		23.42	23	25	28	3.07
			28	24	24	
			31	23	26	
		22.89	29	27	23	3.04
			26	26	24	
			24	25	25	

Table 9 (continued)

Mix type	Age (days)	Compressive strength of each specimen (MPa)	Rebound number of each specimen			UPV of each specimen (km/s)	
40:60	28	34.84	28	29	30	3.23	
			31	30	31		
			29	31	32		
		32.04		24	29	28	3.21
				28	25	23	
				30	28	26	
		34.00		32	29	30	3.17
				29	30	32	
				31	32	30	
40:60	90	43.24	31	34	32	3.48	
			29	32	31		
			28	33	30		
		34.53		32	31	28	3.42
				33	32	29	
				35	34	30	
		37.87		28	34	31	3.44
				37	32	34	
				34	28	35	

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