Compressive Strength of Ternary Blended Geopolymer Concrete Composites

R.Kumutha*
Department of Civil Engineering, Sri Venkateswara College of Engineering, Sriperumbudur, Tamilnadu, India
K.Vijai
Department of Civil Engineering, St. Joseph's College of Engineering, OMR, Chennai, Tamilnadu, India
S.K.Vinu
Department of Civil Engineering, Sona College of Technology, Tamilnadu, India

**Corresponding Author: kumuthar@yahoo.co.in*

ABSTRACT: Use of industrial wastes as supplementary concreting materials in the manufacturing of concrete is very vital at present to obtain a sustainable environmental solution. Some of the commonly used pozzolanic materials are Fly ash, Ground Granulated Blast Furnace Slag (GGBS), Silica Fume and Rice Husk Ash (RHA) etc. In the present experimental investigation, the compressive strength property of ternary blended geopolymer concrete has been studied by considering Fly ash, Ground Granulated blast furnace slag (GGBS) and Rice Hush Ash (RHA) in various percentages as source materials for geopolymerisation. The source materials were activated with alkaline activators consisting of a combination of Sodium Hydroxide (NaOH) & Sodium Silicate (Na_2SiO_3) solutions with the concentration of NaOH being 10 molarity (10M). For various combinations of Fly ash, Rice Husk ash and GGBS the compressive strength for 7 days and 28 days were determined experimentally. From the test results, it has been found that as the GGBS content increases, the compressive strength of the concrete also increases whereas, as the content of RHA increases, the density and compressive strength of the concrete decreases. The optimum combination was found to be F_{60} G_{30} R_{10} and F_{70} G_{20} R_{10} for which the compressive strength of the concrete is 34.67 MPa and 24.87 MPa which can be used in applications where M30 and M20 grades of concrete are required. The density of F_{60} G_{30} R_{10} GPC is 2320 kg/m^3 which is lesser than conventional concrete. It is also found that usage of 90% of rice husk ash in geopolymer concrete is not at all effective. The obtained compressive strengths are in the range of 10 MPa to 34.0 MPa which depends on the ratio of GGBS to RHA. Proper consumption of the RHA contributes in solving the environmental pollution and also to improve the environmental friendliness of concrete to make it suitable as a green building material.

Keywords: Fly ash; Rice Hush ash; Geopolymer; Alkaline activator; Compressive Strength

1 INTRODUCTION

The rapid growth of the global urbanization and the use of cement products leads to environmental pollution. Geopolymer concreting is one of the methods of reduction of cement usage. The geopolymer concreting has lesser Carbon dioxide (CO_2) emissions when compared to conventional concreting. Due to huge demand for concrete as a construction material, the demand for Portland cement also increases substantially which leads to greater emissions of CO_2. Global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO_2) and among the greenhouse gases, CO_2 contributes about 65% of global warming. Cement industry is also contributing to CO_2 emissions because there is an estimate that the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere. Hence in order to preserve the global environment from the adverse impacts of cement production, development of new and alternate binders is essential to replace Ordinary Portland Cement. Use of geopolymer technology not only reduces the CO_2 emissions by the cement industries, but also makes use of the utilization of industrial wastes and or by-products of alumino-silicate composition to produce construction materials which are value added.

Rice is listed as one of the major crops in India and Rice husk is an agricultural residue got from the outer covering of rice grains during the process of milling. Rice is grown in more than a hundred countries, with a total harvested area of approximately 158 million hectares, thereby producing more than 700 million tons annually (470 million tons of milled rice). Nearly 640 million tons of rice are grown in Asia, representing 90% of global production. Rice husk contributes about 20% of the weight of rice. It contains about 50% cellulose, 25-30% lignin and 15- 20% of silica. Traditionally, rice husk has been considered a waste material and has generally been disposed of by dumping or burning, although some of the RHA has been used as a low-grade fuel.

Rice husk ash (RHA) is generated by burning rice husk. Cellulose and lignin are removed on burning leaving behind silica ash. Better quality of rice husk ash can be obtained due to the controlled temperature and environment of burning, as the particle size and specific surface area of rice hush ash are dependent on the conditions of burning. The controlled burning of the rice husk with an incinerating temperature between 550^0C and 700^0C for 1 hour transforms the silica content of the ash into amorphous phase and the reactivity of amorphous silica is directly proportional to the specific surface area of ash. The ash so produced is ground to required fineness and mixed with cement to produce blended cement. RHA utilization by the construction industry is not new. It is interesting to note that it is possible to obtain ashes rich in silica (in crystalline or glassy state) depending on the combustion conditions. In the glassy silica case, ash of highly pozzolanic nature could be obtained, which will be adequate for partial substitution of fly ash and Ground Granulated Blast Furnace Slag (GGBS)

Rice Husk Ash can be used as a replacement for concrete up to 15 to 25%. The compressive strength increases with increasing water - cement ratio for different percentages of RHA in concrete and higher substitution of Rice Husk Ash results in lower water absorption value. As the RHA content increases the workability decreases indicating lower slump values thereby consuming more water. The weight density of concrete reduces by 72 – 75% due to the addition of RHA and hence Rice Husk Ash concrete can be effectively used for the construction of structures where the self-weight of structure is of prime importance. The compressive strength increases with the addition of RHA and RHA has the potential to act as a mineral admixture, which increases the strength, workability and pozzolanic properties of concrete (Nagrale et al. 2012).

The results of durability performance of concrete were reported and the presence of RHA lowers initial surface absorption, permeability, and the absorption characteristics and increases the resistance of concrete to chloride ion penetration as compared to OPC. Concrete containing up to 30% RHA can attain strength of 30 N/ mm^2. Replacement of OPC with RHA in the concrete mixes resulted in lower workability, however, increasing the dosage of Superplasticizer by maintaining the water to binder ratio resulted in the increase of workability. The resistance to chloride ion penetration of concrete increases with incorporation of RHA. Concrete containing RHA with 20% replacement of cement shows that the impermeability was high, having about one-third of the permeability, while those made of 30% RHA and with inclusion of superplasticizer has one-eighth of the permeability value of the OPC concrete taken at 28 days. (Kartini et al 2010).

The effect of Rice Husk Ash on the properties of ordinary Portland cement and Portland slag cement with and without Super plasticizers has been studied. The cement was partially replaced by rice husk ash admixture with 5% 10% 15% of total powder content by weight with & without the super plasticizers. OPC with 10% replacement of RHA shows resistance to acid attack, alkaline attack and sulphate attack and shows increase in compressive strength as the age prolongs up to one year. Out of all the various combinations of both ordinary Portland cement and Portland slag cement with partial replacement by rice husk ash with superplasticizer and without superplasticizer the best one is OPC+10% Microsilica + Superplasticizer as it is showing resistance to acid attack, alkaline attack and sulphate attack and showing increase in the compressive strength as the age prolongs up to one year duration also (Damohara Reddy et al.2013).

The effect of burning temperature of rice husk, the RHA fineness and the ratio of Fly ash (FA) to RHA were studied and the density and strength of the geopolymer mortars with RHA/FA mass ratios of 0/100, 20/80, 40/60, and 60/40 were also tested. It is found that the optimum burning temperature of RHA for making FA-RHA geopolymer is 690°C. The Fly ash received as such and the ground RHA with 1%-5% retained on No.325 sieve is identified as suitable source materials for the making of geopolymer mortar, and the range of compressive strengths are between 12.5-56.0 MPa. The strength is dependent on the ratio of FA/RHA, the fineness of RHA, and the ratio of sodium silicate to NaOH. Relatively high strength mortars are obtained using a sodium silicate/NaOH mass ratio of 4.0, delay time before subjecting the samples to heat for 1 hour and heat curing at 60°C for 48 hours (Detphan and Chindaprasirt, 2009).

The effect of partial replacements of fly ash with rice husk ash on the properties of geopolymer concrete were studied and discussed. Mixes chosen for investigation were GPC-1, GPC-2, GPC-3, GPC-4, and GPC-5 containing respectively 0%, 5%, 10%, 15%, and 20% of Rice Husk Ash in place of fly ash. Parameters like alkaline liquid to source material ratio, molarity of NaOH solution, sodium silicate to sodium hydroxide ratio were kept at their optimum values of 0.45, 12M, and 2.5 respectively. Heat curing was adopted by dry oven curing for initial 24 hours at a specified temperature of 70°C, and then ambient exposure was given to the test specimens for 3, 7, 28, and 90 days respectively (Saraswati Verma and Mayank Kumar 2018).

The development of fly ash and microwave incinerated rice husk ash (MIRHA) blend as the source material for geopolymer concrete was studied through the observation of the hardened specimen strength. Curing temperature has significant effect on the compressive and bonding strength of the specimens. The elevated temperature facilitates the rapid dissolution of silicate monomer and oligomer from MIRHA surfaces, which aids the formation of supersaturated aluminosilicate solution in geopolymer system. It also helps in the refinement of pores structure by increasing the geopolymer gel growth, which is revealed by the consistent development of compressive strength of ambient-cured specimen in comparison to oven-cured specimen (Andri Kusbiantoro et al.2012).

12.5% of Rice Husk Ash by mass of cement can be added in concrete as the optimum dose to produce M_{20} grade of concrete especially when the husk is burnt under field condition to utilize the easily available and low-cost resources for the efficiency of concrete structure with respect to strength, durability and economy. So, the best optimum percentage of rice husk ash for field applications is 10% in order to achieve optimal strength and durability (Sudisht Mishra 2010).

The effect of average size of the particle of RHA and the percentage on the workability of concrete, fresh density, content of superplasticizer and the compressive strength were investigated and even though grinding of RHA resulted in the reduction of the average particle size, it was not the foremost factor that controls the surface area. RHA concrete provided improvement in strength for 10% replacement and up to 20% of cement can be effectively replaced with RHA without adversely affecting the strength (Ghassan Abood Habeeb and Hilmi Bin Mahmud 2010).

From the literature reviews, it can be understood that, rice husk ash can be added up to 10% in concrete as a partial replacement material for cement. Few researches claim that RHA can be added up to 30% in conventional cement concrete. As far as geopolymer concrete is concerned, fly ash & RHA and Fly ash & GGBS were used in different combinations and the properties of binary blended geopolymer concrete have been studied. In spite of many researches available on the mechanical and durability properties of geopolymer concrete utilizing fly ash & RHA and Fly ash and GGBS, very little knowledge is available about the properties of geopolymer concrete blended together using Fly ash, GGBS and RHA. Hence an attempt has been made in the present investigation to study the density and compressive strength properties of geopolymer concrete with Fly ash, RHA and GGBS.

2. EXPERİMENTAL PROGRAM

2.1 Materials Used

Fly ash (ASTM Class F) conforming to IS 3812-2003 and collected from Mettur Thermal Power Station, Salem, Tamilnadu, India was used as the source material to make geopolymer concrete. The chemical composition of fly ash is shown in the Table 1. The specific gravity of fly ash is 2.46. Ground Granulated Blast Furnace Slag (GGBS) is a byproduct which is obtained during the manufacturing process of pig iron in blast Furnace. This process produces a glassy, homogeneous, non-crystalline material that has cementitious properties. GGBS powder was collected from Quality Polytech, Mangalore, Karnataka suppliers in gunny bags. It is white in colour by appearance and the particles are spherical in shape. The specific gravity of GGBS is 3.11. The chemical composition of GGBS is tested and is given in Table 2 along with the requirements as per IS 12089:1987.

For this experimental work Rice Husk was obtained from a local rice mill in Salem, Tamilnadu, India and incinerated at 700°C in a microwave incinerator to obtain Rice Husk Ash. RHA was further ground in a ball mill for 1000 cycles to attain the required fineness. RHA is grey in colour and the specific gravity of RHA is 2.00. The oxide composition of RHA is given in Table 3.

Table 1. Chemical Composition of Fly Ash

S.No.	Parameters	Test result (% by Mass)	Requirements as per IS:3812-2003 (% by Mass)
1	Loss of Ignition	0.62	< 7.0
2	Silica SiO_2	55.99	> 35.0
3	Aluminum Oxide (Al_2O_3)	15.23	-
4	Iron Oxide (Fe_2O_3)	21.78	-
5	$SiO_2+Al_2O_3+Fe_2O_3$	93.00	Total > 70.0
6	Magnesium Oxide (MgO)	2.45	< 5.0
7	Calcium Oxide (CaO)	0.17	< 5.0

Table 2. Chemical Composition of GGBS

Parameters	Experimental Value (%)	Requirement as per IS 12089 - 1987
Silica SiO_2	41.24	CaO + MgO +Al_2O_3) / (SiO_2) > 1.0 = 1.188 >1.0
Calcium Oxide (CaO)	25.45	
Magnesium Oxide (MgO)	2.93	
Aluminum Oxide (Al_2O_3)	20.64	
Iron Oxide (Fe_2O_3)	7.28	-

Fine Aggregate (sand) used is clean dry river sand and the sand is sieved using 4.75 mm sieve to remove all the pebbles greater than 4.75 mm. Fine aggregate has a specific gravity of 2.47, bulk density of 1645 kg/m^3, and fineness modulus of 2.79 and conforms to grading zone II as per IS: 383:1970. Coarse aggregates of maximum size 20 mm and confirming to IS 383:1970 are used. Coarse aggregate has a specific gravity of 2.63, bulk density of 1660 kg/m^3 and fineness modulus of 6.50.

Distilled water was used for preparation of alkaline solution and to improve the workability of the concrete high performance Sulphonated Napthalene based super plasticizer was used. In this investigation, a combination of Sodium Hydroxide solution and Sodium silicate solution are used as alkaline activators for the activation of source materials. Sodium hydroxide is available commercially in flakes or pellets form and for the present study, commercial grade Sodium hydroxide flakes are used for the preparation of alkaline solution. Sodium silicate is available commercially in solution form and hence it is used as such for the preparation of alkaline solution. The concentration of NaOH is maintained as 10M throughout the study.

Table 3. Chemical Composition of RHA

S.No.	Parameters	Test result (% by Mass)
1	Loss of Ignition	3.73
2	Silica SiO_2	84.89
3	Aluminum Oxide (Al_2O_3)	4.68
4	Iron Oxide (Fe_2O_3)	0.73
5	Magnesium Oxide (MgO)	0.47
6	Calcium Oxide (CaO)	1.26
7	Potassium Oxide (K_2O)	Traces

2.2 Mix Design and Preparation of Geopolymer Concrete

In the design of concrete mix, total aggregates (Coarse and Fine) constitute about 75% to 80% of entire concrete mixture by mass. For the present study, in the design of geopolymer concrete mix, coarse aggregates and fine aggregates together were taken as 77% of entire mixture by mass among which fine aggregate was taken as 30% of the total aggregates. From the past research works, it is clear that the average density of fly ash based geopolymer concrete is similar to that of Ordinary Portland Cement concrete and it is about 2400 kg/m^3. From the density of concrete, the combined mass of cementitious materials and alkaline liquids can be determined. By assuming the ratios of alkaline liquid to cementitious materials as 0.4, mass of cementitious materials and mass of alkaline liquid was found out. To obtain mass of Sodium hydroxide and Sodium silicate solutions, the ratio of sodium silicate solution to sodium hydroxide solution was fixed as 2.5. Extra water (other than the water used for the preparation of alkaline solutions) and super plasticizer based on Sulphonated Naphthalene Polymers were added to the mix by 20% and 3% by weight of fly ash respectively, to achieve workable concrete. The mix ratio of geopolymer concrete is given in Table 4. Fly ash, GGBS and RHA are used in different combinations as given in Table 5. Totally 17 mixes were prepared. In Group 1 specimens, content of GGBS is kept as 10%, RHA is varied between to 10 % to 50% and the rest of the cementitious material is Fly ash. In Group 2 specimens, content of GGBS is kept as 20%, RHA is varied between to 10 % to 50% and the rest of the cementitious material is occupied by Fly ash. In Group 3 specimens, content of GGBS is kept as 30%, RHA is varied between to 10 % to 50% and the rest of the cementitious material is occupied by Fly ash. In addition to these three groups, two mixes were prepared, the first mix containing 90% Fly ash and 10% GGBS and the second mix containing 90% RHA and 10% GGBS.

Table 4. Mix Proportions of Geopolymer Concrete

Cementitious material (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	Super Plasticizer kg/m^3	Distilled Water kg/m^3
394.28	554.40	1293.60	45.06	112.65	0.138	0.69

To prepare 10 molarity concentration of sodium hydroxide solution, 400 grams of sodium hydroxide pellets is taken. That is 10 is multiplied by the molecular weight of sodium hydroxide (Molarity x Molecular Weight). The molecular weight of NaOH is 40 and hence the 400grams of sodium hydroxide is dissolved in distilled water to make it up to one liter. The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before mixing the concrete based on the assumed ratio of Na_2SiO_3 to NaOH to get the desired alkaline solution. The solid constituents of the Geopolymer Concrete mix i.e. fly ash, GGBS, Rice husk ash, fine aggregate, coarse aggregate, were dry mixed in the hand for about two minutes. After dry mixing, alkaline solution is added to the dry mix and wet mixing is done for another five minutes. Finally, extra water along with super plasticizer is added to get a workable GPC mix. After thorough mixing, concrete was poured into the moulds and compacted using a table vibrator to achieve the desired compaction.

Table 5. Ternary Blended Mixes for Geopolymer Concrete

Mix ID	Fly Ash kg/m^3	GGBS kg/m^3	RHA kg/m^3	Fine agg. kg/m^3	Coarse agg. kg/m^3	NaOH + Na_2SiO_3 kg/m^3
F_{90} G_{10}	354.85	35.48	-	554.29	1294.29	157.14
R_{90} G_{10}	-	39.43	354.85	554.29	1294.29	157.14
Group 1						
$F_{80}G_{10}$ R_{10}	315.42	39.43	39.43	554.29	1294.29	157.14
F_{70} G_{10} R_{20}	275.99	39.43	78.86	554.29	1294.29	157.14
F_{60} G_{10} R_{30}	236.57	39.43	118.29	554.29	1294.29	157.14
F_{50} G_{10} R_{40}	197.14	39.43	157.71	554.29	1294.29	157.14
F_{40} G_{10} R_{50}	157.71	39.43	197.14	554.29	1294.29	157.14
Group 2						
F_{70} G_{20} R_{10}	275.99	78.86	39.43	554.29	1294.29	157.14
F_{60} G_{20} R_{20}	236.57	78.86	78.86	554.29	1294.29	157.14
F_{50} G_{20} R_{30}	197.14	78.86	118.28	554.29	1294.29	157.14
F_{40} G_{20} R_{40}	157.71	78.86	157.71	554.29	1294.29	157.14
F_{30} G_{20} R_{50}	118.28	78.86	197.14	554.29	1294.29	157.14
Group 3						
F_{60} $G_{30}R_{10}$	236.57	118.28	39.43	554.29	1294.29	157.14
F_{50} $G_{30}R_{20}$	197.14	118.28	78.86	554.29	1294.29	157.14
F_{40} $G_{30}R_{30}$	157.71	118.28	118.28	554.29	1294.29	157.14
F_{30} $G_{30}R_{40}$	118.28	118.28	157.71	554.29	1294.29	157.14
F_{20} G_{30} R_{50}	78.86	118.28	197.14	554.29	1294.29	157.14

2.3 Preparation of specimens and test procedure

The size of the specimens for evaluating the compressive strength of concrete is 100 mm x 100 mm x 100 mm cubes. After demolding of the specimens, they were cured under ambient conditions in room temperature. Cubes were tested for their compressive strength in Compressive Testing Machine at 7 days and 28 days as per the teat procedure given in IS 516: 1959. In total 78 cubes were cast in which 51 cubes were cast for 28 days strength and 27 cubes were cast for 7 days strength as shown in Table 6. The cast specimens are shown in Figure 1. After curing for required days the top surface of the finished surface is placed facing towards us and then it is adjusted and placed on the Compressive Testing Machine for testing. The maximum load at which the concrete fails is noted. The compressive strength is determined by dividing the failure load by area of the concrete. The test is repeated for three specimens and the average compressive strength of blended geopolymer concrete in ambient curing was found out.

Table 6. Details of Specimens

S.No.	Mix ID	Number of Specimens	
		7 Days	28 Days
1.	F_{90} G_{10}	-	3
2.	R_{90} G_{10}	-	3
3.	F_{80} G_{10} R_{10}	3	3
4.	F_{70} G_{10} R_{20}	3	3
5.	F_{60} G_{10} R_{30}	3	3
6.	F_{50} G_{10} R_{40}	-	3
7.	F_{40} G_{10} R_{50}	-	3
8.	F_{70} G_{20} R_{10}	3	3
9.	F_{60} G_{20} R_{20}	3	3
10.	F_{50} G_{20} R_{30}	3	3
11.	F_{40} G_{20} R_{40}	-	3
12.	F_{30} G_{20} R_{50}	-	3
13.	F_{60} G_{30} R_{10}	3	3
14.	.F_{50} G_{30} R_{20}	3	3
15.	F_{40} G_{30} R_{30}	3	3
16.	F_{30} G_{30} R_{40}	-	3
17.	F_{20} G_{30} R_{50}	-	3
	Total	27	51

Figure 1 Cube Specimens

3. RESULTS AND DİSCUSSİON

3.1 Density

All the test specimens were weighed before subjecting them to compression test. The weight density was calculated by dividing the weight by the volume of the specimen. Density of ternary blended geopolymer concrete was found to be in the range of 2430 kg/m^3 to 2120 kg/m^3. The effect of addition of RHA on the density of geopolymer concrete is shown in Figure 2, Figure 3 and Figure 4. From the results it can be seen that addition of Rice Husk Ash reduces the density of concrete. As the RHA content increases, the density of geopolymer concrete decreases. This trend is same for all the GGBS contents of 10%, 20% and 20%. Specimens with 10% RHA have maximum density and specimens with 50% RHA have reduced density values.

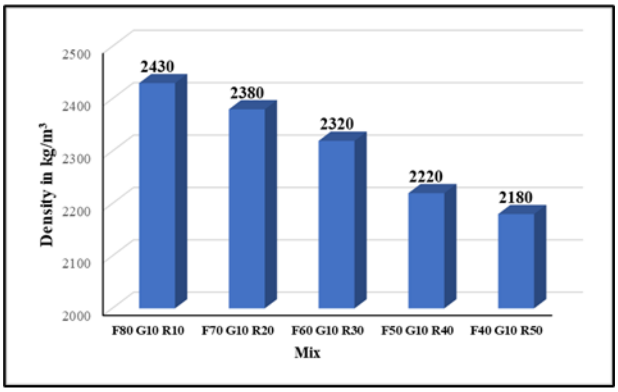

Figure 2 Effect of RHA on Density – 10% GGBS

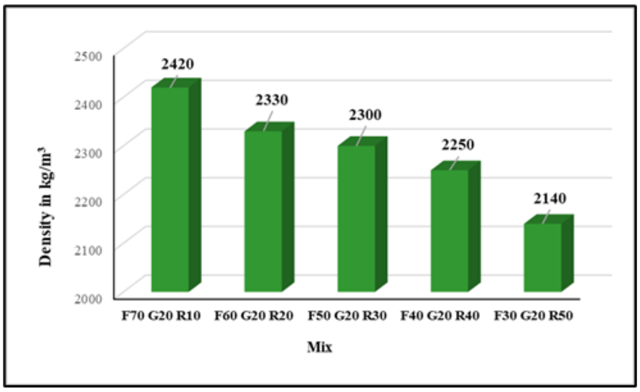

Figure 3 Effect of RHA on Density – 20% GGBS

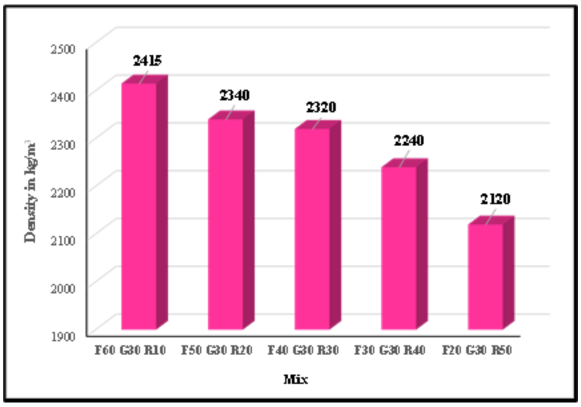

Figure 4 Effect of RHA on Density – 30% GGBS

Also, it is noted that, increasing the GGBS content from 10 % to 30% does not have the appreciable changes in the density of blended geopolymer concrete whereas for the same content of GGBS in the mix, density values decrease as the RHA content increases. The mixes which do have any compromise in strength can be effectively used for applications in light weight structures where the self-weight of the structure has to be reduced based on design considerations and requirements. Those mixes can also be recommended for precast applications wherein light weight components can be easily handled in prefabricated industrial units.

3.2 Effect of age on Compressive Strength

The test results of compressive strength at 7 and 28 days for all the specimens tested are given in Table 6 and Table 7 respectively. The effect of age on compressive strength is shown in Figure 5. For all the nine mixes tested at both 7 and 28 days, it was found that, as the age of the concrete increases, compressive strength also increases as expected. For specimens with 10% GGBS, 63%, 60% and 46% of the 28 days strength was achieved at 7 days itself for RHA contents of 10%, 20% and 30% respectively. For specimens with 20% GGBS, 65%, 41% and 48% of the 28 days strength was achieved at 7 days itself for RHA contents of 10%, 20% and 30% respectively. For specimens with 30% GGBS, 46%, 49% and 50% of the 28 days strength was achieved at 7 days itself for RHA contents of 10%, 20% and 30% respectively. Hence around 40 to 65% of 28 days compressive strength was attained at 7 days itself for the mixes tested.

Table 6. Compressive Strength – 7 Days

S.No	Mix ID	Compressive Strength in MPa			Avg. Strength (MPa)
		Spec.1	Spec.2	Spec.3	
1.	F_{80} G_{10} R_{10}	15.20	14.00	13.5	14.20
2.	F_{70} G_{10} R_{20}	8.60	8.50	8.40	8.50
3.	F_{60} G_{10} R_{30}	2.90	3.50	3.00	3.10
4.	F_{70} G_{20} R_{10}	16.30	16.0	16.20	16.20
5.	F_{60} G_{20} R_{20}	6.00	6.30	6.20	6.20
6.	F_{50} G_{20} R_{30}	4.90	4.50	4.80	4.70
7.	F_{60} G_{30} R_{10}	15.50	16.00	15.90	15.80
8.	F_{50} G_{30} R_{20}	10.20	11.50	11.00	10.90
9.	F_{40} G_{30} R_{30}	6.60	7.80	7.00	7.13

Table 7. Compressive Strength – 28 Days

S.No	Mix ID	Compressive Strength in MPa			Avg. Strength (MPa)
		Spec. 1	Spec. 2	Spec. 3	
1.	F90 G10	1.4	1.3	1.5	34.90
2.	R90 G10	35.8	35.0	34.0	1.4
3.	F_{80} G_{10} R_{10}	21.4	23.3	23.4	22.70
4.	F_{70} G_{10} R_{20}	14.0	14.6	13.6	14.10
5.	F_{60} G_{10} R_{30}	6.0	6.5	7.5	6.67
6.	F_{50} G_{10} R_{40}	3.53	3.63	3.45	3.54
7.	F_{40} G_{10} R_{50}	1.96	2.158	2.207	2.11
8.	F_{70} G_{20} R_{10}	25.0	25.9	23.7	24.87
9.	F_{60} G_{20} R_{20}	15.3	15.0	15.2	15.20
10.	F_{50} G_{20} R_{30}	10.9	9.0	9.50	9.80
11.	F_{40} G_{20} R_{40}	5.0	5.7	6.2	5.600
12.	F_{30} G_{20} R_{50}	3.3	3.5	3.2	3.300
13.	F_{60} G_{30} R_{10}	35.5	34.5	34.0	34.67
14.	F_{50} G_{30} R_{20}	22.2	22.7	22.5	22.47
15.	F_{40} G_{30} R_{30}	13.70	14.20	14.50	14.13

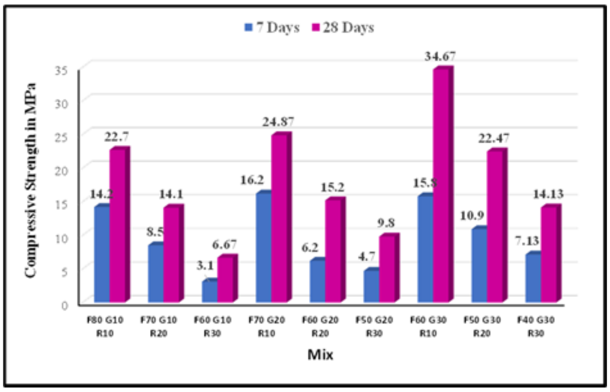

Figure 5 Effect of age on Compressive strength

3.3 Effect of GGBS and RHA contents on Compressive Strength

As mentioned earlier, two mixes were prepared one containing 90% Fly ash and 10% GGBS and the other mix containing 90% RHA and 10% GGBS in addition to the fifteen ternary blended mixes. The average 28 days compressive strength of geopolymer concrete with 90% fly ash and 10% GGBs is 34.90 MPa which is the maximum strength achieved among all the mixes investigated. On the other hand, average 28 days compressive strength of geopolymer concrete with 90% RHA and 10% GGBS is 1.4 MPa which is the least strength achieved among all the mixes which clearly reveals that maximum utilisation of RHA is not at all effective in the making of geopolymer concrete of desired strength. Effect of Fly ash, GGBS and RHA contents on the compressive strength of ternary blended geopolymer concrete mixes is shown in Figure 6. Specimens with 10% RHA exhibited a compressive strength of 22.7 MPa, 24.87 MPa and 34.67 MPa for percentage of GGBS being 10%, 20% and 30% respectively. As per Indian Standard Recommendations IS 456: 2000, the minimum grade of concrete shall not be less than M20 for reinforced concrete work. Hence geopolymer concrete produced with 10% RHA and varying percentages of GGBS can be used for practical applications in R.C.C works such as slabs, beams, columns, footings etc for mild exposure conditions as well as plain concrete works for severe and very severe exposure conditions.

Further when the content of RHA is increased to 20%, compressive strength values for GGBS contents of 10%, 20% and 30% are 14.1 MPa, 15.2 MPa and 22.47 MPa. Here the mix with only 30% GGBS is having a compressive strength greater than 20 MPa whereas mix with 20% GGBS is exhibiting nearly 15 MPa and the third mix with 10% GGBS is having a compressive strength less than 15 MPa. Hence the mix F60 G20 R20 can be used for Plain Cement Concrete (P.C.C) works for moderate exposure conditions and also for P.C.C works such as levelling course, bedding for footings etc. For specimens having more than 20% of RHA, the compressive strength is less than 15 MPa and the mixes with compressive strength up to 5 MPa can be used for P.C.C works.

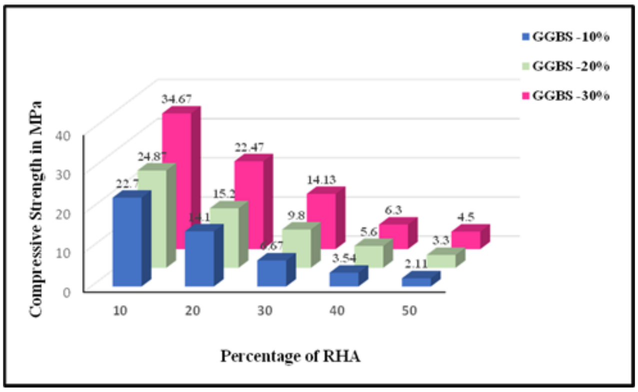

Figure 6 Effect of GGBS and RHA on Compressive strength

4. CONCLUSİONS

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

- The weight density of geopolymer concrete decreases as the RHA content increases. This is applicable for all the GGBS contents tested. GGBS content has no significant effect in the weight density of concrete.
- As the age of the concrete increases from 7 to 28 days, the compressive strength of ternary blended geopolymer concrete also increases.
- Geopolymer concrete with 90% Fly ash and 10% GGBS can be used for reinforced concrete works as it produces a compressive strength greater than 20 MPa.
- Geopolymer concrete with 90% RHA and 10% GGBS has a compressive strength of 1.4 MPa at 28 days and hence this mix cannot be used for practical applications
- Geopolymer concrete mixes with 10% RHA and varying percentages of GGBS can be used for practical applications in R.C.C works such as slabs, beams, columns, footings etc for mild exposure conditions as well as plain concrete works for severe and very severe exposure conditions.
- The mix F60 G20 R20 having 60% fly ash, 20% GGBS and 20% RHA can be used for Plain Cement Concrete (P.C.C) works for moderate exposure conditions and also for P.C.C works such as levelling course, bedding for footings etc.
- For Geopolymer concrete mixes having more than 20% of RHA, the compressive strength is less than 15 MPa and the mixes with compressive strength upto 5 MPa can be used for P.C.C works.
- As the present experimental study dealt with the study of ternary blended geopolymer concrete cured under ambient conditions, the future study can focus on the heat curing of concrete varying the type of curing like oven curing or steam curing, curing temperature and curing time in order to investigate the strength development of ternary blended geopolymer concrete with fly ash, GGBS and RHA on the above-mentioned conditions.

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