EVALUATION OF MECHANICAL PROPERTIES OF FLY ASH AND GGBS BASED GEOPOLYMER CONCRETE

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Abstract*—Geopolymer concrete is emerging as a promising alternative to conventional concrete. It is produced from by-product materials such as Fly ash (FA), Silica fume, and Ground granulated Blast furnace slag(GGBS), recognized as a low emission alternative binder for concrete. Recent studies have shown that the properties of Geopolymers are mostly similar to those of the OPC binder that is traditionally used for concrete. Geopolymer has limitations of slow setting at ambient temperature which can be eliminated by using GGBS. In the present study, an attempt is made to study the mechanical properties of Geopolymer concrete (GPC) containing GGBS as an additional ingredient. Five mix cases having varying GGBS dosages have been considered to study the mechanical properties. Standard cubes (150 mm), cylinders (150 mm dia. x 300mm. Length) and prisms (100 x 100 x 500 mm) were moulded to evaluate the mechanical properties of Fly Ash and GGBS based Geopolymer concrete. The results of the investigations indicate that all the mechanical properties of Fly ash and GGBS based Geopolymer concrete are in good agreement with conventional concrete properties.

Keywords: Geopolymerconcrete,OPC,Flyash,GGBS

I. INTRODUCTION

A Production of cement is on rise each passing day due to its extensive use by the construction industry. But the production of cement not only consumes natural materials but also emits CO_2 into atmosphere during its production. With worldwide annual consumption of Ordinary Portland Cement (OPC) being close to 1.56 billion tons, CO_2 released into the atmosphere due to every ton of OPC produced leads to an alarming situation. Every ton of Ordinary Portland Cement is responsible for 7% of world's atmosphere CO_2 loading which indeed warrants Engineers to identify alternate binding material for production of concrete. Geopolymer concrete (GPC) has emerged a new environment friendly alternate material for use in place of conventional concrete.

Geopolymer concrete is a potential material for structural application. OPC is a ceramic material, where as Geopolymers are materials bonded by polymerization. It can play a significant role in green concrete technology by eliminating cement and utilizing various by-product materials such as Fly ash and other pozzolonic materials [1]. Previous studies indicated prospective benefits of Fly ash based Geopolymer over OPC concrete [2, 3]. Some studies reported that, low calcium Fly ash based Geopolymer concrete attained excellent mechanical and durability properties, when cured in high temperature [4, 5, 6].

Geopolymer materials symbolize green building technology that is generating enormous interest in the construction industry in view of it being sustainable material. Prof. J. Davidovits invented that the polymerization process involves a chemical reaction under alkaline condition on Si-Al minerals that result in 3D polymeric chain and ring structure consisting of Si-O-Al-O bonds. The main theory behind this Geopolymer is that when source materials like Fly ash or rice husk which is rich in silica and alumina is mixed with alkaline activating solution (NaOH & Na_2SiO_3 solution or KOH & K_2SiO_3 solution) and Geopolymer can be developed in the form of -Si-O-Al-O- or –Si-O-Al-O-Si-O- or –Si-O-Al-O-SiO-Si-O-.

Geopolymer is an inorganic polymer, that is produced from various alumino-silicate materials such as Fly ash, blast furnace slag etc. reacted by alkaline solution [7]. Geopolymerisation concept can be explained with different reactions like destruction-coagulation, coagulation-condensation and condensation-crystallisation [8, 9].

Many factors influence the polymerisation reaction, which include chemical composition of the binder, the alkaline solution, curing condition and water content. Polymerization process of such concrete is accelerated at higher temperature than ambient. Fly ash based Geopolymer paste reacts slowly at low ambient temperature as compared to heat cured samples at temperature of up to 85^0C [10, 11, 12].

The calcium content in the Fly ash was found to have major impact on the resulting hardened Geopolymer. Calcium oxide is believed to form calcium silicate hydrate (C-S-H), along with the aluminosilicate Geopolymer gel [13, 14, 15]. Most studies reported are on the Fly ash Geopolymer blended with some additional materials [16]. The amount of internal and external calcium in the Fly ash is found to have significant impact on the resulting Geopolymer [17]. Several researchers have studied the suitability of Fly ash based Geopolymers mixed with silica fume, metakaolin and blast furnace slag. Temuujin et al. [18] explained that, addition of calcium oxide and calcium hydroxide as a replacement of Fly ash improved mechanical properties of ambient cured samples and decreased properties of oven cured samples at 70^0C. Fly ash based Geopolymer has also been reported to improve by enhancing the reactivity of Fly ash [19]. But, the Geopolymerisation process and its resulting products may also be influenced by other factors such as, the type and properties of aluminosilicate sources and composition of alkaline solution [20, 21, 22].Some studies are also reported on identifying compressive and flexural strengths of Fly ash and GGBS based Geopolymer concrete [23].

It may be noted that, most of the studies on Geopolymer concrete have been done on either heat cured or steam cured condition than ambient one. This type of concrete can be precast easily. But it is not always practicable in cast-in-situ applications due to delayed setting and slow strength development in ambient condition. Therefore it is necessary to investigate the Geopolymer concrete properties suitable for ambient curing condition. This study is aimed at identifying improved mechanical properties of low calcium Fly ash based Geopolymer with addition of GGBS. In the earlier studies [24,25], authors investigated influence of GGBS on micro structural properties of Fly Ash based Geopolymer concrete and also designated the mixes based on compressive strength values.

II. Experimental Programme

2.1 Materials

Source materials such as low-calcium Fly ash-Class F, and GGBS have the chemical composition as shown in Table 1 and is within the limits specified by IS 3812-2003 & IS 12089-1987. The combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solution is used as alkaline solution. Natural river sand was used as fine aggregate and Crushed granite stones of size 20 mm and 10 mm were used as coarse aggregate. The gradation of fine aggregate and coarse aggregate was determined as per IS 383-1970 & IS 12089-1987.

Table 1 Chemical Composition of Fly Ash and GGBS

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	SiO_2/Al_2O_3	Loss of ignition
Fly ash %	60.59	24.54	2.83	3.39	1.60	0.27	0.83	0.55	1.5	1.45
GGBS%	35	10	1.3	40	8	0.3	0.6	2.93	3.5	1.87

2.2 Mixture Proportions

In the design of the Geopolymer concrete mix, total aggregate is taken as 70% of entire mixture of mass. The remaining proportion of the entire mixture other than aggregates is of the binding materials Fly ash and GGBS. Five mixture proportions pertaining 5 grades of concrete used in the present work are shown in Table 2.

Table 2 Details of Mixture Proportions in kg/m^3

Mix ID	Fly Ash	GGBS	Sand	Coarse Aggregate	NaOH	Na_2sio_3
G20	432	48	590	1090	69	171
G30	384	96	590	1090	69	171
G40	336	144	590	1090	69	171
G50	288	192	590	1090	69	171
G60	240	240	590	1090	69	171

2.3 Method of Preparation

In the laboratory, Fly ash, GGBS and the aggregates were first mixed together dry on pan mixer for about three minutes (Figure 1). Alkaline liquid is then added to the dry materials and the mixing continued usually for another four minutes. The Fly ash, GGBS and alkaline activator were mixed together in the mixture until homogenous paste is obtained (Figure 2). The fresh concrete has a medium consistency with cohesive nature and was glossy in appearance. Fresh Geopolymer mixture is tested for setting time, workability, then filled in respective moulds and kept under shade for one day. Specimens were demoulded after one day and were kept under the shade until the day of test. Six cubes of 150 mm, 6 prisms of 100x100x500 mm, 12 cylinders of 150x300 mm were moulded to evaluate Compressive strength, Flexural strength, Split tensile strength, Modulus of elasticity and Poisson’s ratio values. GPC samples are tested in accordance with the standard guidelines given for OPC samples and the same are shown in Figure 3

Figure 1 Constituents of GPC

Figure 2 View of Fresh GPC Mixture

Figure 3 Test Setup for Mechanical Properties of GPC

III. RESULTS AND DISCUSSIONS

(a) Compressive Strength

GPC cubes are tested for compressive strength after 28 days of ambient curing. Compressive strength values have increased from 27.3 MPa to 70.8 MPa which are designated as G20 to G60 as shown in Figure 4. Geopolymerisation reaction gives a byproduct called, Si-O-Al-O-Si which gives strength property to GPC. But as GGBS is added to Fly Ash based GPC, additional calcium will react with silicates and shows formation of similar bond like C-S-H. This may be the reason to show increased strength values as GGBS dosages increased. The same is confirmed by authors through microscopic investigations in the earlier research [24].

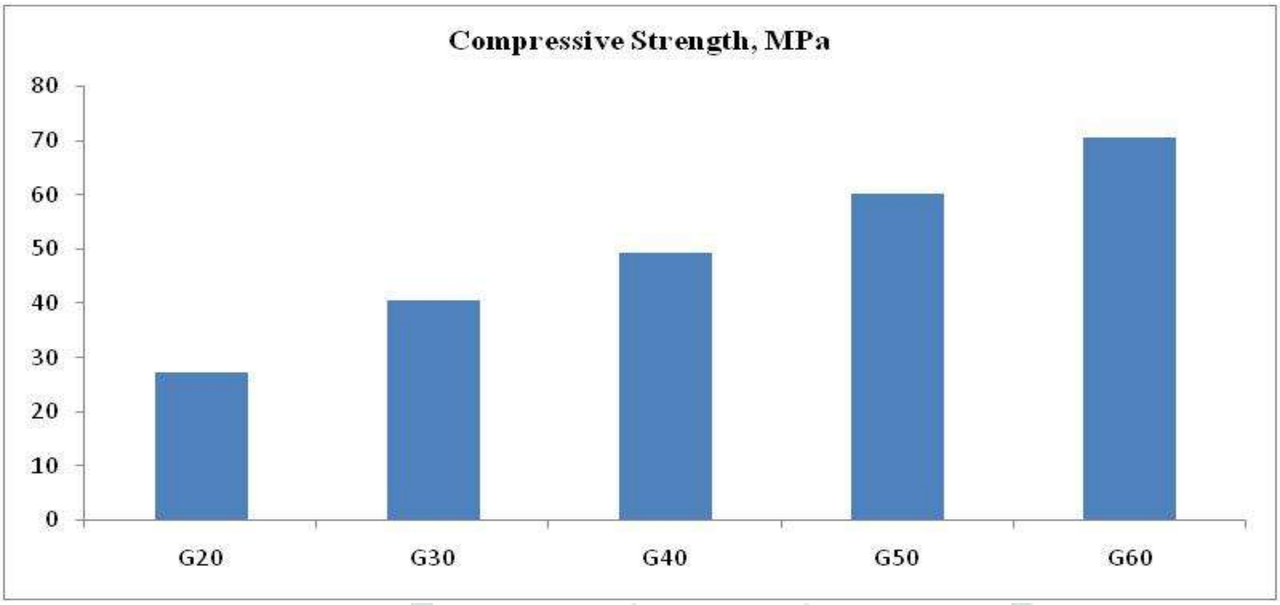

Figure 4 Experimental Target Compressive Strength v/s Designated Grade

The results of compressive strength results are close to target strength value of all the grades. The percentage error between target compressive strength and experimental compressive strength for different grades of Geopolymer concrete is within 6 % as shown in Table 3.

Table 3 Comparative Results of Theoretical and Experimental Compressive Strength

MIX-ID	Theoretical Target strength, f_{ck}	Experimental compressive strength , f_{ck}	% error
G20	26.6	27.3	2.5
G30	38.2	40.5	6.0
G40	48.2	49.3	2.1
G50	58.2	60.4	3.6
G60	68.2	70.8	3.6

(b) Flexural Strength

As depicted in Figure 5, flexural strength test results are found to increase with the grade of Geopolymer concrete.

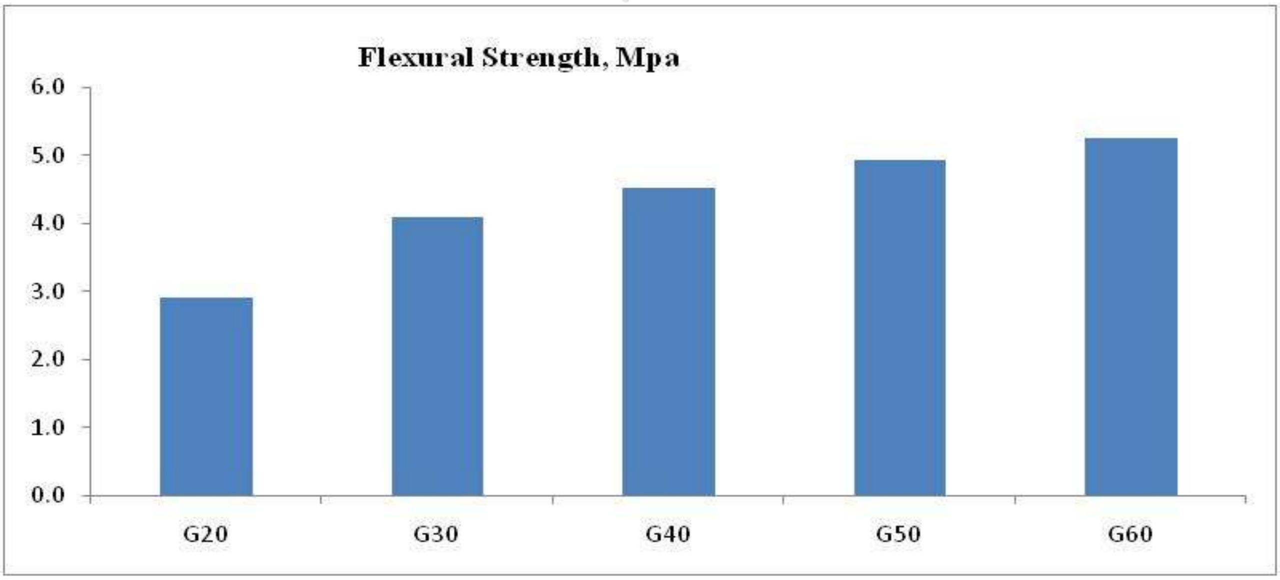

Figure 5 Experimental Flexural Strength v/s Designated Grade of GPC

Theoretical flexural strength for each grade of GPC is computed by using standard relation between compressive strength and flexural strength of concrete given in IS 456 and they are compared with the experimental test results. The percentage error between experimental and theoretical values are found to be in the range of -2.0 to +7.7 as shown in the Table 4.

Table 4 Comparative Results of Experimental and Theoretical Flexural Strength

MIX-ID	f_{ck}, MPa	Experimental flexural strength, f_t, MPa	Theoretical flexural strength, $ft=0.7\sqrt{f_{ck}}$	%error
G20	20	2.9	3.1	7.7
G30	30	4.1	3.8	-6.7
G40	40	4.5	4.4	-2.1
G50	50	4.9	4.9	0.0
G60	60	5.3	5.4	2.8

(c) Split Tensile Strength

Split tensile strength is calculated after testing cylinder specimens and the results are shown in Figure 6.Test results are increased from 2.5 to 4.8 MPa for G20 to G60 mixes.

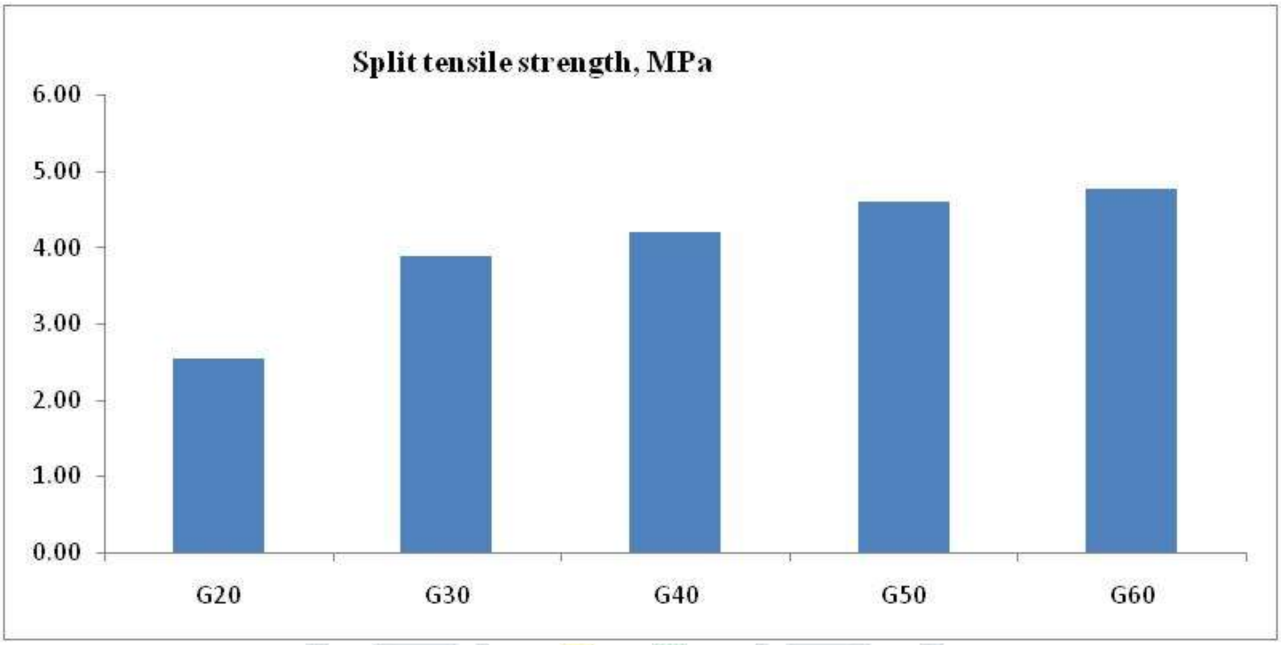

Figure 6 Experimental Split Tensile Strength v/s Designated Grade of GPC

(d) Modulus of Elasticity Results

Modulus of elasticity is evaluated after testing cylinder specimens and the results are shown in Figure 7.

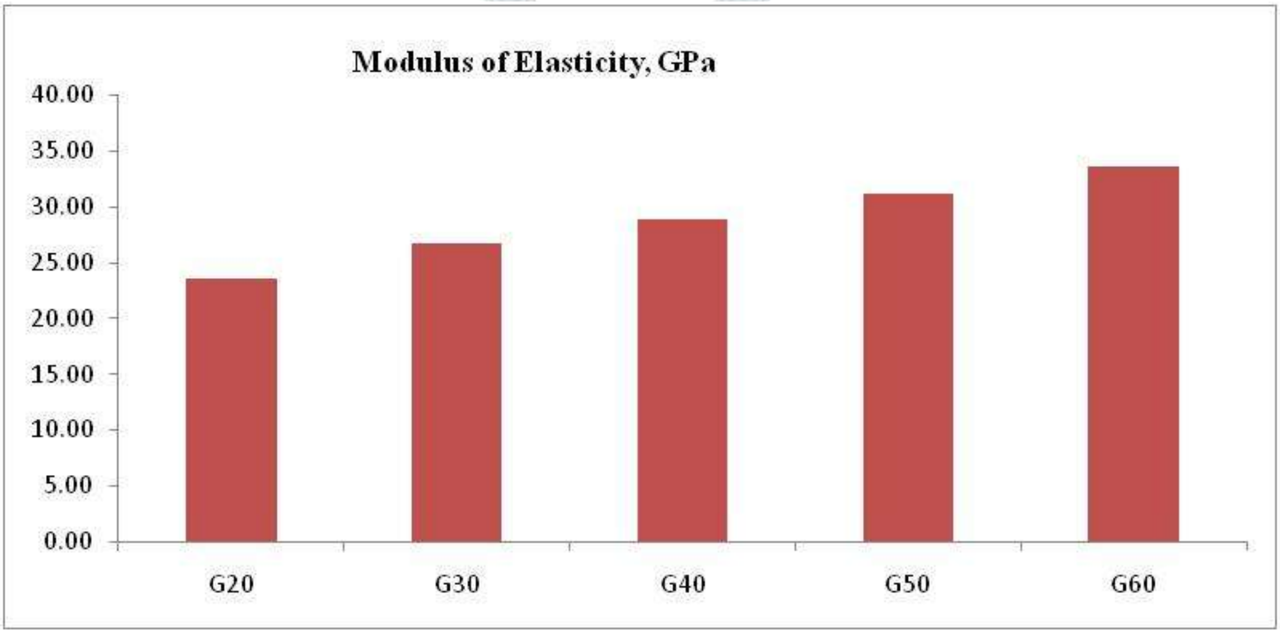

Figure 6 Experimental Modulus of Elasticity Values v/s Designated Grades of GPC

Experimental Modulus of elasticity results are compared with theoretical results by using relation between compressive strength and modulus of elasticity of concrete given in IS 456-2000 code. The percentage error between experimental and theoretical values of Modulus of elasticity is observed to be is in the range of -5% to +13%.

Table 5 Variation between experimental and theoretical modulus of elasticity results

MIX-ID	f_{ck}, MPa	Experimental modulus of elasticity, E_c, GPa	Theoretical modulus of elasticity, $E_c = 5000\sqrt{f_{ck}}$	%error
G20	20	23.6	22.3	-5.2
G30	30	26.7	27.3	2.5
G40	40	28.9	31.6	9.5
G50	50	31.2	35.3	13.2
G60	60	33.6	38.7	15.0

(e) Poisson's Ratio

For evaluating Poisson's ratio, two dial gauges are kept along longitudinal and lateral directions to observe both strains simultaneously and thus Poisson's ratio values are calculated. These experimental values for the corresponding designated grades of GPC are shown in Figure 7.

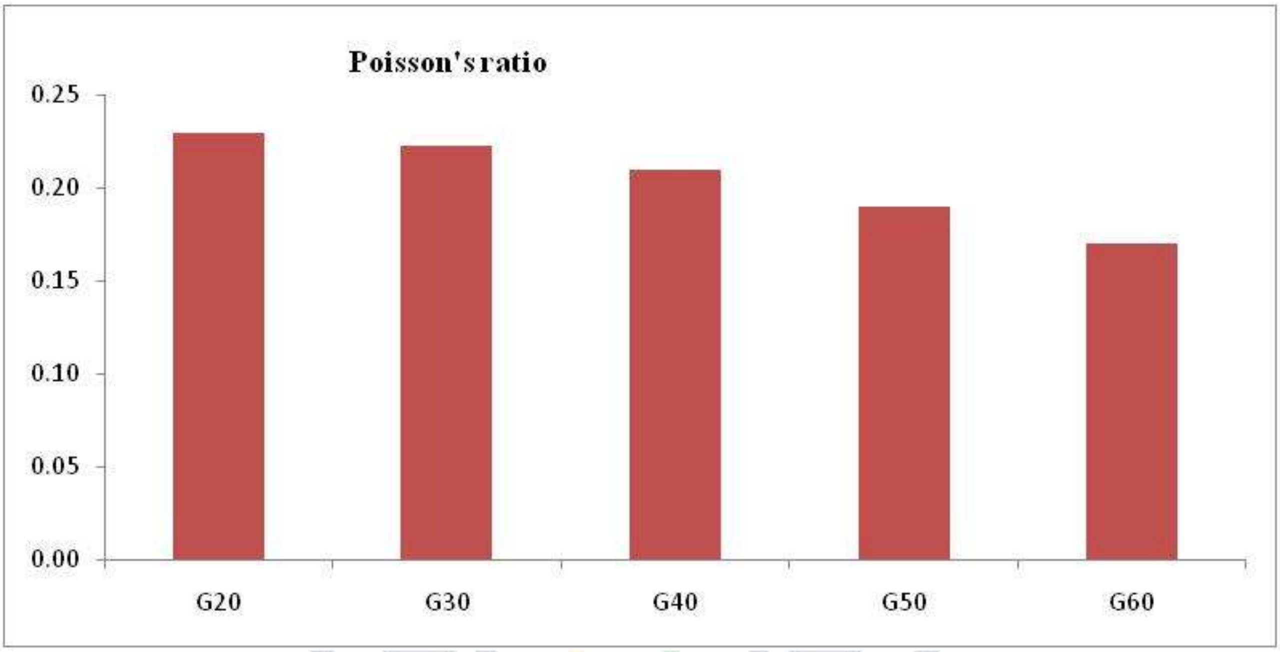

Figure 7 Experimental Poisson's Ratio values v/s Designated Grades of GPC

Poisson's ratio for normal concrete ranges from 0.15 to 0.2, whereas GPC shows slightly higher values from 0.17 to 0.23. This is because GPC shows slightly higher lateral strain values than OPC samples.

IV. Conclusions

Based on the experimental work carried out, the following conclusions are drawn:

- Compressive strength of GPC mixtures range from 27.3 to 70.8 MPa for G20 to G60 grades. Maximum percentage error between target strength and experimental compressive strength is 6%.
- While Flexural strength values for G20 to G60 grades of GPC range from 2.9 to 5.3 MPa, the maximum percentage error between theoretical and experimental results is 7%.
- Split tensile strength results range from 2.5 to 4.8 MPa for all five grades of GPC.
- Modulus of Elasticity values of GPC mixture vary from 23.5 to 33.6 GPa with maximum percentage error between theoretical and experimental results as 15%.
- Poisson's ratio values for GPC mixtures are slightly higher than OPC mixtures with maximum value of 0.23.
- The results of investigation are encouraging with GPC mixtures satisfying the relationships between key mechanical properties of conventional concrete given in IS 456. As the experimental results are within plus or minus 15% of error, the same relationship hold good for Geopolymer concrete mixtures.

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