STUDIES ON THE BEHAVIOR OF COMPRESSIVE STRENGTH OF GEO-POLYMER CONCRETE USING RECYCLED AGGREGATES

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Abstract

Geopolymer is a material which can be made by the use of industrial waste products for the 100% replacement of cement. In this present article the experimental program consists of testing of natural and recycled coarse aggregates and hardened concrete specimens is been done. The aggregate tests mainly include specific gravity, water absorption, impact value test and crushing test. The hardened concrete test consists of testing compressive strength of $150 \times 150 \times 150$ mm concrete cube specimens at the age of 7 days and 28 days in accordance with the Indian standards. For consistency, the gradation of the recycled concrete aggregate was the same as that of the natural aggregate. At the beginning, the gradation of the natural aggregate was obtained by sieving as per standards. After crushing the hardened concrete, the recycled coarse aggregates were then sieved. The final gradation of the recycled aggregate matched that of the natural aggregates. The mix design will be carried out as per Indian standards. After the experimental work a comparative study of behavior of Geo-polymer and normal concrete with recycled aggregate has been done. Adopting normal mix design of conventional concrete to geo polymer concrete, the result of compressive strength of Geopolymer concrete is approximately 1.5 times higher than conventional concrete.

Key words: Geopolymer; Natural aggregate; Recycled aggregate (RA); Fly ash; GGBS;

I. INTRODUCTION

In recent years, due to the lot of demand for the production of cement many countries is generating enormous amount of carbon-dioxide waste due to the development in infrastructure which causes increase in global warming. Among the greenhouse gases, CO_2 contributes about 65% of global warming and the cement industry is responsible for about 6% of all CO_2 emissions because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere [1]. In this respect it is time to think whether it is possible to reduce the use of cement by replacing it by other industrial waste products for the reduction of emission of carbon dioxide. There is one such material which can be made by the use of industrial waste products for the 100% replacement of cement known as Geopolymer. Geopolymer binder is one such alternative material which is synthesized by mixing alumino silicate material and high alkali solution. Geopolymer utilizes an industrial waste which contains higher percentage of alumina and silica such as fly ash (FA), Ground granulated blast furnace slag (GGBS), metakolin as a binder in the complete replacement of cement to react with high Alkali solutions of sodium based. Here an alkali solution binds fine and coarse aggregates. Fly ash Geopolymer concrete have been studied by several researchers and were found to have high early strength, high later age strength, and excellent resistance to Sulfate and Acid attack [2,3].In Geopolymer concrete, the alumina present in the source materials are first induced by alkaline activators to form a gel. This Geopolymer gel binds the loose aggregates and other inert materials in the mixture to form the Geopolymer concrete. In this experimental work, Fly ash and Ground granulated blast furnace slag is used as the source material to make Geopolymer paste as the binder, to produce concrete. The manufacture of Geopolymer concrete is carried out using the usual mix design methods. As in the Portland cement concrete and also in fly ash-based Geopolymer concrete the aggregates occupy the largest volume of about 75-80% by mass. The silicon and the aluminum in the flyash and GGBS observations are activated by a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions. Geopolymer concrete also showed good properties such as high compressive strength, low creep, good acid resistance and low shrinkage.

Nowadays the use of recycled aggregate (RA) in concrete can be described in environmental protection and economical terms [4]. There is lot of research is going on about the use of recycling of old concrete for the construction. Recycling of old concrete will save the natural resources because the materials used for the concrete is naturally occurring and renewable sources of energy. Another important issue is the cost of materials is rising rapidly and becoming scare. So there is necessity to use the waste for the construction purposes. The use of recycled aggregate not only needed to fulfill the demand but also should be able to use for repairs and rehabilitation of structures which is constructed in previous decades. Much research has been done to use of recycled aggregate to normal concrete and it is found out that upto 30% replacement of natural aggregate [5]. An attempt has been done to replace coarse aggregates by recycled aggregates to some percentage in Geopolymer concrete to make this concrete still more economical[6-8].

In this present article the experimental program consists of testing of natural and recycled coarse aggregates and hardened concrete specimens is been done. The aggregate tests mainly include specific gravity, water absorption, impact value test and crushing test. The hardened concrete test consists of testing compressive strength of $150 \times 150 \times 150$ mm concrete cube specimens at the age of 7 days and 28 days in accordance with the Indian standards [9]. For consistency, the gradation of the recycled concrete aggregate was the same as that of the natural aggregate[10-12]. At the beginning, the gradation of the natural aggregate was obtained by sieving as per standards. After crushing the hardened concrete, the recycled coarse aggregates were then sieved. The final gradation of the recycled aggregate matched that of the natural aggregates. The mix design will be carried out as per Indian standards. After the experimental work a comparative study of behavior of Geo-polymer and normal concrete with recycled aggregate has been done.

II. EXPERIMENTAL DETAILS

A. Sample Preparations

For the preparation of mixes: water, cement, sand, natural aggregate, recycled aggregate, fly ash, GGBS, alkaline solution were used [8]. The majority of mixes, tap water has been used for mixing and curing of concrete. Effect of using distilled water for mixing is studied. However the results are compared with mixes using tap water. No much difference has been noticed in the performance of concrete. Aggregates used are mainly Sand. Good river bank sand in absence of any earthy matter and organic matter. Particles are angular in shape passing 250 micron and retaining 150 micron standard sieve. Sample is washed in water to get free from earthy and silty content and dried over a period of 48 hours in sunlight. The Specific gravity of the sample is 2.64, Sieve analysis is Zone I, Water absorption is 1.6. The coarse aggregate in the present investigation, both of natural and recycled the total coarse aggregate is divided into two fractions of practical size 20mm and particle size of size 12mm.

Table 1. Test Results of natural and recycled total coarse aggregate.

Sl.No.	Tests	20 mm	12 mm
1.	Specific gravity	2.71	2.69
2.	Aggregate impact strength	24.6	29.6
3.	Aggregate Crushing Value	27.2	33.2
4.	Flakiness Index	15.1	20.8
5.	Elongation Index	30.6	12.4
6.	Water Absorption	0.2	0.4

Recycling aggregate of concrete is obtained by simple process which involves breaking, removing, and crushing existing concrete into a material with a specified size and quality. The quality of concrete with RCA is very dependent on the quality of the recycled material used. Reinforcing steel and other embedded items, if any, must be removed, and care must be taken to prevent contamination by other materials that can be troublesome, such as asphalt, soil and clay balls, chlorides, glass, gypsum board, sealants, paper, plaster, wood, and roofing materials [13]. The Specific gravity of the materials is 2.69.The cement used is of 53Grade ordinary Portland cement is a higher strength cement to meet the needs (UltraTech, Grade of cement – 53 grade)

Table 2. Test Results of Cement

Sl. No.	Text conducted	Results Obtained	Required IS: 8112-1989
1.	Initial setting time	45 mints	30 minutes
2.	Final setting time	260 mints	600 minutes
3.	Standard consistency	30%	– –
4.	Specific gravity	3.10	3.15
5.	Compressive strength 7 days ++28 days	40 MPa 55 MPa	– –

The Fly ash procured from Udupi Power Corporation Limited UPCL having the specific gravity 2.1 and is of cream white color. The Ground Granulated Blast Furnace Slag Powder procured from Jindal steel works JSW having Specific gravity of 2.70.

B. Preparation of the alkaline solution

Alkaline solution is the combination of the sodium silicates and sodium hydroxide (97% purity). Sodium silicate solution is having chemical composition is Na_2O-13.72%, SiO_2-34.16% and H_2O-47.2% is used. The preparation of alkalinity solution of 10 molarity is done by adding 400 grams of NaOH pellets to the 1000 ml of water in standard flask and allows it to dissolve for half an hour. Further 2500 ml of sodium silicate is mixed with sodium hydroxide and kept it for 24 hours then it can be used preparation of geo – polymer concrete [14]. The prepared solution can be used after 24 hours and before 36 hours.

C. Mix design (Normal Concrete)

The mix design proportion is been taken from the according to IS 10262 standards. The mixes have been done by checking the mix design with absolute volume method. The 10 molarity of mix proportion is taken and the mixes procedure is done by mixing NAOH solution with sodium silicate solution prior to the addition of solid reactants (materials like Fly ash and GGBS) which can generate a homogeneous paste and also results in Geopolymer mixes with higher compressive strength. A machine trial mixer is used to mix the concrete ingredients [15]. The following step by-step procedure is used while mixing the ingredients for all the concrete mixes. Initially all the materials are been weighed according to the mix design of the IS standards. Dry mixing of the fine aggregate and coarse aggregate are dumped in the trial mixer. The mixer is been left to rotate for a period of 20 sec. Then cement, GGBS, Fly ash is been added to the mixer and been left for a period of 20 sec. Add the required amount of water the mixer and allow it for mix for a minute. After proper mixing of the materials the slump value is to be taken. Then the standard oiled molds are filled by prepared sample of concrete is filled in 3 layers by giving 35 blows for each layer and they are been kept for curing for 24hrs. The cured cubes are kept in water for curing of 7days and 28 days. After completion of the curing period the cubes is been tested and noted down the readings.

D. Mix proportions

Mix Proportions for Trials is done by using 394 kg / cum of cement, 1098 kg / cum Coarse Aggregate, 716 kg / cum of Fine Aggregate and 0.5 Water Cement Ratio. The proportion ratio is 1: 1.817: 2.786

Table 3. Materials for normal control mix

Sl.No.	Materials	Quantity Kg
1.	Cement	10.24
2.	Coarse	
	Aggregate	14.27
	20 mm	14.27
	12 mm	
3.	Fine	18.61
	Aggregate	
4.	Water	5.12 lts

Keeping coarse aggregate, Fine aggregates and water ratio constant quantity as taken for normal control mix, the samples were prepared by cement ratio replacing 50% by GGBS , other sample by 16% fly ash replacement and last sample by 30% fly ash replacement. Further many samples were prepared by 25%, 50% and 100% replacement of recycled aggregate.

E. Preparation of Geopolymer Concrete Mixes

The catalytic liquid was prepared by mixing the appropriate amount of NaOH solution and sodium silicate solution was taken in a glass beaker. Then Uniform amount of fine aggregates and coarse aggregates were added to the mixer. Proper mixing was done by adding of materials (Fly ash and GGBS) followed by catalytic liquid. After the thorough mixing of all the above ingredients, the slump value has been taken. Then the standard oiled molds are filled by prepared sample of concrete in 3 layers by giving 35 blows for each layer and then it is finished. The prepared cubes of size $150\ mm \times 150\ mm \times 150\ mm$ were kept for air curing until the cubes get hard. Then the cubes is been done water curing for a period of 7 days and 28 days. The cured cubes is been tested in the laboratory and the values is been noted. For preparing the mix proportions the amount of Alkaline Liquid taken is $0.58 \times 430 = 249.9$ kg/cum, Fly Ash in chart $= 430$ kg/cum, Coarse Aggregate $= 1087.6$ kg/cum, Fine Aggregate $= 725.1$ kg/cum. Samples were prepared by using control mix of Geo-polymer concrete using GGBS with 25% RCA, 50 percent replacement of RCA, 100 % replacement RCA, Fly ash and 25% replacement of RCA, Fly ash and 50% replacement RCA, Fly ash and 100% replacement of RCA. The specimens have to be kept in open condition in laboratory till demoulding and were followed with water curing till test. After specified curing period, the concrete cubes were subjected to compressive load using a 1000 T capacity compression testing machine. The load at failure was recorded and compressive strength is computed. The Compression test (IS: 516-1959) has been conducted on the prepared specimen.

III. RESULTS & DISCUSSION

A. Compressive strength behavior of control mixes

Test strength results of control mix for seven days were found to be 29.93 but for 28 days it was 41.47. Test results of control mix of GPC using GGBS for seven days are 43.54 and for 28 days it is 65.59. Test results of control mix of GPC using fly ash for 7 and 28 days is 32.97 and 48.63. Test results of control mix of GPC using GGBS + fly ash for 7 and 28 days are 34.17 and 51.46.

Thus In comparison with control mixes of normal and GPC mixes, results that control mix of GPC using GGBS yielded the highest strength where the replacement was 100 %. However the next highest strength that is control mix of GPC using both GGBS and fly ash in a ratio of 50: 50.Since GGBS got high efficiency over cementitious property than fly ash though indicated through compressive strength of geo-polymer concrete using recycled aggregates.

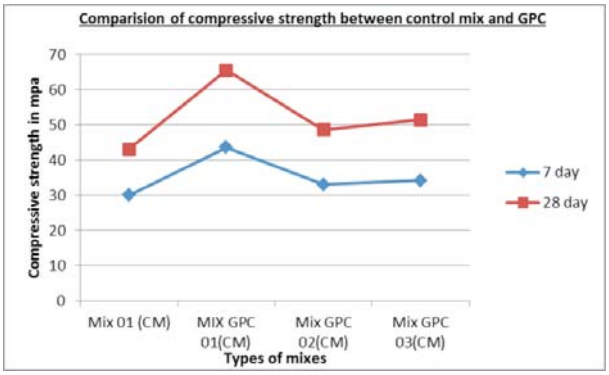

Fig 1. Behaviour of compressive strength verses different control mixes

B. Compressive strength behavior of % replacement of ggbs & fly ash in control mixes

Test strength results of normal mix using 50% GGBS for 7 and 28 days are 27.32 and 41.43.For normal mix using 16% fly ash is 26.03 and 42.53. Normal mix using 30% fly ash is 23.72 and 39.08 respectively for 7 and 28 days.

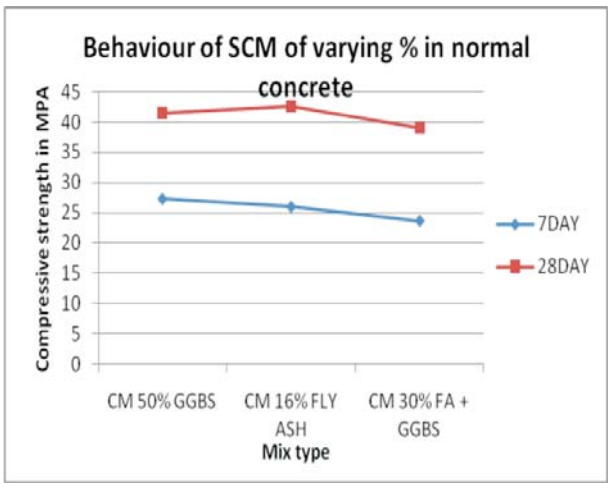

Fig 2. Behaviour of compressive strength verses different normal mixes of varying FA, GGBS

C. Compressive strength behavior of RCA % replacement in normal concrete mixes

The strength of normal mixes of 25% RCA replacement is 29.01 and 44.61, for 50% RCA replacement is 27.13 and 43.10, for 100% RCA replacement is 22.80 and 36.53 respectively for 7 and 28 days.

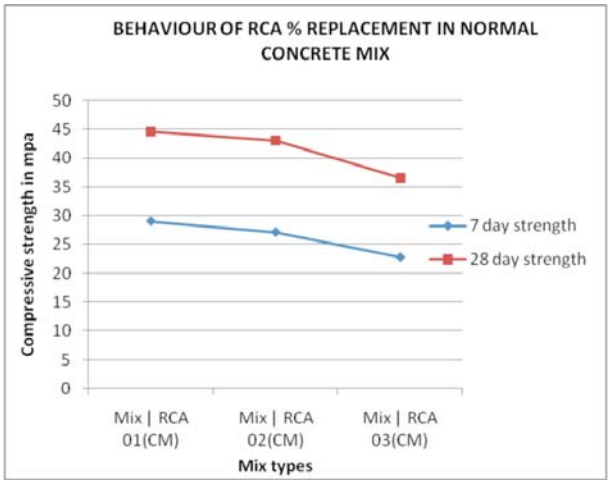

Fig 3. Behaviour of compressive strength verses different normal mixes RCA 25, 50,100% replacement in normal concrete mix

D. Compressive strength behavior of RCA % replacement in geo-polymer concrete (ggbs)

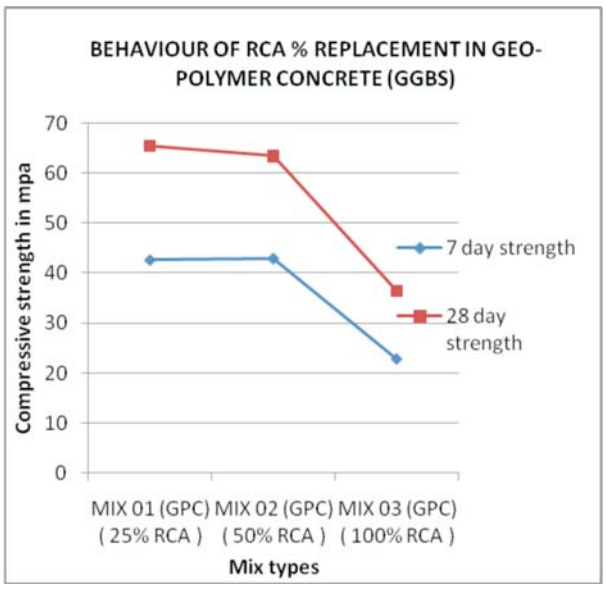

Fig 4. Behaviour of compressive strength verses different normal mixes RCA 25, 50,100% replacement in GPC mix

Test strength results of GPC mix with GGBS and 25% RCA replacement is 42.65 and 65.36, for GPC mix with GGBS and 50% RCA replacement is 42.94 and 63.36, for GPC mix with GGBS and 100% RCA replacement is 22.74 and 36.53 respectively for 7 and 28 days.

E. Compressive strength behavior of RCA % replacement in geo-polymer concrete (fly ash)

Test strength results of GPC mix with Fly ash and 25% RCA replacement is 33.59 and 47.43, for GPC mix with Fly ash and 50% RCA replacement is 31.67 and 44.30, for GPC mix with Fly ash and 100% RCA replacement is 26.27 and 35.30 respectively for 7 and 28 days.

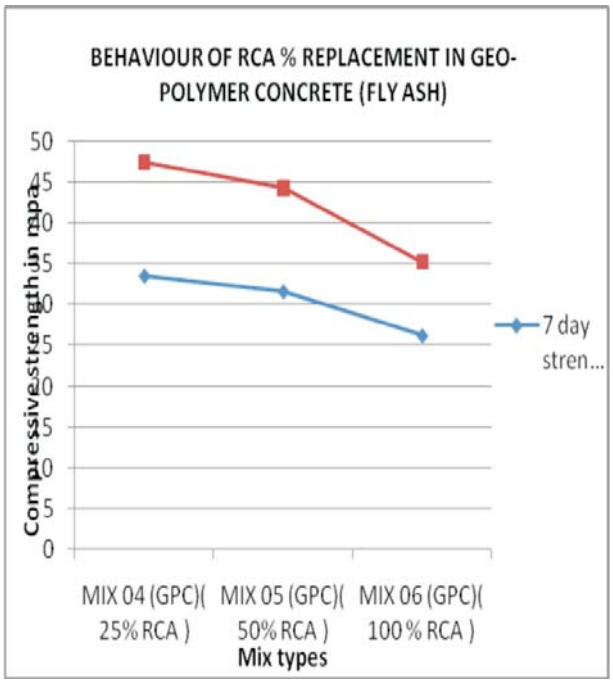

Fig. 5. Behavior of compressive strength verses different normal mixes RCA % replacement in Geo-polymer concrete (fly ash)

F. Compressive strength behavior of RCA % replacement in geo-polymer concrete (fly ash + ggbs)

Test strength results of GPC mix with GGBS + Fly ash and 25% RCA replacement is 32.45 and 50.87, for GPC mix with GGBS + Fly ash and 50% RCA replacement is 32.17 and 48.27, for GPC mix with GGBS + Fly ash and 100% RCA replacement is 27.27 and 38.23 respectively for 7 and 28 days.

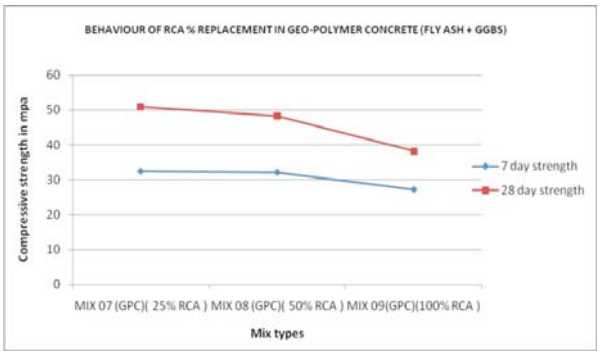

Fig 6. Behaviour of RCA % replacement in Geo-polymer concrete (fly ash + GGBS)

G. Overall comparison of strength of RCA in different per cent with control mixes types and GPC types

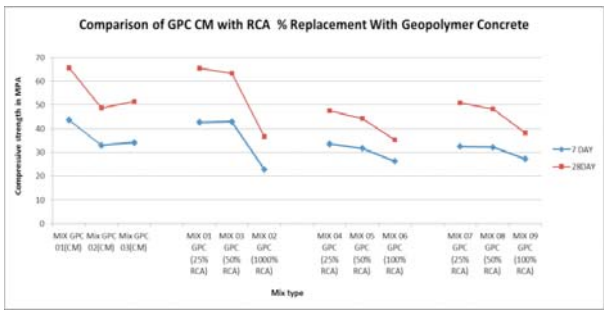

Fig 7. Graph of compressive strength of GPC (CM) with % RCA GPC mixes

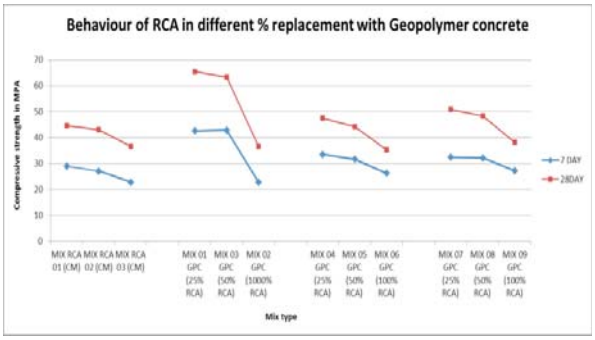

Fig 8. Graph of compressive strength of RCA in different per cent with control mix and GPC mixes

IV. CONCLUSION

A comparative study of behavior of Geo-polymer and normal concrete with recycled aggregate has been done and following conclusion is drawn out.

- Over all observation concludes that RCA replacement of 25% and 50% will not alter much of compressive strength although 100% replacement shows considerable changes in compressive strength. However GPC mix with GGBS replacement gains highest strength because of its rich cementitious property.
- In comparison with control mixes of normal and GPC mixes, results that control mix of GPC using GGBS yielded the highest strength where the replacement was 100 %. However the next highest strength that is control mix of GPC using both GGBS and fly ash in a ratio of 50: 50.Since GGBS got high efficiency over cementitious property than fly ash though indicated through compressive strength.
- Geopolymer concrete is done by utilizing the industrial waste such as fly ash and Ground granulated blast furnace slag. So use of waste and non-eco-friendly material can be made into useful end product
- The presence of alkali solution and finer particles of industrial wastes forms a good bonding when mixed together, which is the main reason for early strength.
- Adopting normal mix design of conventional concrete to geo polymer concrete, the result of compressive strength of Geopolymer concrete is approximately 1.5 times higher than conventional concrete.
- The use of recycled aggregates in Geopolymer concrete has proved that average of 25 to 50 percent of RCA replacement with NCA with any of cementitious material can produce a fairer and a consistent strength yielding factor in comparison with 100 percent NCA replaced concrete.

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