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Research paper

Strength and Durability Studies on Geopolymer Recycled Aggregate Concrete

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Abstract

This paper aims to study the engineering and durability properties of fly ash-based geopolymer recycled aggregate concrete and the results were presented in this paper. The addition of recycled coarse aggregate (RCA) retrieved from construction and demolition(C&D) wastes showed promising function in construction industry as an alternative to natural aggregates. It conserves enormous quantities of natural resources and reduces the space required for the landfill disposal of C&D wastes. In this study an increment of 25% partial replacements by weight of natural aggregates with recycled aggregates in geopolymer concrete up to 100% replacements were studied. The concrete containing virgin aggregate and ordinary Portland cement was consider as control concrete and the results of geopolymer recycled aggregate concrete (GP-RAC) were compared with this. The fresh and mechanical properties of all the above four concrete mixes has been investigated. Results indicated that workability of geopolymer concrete decreases than control concrete and it took more than 24 hours to set. Geo polymer based recycled aggregate concrete exhibits better strength and durability performance than ordinary recycled aggregate concrete.

Keywords: *Geopolymer, fly ash, recycled coarse aggregate, recycled aggregate concrete, workability, strength and durability performance*.

1. Introduction

During the last few decades, Portland cement concrete has become the highest-volume of manufactured product in the world. These materials possess high reliable performance, low cost, versatility and widespread availability of raw materials. Presently the construction industry has been facing serious consequences as the concrete matrix materials are becoming threatening and unsustainable. Large amount of raw materials and energy is consumed for meeting this ever increasing demand .The aggregates and Portland cement production had more impact on the environment due to the depletion natural resources and emission of large amount of greenhouse gas into the atmosphere. The cement production contributes equal amount of CO_2 emission into the atmosphere. These leads to the increase in the demand on sustainable material and many researchers pay attention on identifying new materials for the sustainable development.

For the sustainable development, construction and demolition waste materials and industrial wastes were used in concrete. The reduction in workability with the increase in the recycled coarse aggregate has been very much avoided with the addition of chemical admixture and using saturated surface dry (SSD) aggregates [1, 2]. Geopolymer concrete has become the recent interest of civil engineers mainly due to their strength and durability properties and it reduced the CO_2 emission [3 - 7].

Fly ash have proved to be a promising source material in the manufacture of geopolymer concrete owing to their high silica and alumina content and also because of their fineness [8 - 10]. The nature of the material and the type of the liquid are responsible for the strength of the concrete. Hydroxides and Silicates of Sodium ($NaOH$, Na_2SiO_3) or Potassium (KOH, K_2SiO_3) were some of the commonly used alkaline activators. These solutions reacted with source material to form a gel which binds the aggregates in the concrete. The physical and durability properties of geopolymer concrete are better than OPC concrete containing same amount and type of RCA [11 - 16].

In this present investigation, the mechanical characteristics of Geopolymer based recycled aggregate concrete and its resistance against sorption characteristics to estimate its durability property was studied.

2. Materials and Methods

2.1. Materials

2.1.1 Coarse Aggregate

Coarse aggregates obtained from crushed granite of maximum size 20 mm were used in this study. Table 1 showed the properties of coarse aggregates.

2.1.2 Recycled Coarse Aggregate

The crushed recycled C&D wastes were used as coarse aggregates. The mortar present in the recycled coarse aggregate was removed to the possible extent by modified acid technique which involves soaking of recycled aggregate in sulphuric acid solution for 24 hours [17]. In this process the mortar gets detached from the aggregate and the detached mortar was removed completely by sieving it in 4.75 mm sieve and the aggregates were thoroughly washed and dried

(Figure 1). Table 1 showed the properties of recycled coarse aggregates.

Table 1: Properties of Crushed Granite Aggregates and Recycled Aggregates

S.No.	Property	Values	
		Crushed Granite Aggregates	Recycled Aggregates
1	Specific Gravity	2.74	2.54
2	Fineness modulus	7.4	7.1
3	Water Absorption (%)	1.5	6.5
4	Crushing strength (%)	20.5	33
5	Impact strength (%)	17	20.5
6	Abrasion resistance (%)	24	48

Fig. 1: Recycled Coarse Aggregate

2.1.3. Fine aggregate

Locally available river sand having a fineness modulus of 2.75, specific gravity of 2.81 and conforming to grading zone-III as per Indian Standards IS: 383 – 1970 [18] was used. Bulk density of the fine aggregate is 1693 kg/m^3.

2.1.4 Ordinary Portland cement (OPC)

Ordinary Portland Cement with specific gravity 3.15 was used in this study. Table 2 showed the chemical composition of the cement.

2.1.5 Fly ash

Fly ash is considered as the main constituent of the binding material in geopolymer concrete. Class F dry fly ash conforming to IS 3812-2003 [19] was used for mix preperation. The chemical composition of cement and flyash were shown in Table 2.

Table 2: Chemical Composition of Cement and Fly Ash

Description	SiO_2	Al_2O_3	CaO	Fe_2O_3	Na_2O	MgO	K_2O	SO_3	Cl	TiO_2	Sp.gravity
Cement %	24.5	7	63	0.55	0.4	2	0.6	1.5	0.05	-	3.15
Fly ash %	56.6	33.71	1.07	3.97	0.16	0.42	1.02	0.18	0.03	2.1	2.45

2.2 Alkaline solution

From the past studies it was clear that the activation of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions leads to the high strength of concrete mix. In the present experimental work, a combination of hydroxide and silicate of sodium with molarity 8M was chosen as the alkaline liquid. To prepare the alkaline activator 97% pure Sodium hydroxide solids in the form of flakes and Sodium silicate in the form of solution were used in this study.

2.3 Super Plastisizer

To enhance the workability of the geopolymer concrete, High Range Water Reducing (HRWR) super plasticizer was used. Use of super plastisizer also reduces the early setting time of the concrete which in turn improve the mechanical behaviour of GPC. A polymer-based super-plasticizer Conplast X421IC was acquired in this work.

2.4 Mix proportion

Concrete mix design process was generally based on performance criteria. For mix design, the mass of combined aggregates constitutes 76% of the mass of geopolymer concrete. For studying the fresh and hardened concrete properties, the compressive strength and workability were selected as the performance criteria. It was observed from the past studies made by researchers that the fly ash-based geopolymer concrete had also an average density of 2400 kg/m^3 as like OPC concrete. The quantity of flyash and alkaline liquid were found out by assuming the alkaline liquid to flyash ratio as 0.4. It was understood that from the literatures the sodium hydroxide solution must be prepared a day prior to use and also that if it exceeds 36 hours it transforms to semi solid liquid state. The recycled coarse aggregate were prewetted and saturated to satisfy the surface saturated condition. Laboratory experience suggested that the ratio of sodium silicate solution-to-sodium hydroxide solution was taken as 2.5 by mass. The sodium hydroxide solids (NaOH) which was 97-98% purity were mixed with water to make a solution with a concentration of 8 Molar. This solution comprises 30.2% of NaOH solids and 69.8% water, by mass. To achieve the workable concrete, 2% of super plasticizer was used in the mix. Table 3 showed the mix proportion for all Geopolymer recycled aggregate concrete mixes and control mix.

The fine aggregate, coarse aggregate and fly ash were mixed in dry condition for 4 to 5 minutes and then the alkaline activator solution was added to the dry mix. Water was taken as 10 % of the cementitious material (flyash). Through mixing was done for proper bonding for a period of 6 to 8 minutes. After the mixing was done, specimens were cast by giving proper compaction. After 28 days of curing, the specimens were kept in room temperature for 4-5 hours to remove the surface wetness. Then the specimens were tested to determine the strength by compression and split tensile test.

Table 3: Concrete Mix Proportion

Mix Series	OPC	GPC	GPC25	GPC50	GOC100
RCA replacement %	0	0	25	50	100
NCA (kg/m^3)	1172	1294	971	647	0
RCA replacement %	0	0	323	647	1294
Fine aggregate (kg/m^3)	693	554	554	554	554
Cement(kg/m^3)	425	---	---	---	---
Fly ash (kg/m^3)	---	394	394	394	394
Sodium silicate	---	113	113	113	113
Sodium hydroxide 8M	---	45	45	45	45

2.5 Testing mechanism

As per ASTM C143/C143M [20] the workability of the mixes were evaluated from the slump cone test. The consistency of fresh concrete was also accessed from this test. Super plasticizers of 2% by weight were added to increase the workability. The compressive strength and were determined using cube specimens of size 150 mm*150mm*150mm and splitting tensile strength was obtained from the cylindrical specimen of diameter 150mm and 300 height as per ASTM C496/C496 M [21].

The 100mm x 50mm Cylinder specimens were subjected to sorptivity test to ensure and verify their working life and the results were recorded. The samples were preconditioned by drying the sample for 7 days in a 50^0C oven and then allowed to cool in a sealed container for three days. The sides of the concrete sample were sealed, to avoid water penetration through the sides with insulation tape. Before testing the mass of the sample was measured and it was immersed in the to a depth of one fifth to one tenth of its height in the water. At selected time interval (typically 1, 2, 4, 9, 16, 25, 30 minutes) the samples were removed from water, and the excess water was wiped off with a towel and weighed. The gain in mass per unit area over the density of water was plotted versus the square root of the elapsed time. The slope of the line of best fit of these points (ignoring the origin) was reported as the sorptivity.

3. Results and Discussions

3.1 Workability

With the increase in the RCA volume the workability of concrete was reduced. The volume of voids increased with increase in the RCA volume which leads to the reduction in the workability [23]. Superplasticizer played an vital role in the workability property. The superplastizer improves the workability and decrease in the percentage reduction of slump with increased RCA content. Workability of geopolymer concrete was lesser than the control concrete and it took more than 24 hours to set. Superplasticizer addition and saturated surface dry state aggregates in concrete helped to achieved the slump value ranges from 75mm to 100mm for all mixes.

3.2. Mechanical property

3.2.1 Compressive Strength

Compressive strength of geopolymer concrete cubes were cast with and without recycled aggregates and tested at the age of 7, 14 and 28 days to study the effect of various percentage replacement of recycled aggregate on geopolymer concrete. From the experimental results it was understood that the compressive strength of the concrete gets decreased with the increase in the percentage replacement of recycled coarse aggregate. When age increases, the strength of the concrete gets increased irrespective of all mix combinations. The Figure 2 showed the specimen casting and testing. The strength variation of the geopolymer recycled concrete was shown in Figure 3. For control specimen at the age of 28 days the strength of the concrete was 47.46 MPa but for geopolymer concrete it was decreased by 3%. For 25%, 50% and 100% recycled Coarse aggregate geopolymer concrete the decrement was 18%, 24% and 31% respectively. The fall in the strength of RCA Geopolymer concrete was because of the adhered mortar present in the recycled aggregate. The strength improvement of control concrete was found as 31% from 7 to 28 days whereas for geopolymer concrete it was noticed as 11%. In geopolymer concrete most of the geo-polymerisation reaction happens within the first few days of the curing [12, 24, 25]. The strength attainment was further accelerated in geopolymer concrete with 25%, 50% and 100% RCA the strength increment was found 8%, 6% and 5% respectively from 7 to 28 days. When compare to the earlier studies made on RAC by the authors [26] the reduction in strength was reduced to an extent of approximately 5% in Geopolymer recycled aggregate concrete.

Fig. 2: Casting and Testing of Cube Specimens

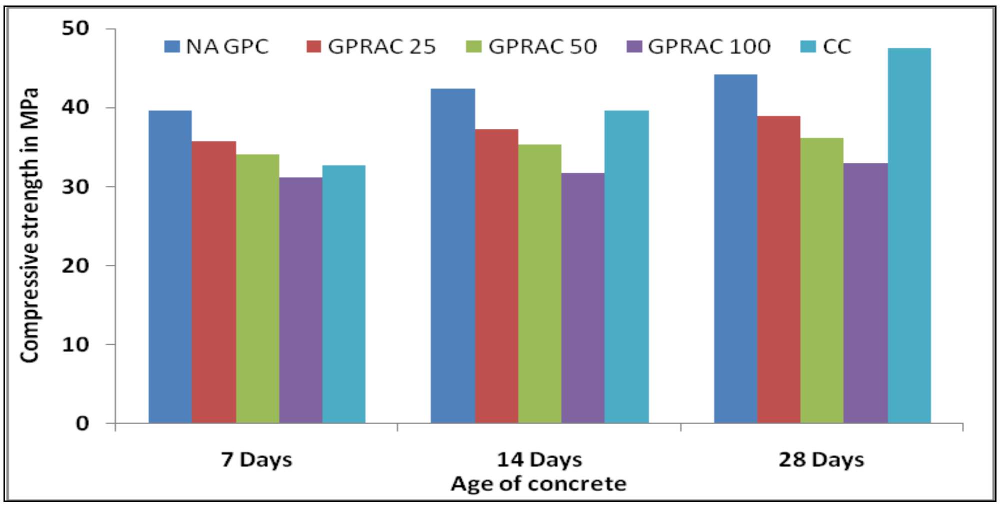

Fig 3. Compressive Strength of Concrete Mixes

3.2.2 Split tensile strength

Split tensile strengths for various mixes were obtained from the cylinder specimens at the age of 7, 14 and 28 days under ambient curing temperature with various replacement percentage of RCA was shown in Figure 4. A similar trend like compressive strength was also observed in case of the split tensile strength (Figure 5). The split tensile strength of the geopolymer concrete was decreased with the increase in the percentage replacement of recycled aggregate. When age increases, the tensile strength of the concrete gets increased irrespective of all mix combinations. For control specimen at the age of 28 days the tensile strength of the concrete was 3.6 MPa which was 13% greater than geopolymer concrete with virgin coarse aggregates. For 25%, 50% and 100% recycled aggregate geopolymer concrete the decrement was 16%, 24% and 30% respectively.

Fig. 4: Casting and Testing of Cylinder Specimens

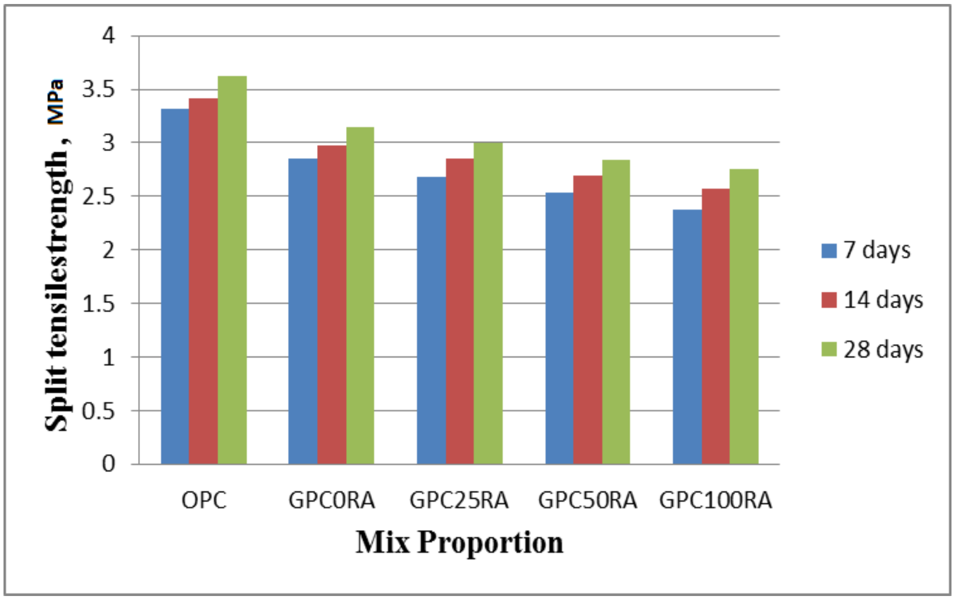

Fig. 5: Split Tensile Strength for Concrete Mixes

3.3 Durability property

3.3.1 Sorptivity test

The effect of RCA on the rate of capillary water absorption of geopolymer concrete containing different RCA contents was reported in Figure 6. From the experimental results it was found that, the water absorption of geopolymer concrete containing RCA increases with increase in RCA contents, with about 15%, 35% and 70% more water absorption at RCA content of 25%, 50% and 100%.

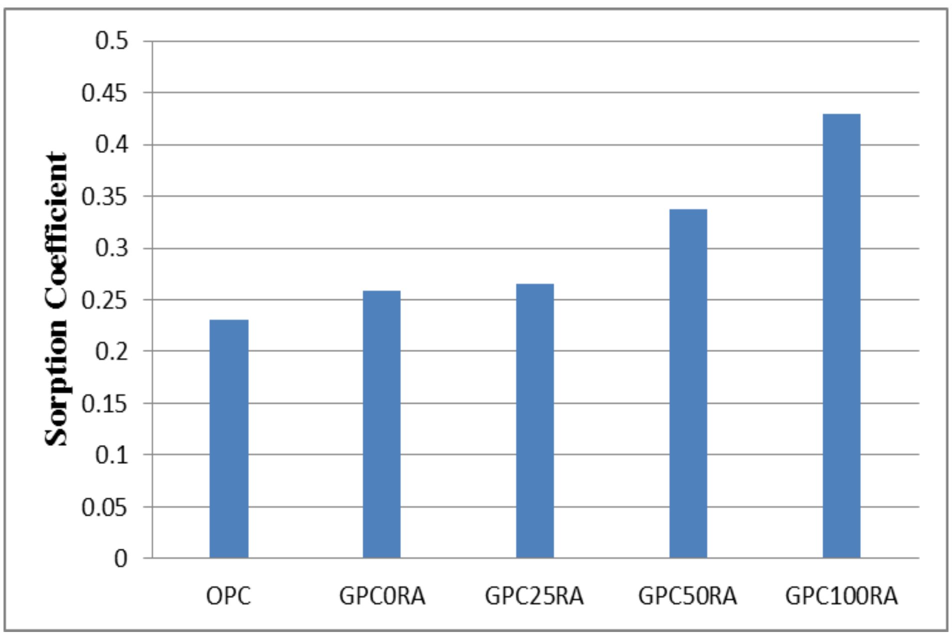

Fig. 6: Sorptivity Coeffecient

The adherences of old mortars in the RCA which are generally more porous than the NCA absorb more water results higher sorptivity value. When compare to the previous study made by various authors [27, 28] reported that the RAC increased the sorptivity by almost twice the times of ordinary concrete. But in GP-RAC it was restricted to 70% only. Hence GP-RAC showed better sorptivity than RAC.

4. Conclusion

This experimental work studied the influence of recycled coarse aggregate obtained from the demolished concrete on engineering and durabilty characteristics of the goepolymer recycled aggregate concrete and the following conclusions were made.

1. Reduction in the slump value with the increase in the RCA volume.
2. Addition of super plasticizer and using SSD aggregates greatly reduces the excess the excess amount of water needed.
3. The compressive and tensile strength of concrete gets decreased, as the recycled aggregate content increased.
4. Geopolymer concrete attains its strength at higher rate in early stages compared to the control concrete.
5. The Geopolymer recycled aggregate concrete showed better strength characteristics than ordinary recycled aggregate concrete.
6. The sorptivity was directly proportional to replacement of natural aggregate with recycled aggregate. GP-RAC showed better sorptivity than ordinary RAC

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