STUDIES ON MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE USING RECYCLED CONCRETE AGGREGATE

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ABSTRACT. The Geopolymer concrete is a useful invention in the world of concrete in which cement is totally replaced by pozzolanic material that is rich in silica and alumina and activated by alkaline liquid to act as binder in concrete by means of polymer chains. In addition to that, recycled concrete aggregates (RCA) are available abundantly, they are the waste materials that are not easily disposed and hence it is essential to make the efforts to utilize these by product in concrete manufacturing industry in order to make the concrete more environmental friendly. In the present study, the RCA is used as a partial replacement of natural coarse aggregate in Geopolymer concrete at 10%, 20% and 30% by weight. The class F fly ash is used as the source material for the geopolymer and 16 M sodium hydroxide and sodium silicate alkali activators are used to synthesise the fly ash Geopolymer. The mechanical properties of geopolymer concrete are measured in terms of compressive strength, split tensile strength and flexure strength measured at 7 and 28 days at 27˚C temperature. The compressive as well as split tensile strength is increasing upto 10% replacement of RCA. Also it is observed that for ambient curing condition, with 10% replacement of RCA the flexural strength shows good results as compare to compressive strength.

Keywords: Geopolymer concrete, Recycled concrete aggregate, Heat curing, Mechanical properties,

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INTRODUCTION

The amount of the CO_2 released during the manufacturing of OPC is nearly one ton for every ton of OPC produced and is responsible for approximately 7% of the world's carbon dioxide emissions. The fly ash replaces the use of Portland cement in concrete to make an environment friendly and waste material is reused. On the other hand, the abundant availability of fly ash worldwide creates opportunity to utilise this by-product as a substitute for OPC to manufacture concrete. It was observed that a research on low calcium fly ash based geopolymers has concluded better performance characteristics such as high strength, durability, excellent resistance against chloride attack, low environmental impact compare to Portland cement. It is further envisaged that the structural usage of geopolymer elements minimizes production cost and environmental pollution. To carry out the study of geopolymer concrete in a successful way, literature review reports from national and international journals have been referred. **Hardjito et al. [1-2]** found that geopolymer concrete has higher compressive strength and higher density of hardened concrete. The extended mixing time resulting in better polymerisation thus enhanced properties of hardened concrete. **Raijiwala et al. [3]** concluded that the properties of geopolymer Concrete (compressive strength, tensile strength, flexural strength) are better than other concrete except durability. Also, found that the compressive strength was 1.5 times more than control mix , split tensile 1.45 times , flexural 1.6 times , pull out 1.5 times than control mix. At 12 % molarity cost per m^3 reduces by 12% over controlled Concrete. **Davidoits [4]** concluded that the fresh geopolymer concrete is easily handled up to 120 min without any sign of setting and without any degradation in the compressive strength. The resistance of geopolymer concrete against sodium sulphate is excellent. **Jimene et al. [5] and Palomo et al. [6]** concluded that the curing temperature was a reaction accelerator in fly ash-based geopolymers, and significantly affected the mechanical strength, together with the curing time and the type of alkaline liquid. Also concluded that the type of alkaline liquid plays an important role in the polymerisation process. Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate, compared to the use of 14M hydroxides. The compressive and tensile strengths of geopolymer concrete are high and rapid strength gain and lower shrinkage, **[7-11]**. Durability aspects of geopolymer products include good sustainability to weathering effects, **[12-14]**. Several experimental studies showed that geopolymer concrete specimens immersed in sulphuric acid and caloric acid were found to be resistant to acid attack **[1-14]**. The gaps identified based on literature survey and it was observed that the properties of geopolymer concrete using recycled concrete aggregates at different curing temperatures have not yet been studied. In addition to recycled concrete aggregates chemicals variations in GPC concrete due to sodium hydroxide or potassium hydroxide has not been studied heretofore. From literature review it has been concluded that the strengthening properties of geopolymer concrete vary with proportion of alkali activator, water binder ratio, curing and fineness of fly ash. Hence present study is focused to utilize the waste material such as recycled concrete aggregates, fly ash in geopolymer concrete. The variation in the mechanical properties of geopolymer concrete on addition of recycled concrete aggregates with respect to variation curing time period is focused in Section 2 and 3. Also, the study includes the variation in the properties of geopolymer concrete using recycled concrete aggregates due to sodium hydroxide and sodium silicate.

MATERIALS AND METHODOLOGY

In this Section, there is an elaborate depiction of the materials which has been used in the experimental work. The method that has been adopted to carry out the work has also been described. The experimental program includes compressive strength test, split tensile strength test and durability tests and discussed here.

Fly ash

Class F Low calcium fly ash (**ASTM [15]**) collected from Ropar Thermal Power Station, India has been utilized. It was noticed that the fly ash contained a very low percentage of carbon as indicated by the low Loss on Ignition (LOI) values. The iron oxide (Fe_2O_3) content is relatively high. The silicon and aluminium oxides constitute 88.7% of the fly ash and the Si to Al molar ratio is 2.3 satisfying the basic requirements suggested by **[4]** for producing cement and concrete. Sieve analysis of fly ash reveals that 65% of particles are smaller than 45 micron. The specific gravity of fly ash using the density bottle test was found to be the 2.06.

Alkaline Liquids

Sodium hydroxide and sodium silicate is used for polymerization with fly ash to make binder. In this research Analytical Grade Sodium Hydroxide pellets were used with 98% to 100% purity dissolved in distilled water and Sodium Silicate Solution (Na_2O = 7.5-8.5% and SiO_2 = 25-28%.) were used as alkaline activator liquids. The sodium hydroxide is in pellet form and sodium silicate is in solution form. The alkaline solution is prepared by mixing both the sodium hydroxide and sodium silicate solution together. Sodium hydroxide pellets were dissolved in distilled water. Thereafter, some amount of heat is released due to the mixing. After cooling sodium hydroxide, sodium silicate mixed in it. The quantity of NaOH solids in a solution varies depending on the concentration of the solution is expressed in terms of molar, we have used 16M. The NaOH solution with a 16M contain 16x40 = 640 grams of NaOH solids pellet per litre of the solution, where 40 is the molecular weight of NaOH. The Sodium hydroxide was obtained from VEE ESS Corporation Pvt. Ltd.Chandigarh. The sodium hydroxide (NaOH) AR solution was prepared by dissolving pellets in distilled water. Sodium silicate solution (A53 grade) AR obtained VEE ESS corporation Pvt. Ltd. Chandigarh was used.

Fine Aggregates

Fine aggregate (sand): are those that pass through 4.75 mm sieve and are retained on the 75 μm sieve. Specific gravity and fineness modulus of fine aggregates were obtained through the experiments 2.6 and 3.32, respectively. The fine aggregates were tested as per IS: 383-1970 [16], the sieve analysis of fine aggregates shown in Table 1.

Table 1 Sieve analysis results of fine aggregate

WEIGHT OF SAMPLE TAKEN = 1000gm					
Sr. No	IS-Sieve (mm)	Wt. Retained (grams)	% retained	Cumulative % retained	% Passing
1	4.75	48	4.8	4.8	95.2
2	2.36	62	6.2	11	89
3	1.18	90	9.0	20	80

4	600µ	106	10.6	30.6	69.4
5	300µ	398	39.8	70.4	29.6
6	150µ	260	26.0	96.4	3.6
7	75µ	026	2.6	99	1
8	Pan	8	0.8	99.8	0.00
	Total	1000.00	100.0	332.2	

Coarse Aggregates

Coarse aggregate are those, retained on the 4.75 mm sieve and sieve analysis helps to find out size of aggregate and to determine the particle size distribution of coarse aggregates, see Table 2 and 3. The aggregates were tested as per IS: 383-1970 [16]. Specific gravity of coarse aggregates is was 2.74. Combination of two different aggregate 20mm & 10mm in the proportion 60% & 40% was used. These aggregate mixed together as per grading requirements to convert into the graded aggregate.

Table 2 Sieve analysis for 10mm aggregate

WEIGHT OF SAMPLE TAKEN = 1000gm					
Sr. No	IS-Sieve (mm)	Wt. Retained (grams)	% Retained	Cumulative % retained	% Passing
1	12.5	6	0.6	.6	99.4
2	10	168	16.8	17.4	82.6
3	4.75	632	63.2	80.6	19.4
4	2.36	186	18.6	99.2	.8
5	Pan	8	0.8	100.00	0.00
	Total	1000.00	100.0	297.8	

Table 3 Sieve analysis for (20 mm & 10 mm = 60:40)

WEIGHT OF SAMPLE TAKEN = 2000gm					
Sr. No	IS-Sieve (mm)	Wt. Retained (grams)	% Retained	Cumulative % retained	% Passing
1	20	000	000	0.00	100.00
2	12.5	1088	54.4	54.4	45.6
3	10	284	14.2	68.6	31.4
4	4.75	502	25.1	93.7	6.3
5	2.36	120	6	99.7	0.3
6	Pan	6	0.3	100.0	0.0
	Total	2000.00	100.0	382.4	

Experimental Work

The replacement of RCA was 10%, 20%, 30%. For testing the compressive strength of concrete, cubes of 150 mm X 150 mm X 150 mm dimensions were casted and tested. The compressive strength of concrete is measured at 7 and 28 days. Flexural Strength test was carried out by casting beams of size 100mm X 100mm X 500mm dimensions, testing was carried on 7, 28 days. Split tensile test was also carried out by casting cylinder of size 100 mm X 200mm and testing was carried out after 7, 28 days. The mix design was chosen from [17]. In the beginning, trial mixtures of geopolymer concrete were prepared, and the specimens were tested. The trial mixes were for several molarities, like 8M, 12M, and 16M at different curing temperature, 30°, 60°, 90° and 100°C. It was found that the trial mix of 16M at 90°C temperature achieved highest strength and there is no much appreciable increase at 100°C. However, in the present study, NaOH solution of 16 molarity was used and the tests were carried out on the specimens cured at ambient temperature due to less time. The ratio of fine aggregate to total aggregate was 0.35 and the ratio of sodium silicate to sodium hydroxide was 2.5. The final mixture of proportions adopted as shown in Table 4.

Table 4 Mix proportions

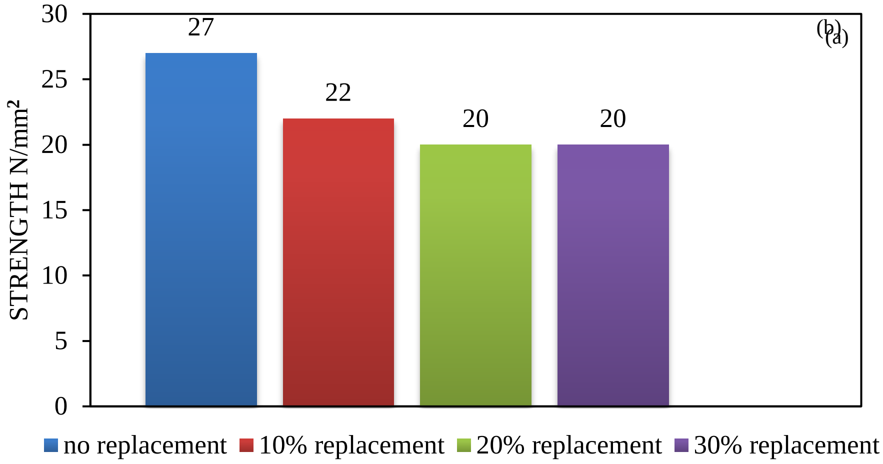
MATERIAL	0% REPLACEME-NT OF RCA	10% REPLACEMENT OF RCA	20% REPLACEMENT OF RCA	30% REPLACEMENT OF RCA
Fly ash	394.3	394.3	394.3	394.3
Sand	646.8	646.8	646.8	646.8
Natural aggregates	1201.2	1081.08	960.96	840.84
RCA	00	120.12	240.24	360.36
NaOH	45.06	45.06	45.06	45.06
Na_2SiO_3	112.64	112.64	112.64	112.64
Molarity	16	16	16	16
Ratio of mix Proportion	1:1.64:3.04	1:1.64:3.04	1:1.64:3.04	1:1.64:3.04
Liquid/ binder Ratio	0.40	0.40	0.40	0.40
Liquid/ binder Ratio	0.40	0.40	0.40	0.40

RESULTS AND DISCUSSION

In the present study, compressive strength, tensile strength and flexural strength were measured as per recommendation of IS codal recommendations. The results obtained in terms of mechanical properties of geopolymeric concrete after 7 and 28 days were compared each other and presented in this Section.

Compressive Strength

The compressive strength tests were carried out at 7 and 28 days curing period. The specimens of cubes were tested by compression testing machine shown in Fig 1(a)-(b). It is observed from Fig 1(a), the compressive strength of conventional geoplolymer concrete has been found to be maximum, and the compressive strength of 10% replacement of RCA was found to be decreased by 18% as compared to conventional concrete mix. Thereafter, the strength reduction was found to be insignificant as the increase of percentage of replacement of RCA. In case of compressive strength of conventional concrete at 28 days was found to be 25 MPa is almost equal to the compressive strength of 7 days, see Fig. 1(b) however, the target strength is 40 MPa and the reason for being low strength is due to high volume of the flyash in the mix. Also it was observed that at 28 days compressive strength was found to be increased 10 to 25% by 10 percent replacement of RCA. However, further increase in RCA upto 30/% is significantly affecting the compressive strength by same proportion. The reason may be due to the presence of porosity in large amount which leads to reduce the density of concrete and reduce the interfacial bonding behaviour due to existing mortar on the RCA. Overall, it is observed that the compressive strength of concrete was found to be achieved 65% of target mean strength at 7 and 28 days. Therefore, it is concluded that the 10% of RCA contribute much in the case of compressive strength of the concrete.



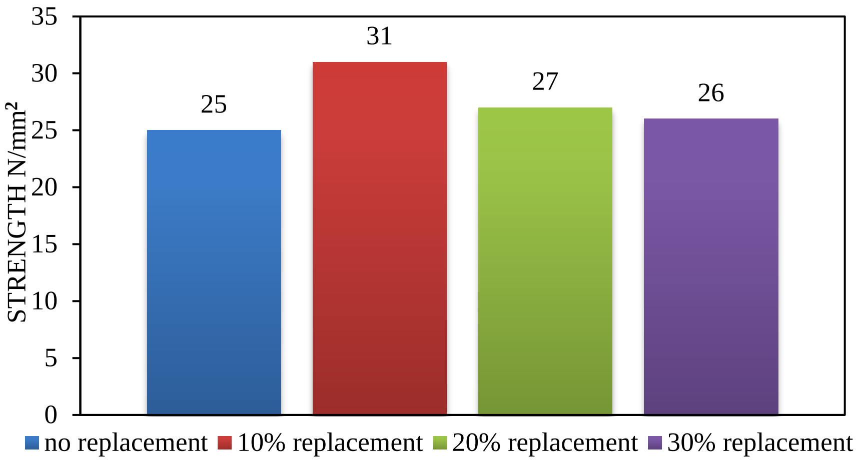
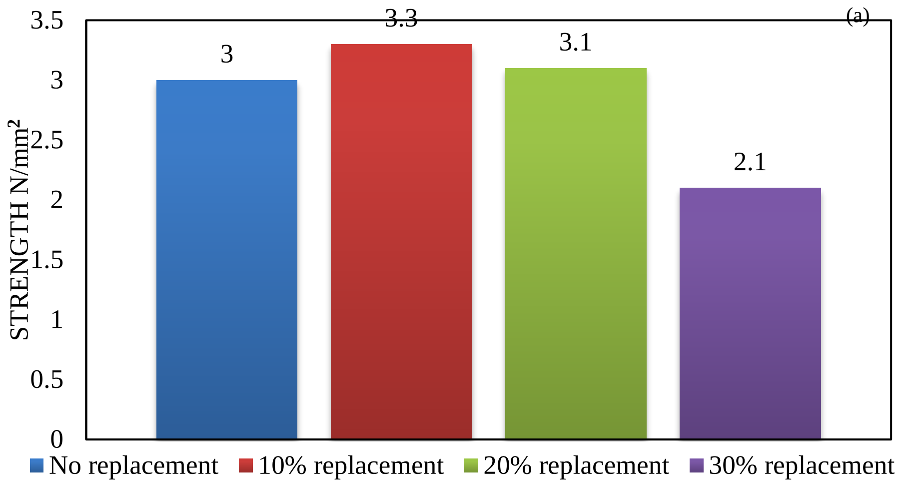


Figure 1 Compressive strength of concrete with different percent of RCA replacement at (a) 7 days and (b) 28 days

Split Tensile Strength

The split tensile strength of geopolymeric concrete different proportions of recycled concrete aggregate have been studied. The split tensile tests on cylinders were carried out at 7 and 28 days curing period. The specimens of cylinders were tested by compression testing machine shown in Fig 2(a)-(b). It is observed from Fig 2(a)-(b), the split tensile strength has been found to be increased considerably with increasing of RCA of 10% for both 7 and 28 days curing period. The split tensile strength of 10% RCA replacement has been found to be increased 11% as compared to conventional geopolymeric concrete. However the 30% RCA replacement geopolymeric concrete strength of was found to be decreased by 30% as compared to conventional geopolymeric concrete. Overall, it is observed that the split tensile strength of concrete was found to be decreased after 28 days except the mix 10% replacement of RCA. Therefore, it is concluded that the 10% RCA replacement in geopolymeric concrete shows significant improvement against the addition of varying percentage of RCA.



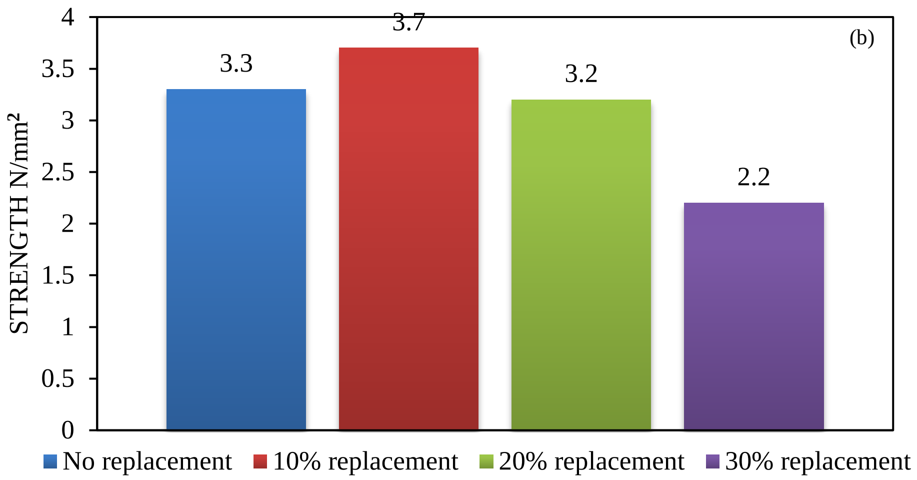
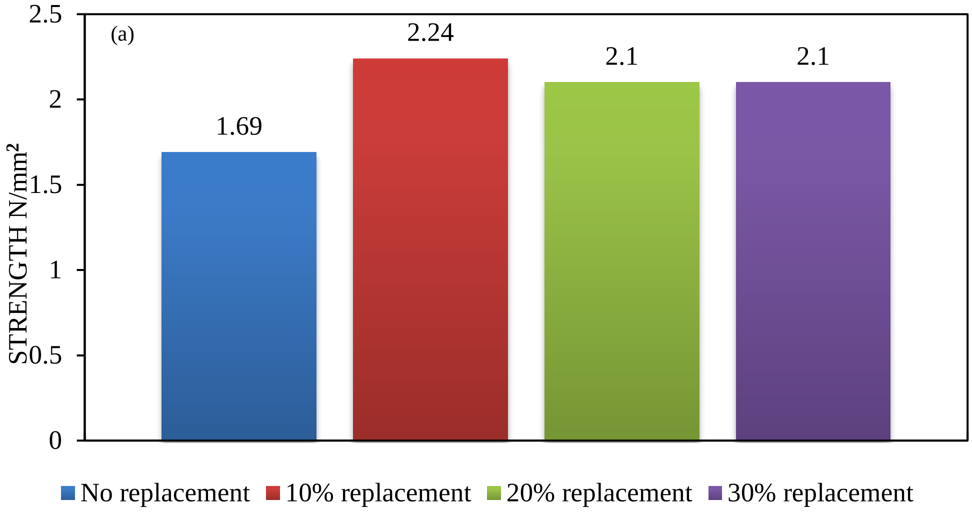


Figure 2 Split tensile strength of concrete with different percent of RCA replacement at (a) 7 days and (b) 28 days

Flexural Strength

The flexural strength of geopolymeric concrete containing different proportions of recycled concrete aggregate was studied. After casting the specimens were tested by Servo-controlled Actuator at 7 and 28 days of curing. The specimens of prisms were tested by compression testing machine shown in Fig 3(a)-(b). It is observed from Fig 3(a)-(b), the split tensile strength has been found to be increased considerably with increasing of RCA of 10% for both 7 and 28 days curing period. It has been observed that during same time period the flexural strength is increased upto 40% by 10 percent replacement of RCA at 7 days curing and same as in 28 days curing. It was also observed that flexural strength of conventional geopolymeric concrete found to be very good. It is clearly indicated by the test results that the behavior of geopolymer concrete is similar for both 7 and 28 days with respect to replacement of RCA. It is concluded that the 10% replacement of RCA by normal aggregates the flexural strength shows good results compare to other mixes.



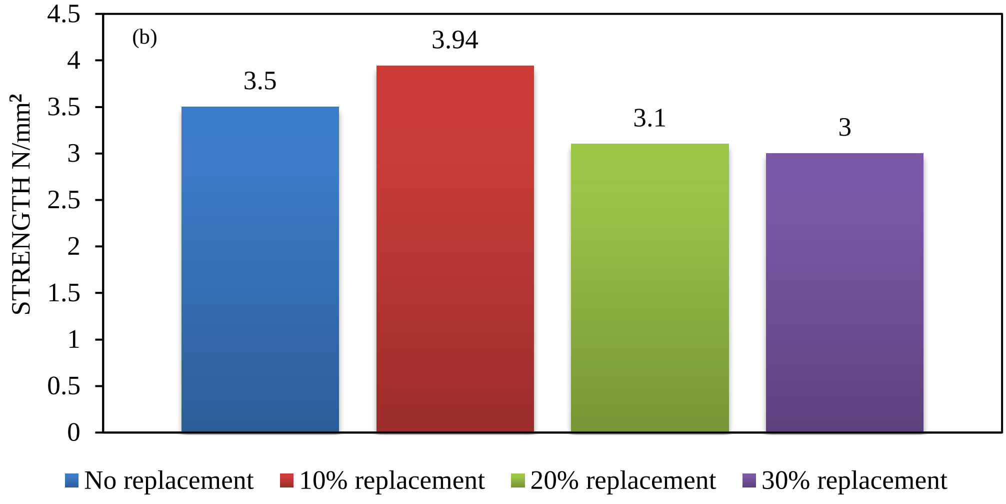


Figure 3 Flexural strength of concrete with different percent of RCA replacement at (a) 7 days and (b) 28 days

CONCLUDING REMARKS

The experimental investigations were carried out on geopolymeric concrete elements subjected to monotonic loading to study the influence of recycled concrete aggregate in terms of compressive, split tensile strength and flexural strength tests. Fly ash-based geopolymer concrete using RCA offers several economic benefits over Portland cement concrete and based on the results of the experimental investigation, following conclusions are drawn: -

- The compressive strength of Geopolymer concrete was found to be increasing with replacement of RCA. It is found that replacement of 10% of RCA gives highest compressive strength among the chosen mixes.
- In light of split tensile strength of concrete, it is concluded that the 10% RCA replacement in geopolymeric concrete shows significant improvement against the addition of varying percentage of RCA.
- The 10% replacement of RCA by normal aggregates the flexural strength shows good results compare to other mixes. Also it is observed that for ambient curing condition, with 10% replacement of RCA the flexural strength shows good results as compare to compressive strength.

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