International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 03 | March - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Experimental Investigation on Geopolymer Aggregates Concrete

M. P. Naveena, G. Narayana

Abstract The excessive use of natural aggregates is having an adverse effect on the environment and raises major environmental issues; hence, an attempt has been made to develop artificial aggregates. These artificial aggregates are made from using GGBS, sodium hydroxide and sodium silicate. This paper focuses on the fresh, hard- ened and durability properties of self-compacting concrete with artificial geopolymer aggregates (GPAs) as partial to full replacement of natural aggregates. Mix design was carried out with varying content of GPA (0–100%) and cements contents (300, 350 and 400 kg/m^3). Flow, passing ability and segregation resistance were found to increase when 400 kg of cement and 100% replacement of 10 mm GPA is used as compared to crushed gravel. However, the compressive strength was found to be marginally less with the increase in aggregate size. After examining, the properties of SCC with geopolymer aggregate of size varying from 10 to 20 mm are used in casting of the sleepers. The sleepers were precast in Malu sleeper yard, Birur, Karnataka, and subjected to bending, electrical resistivity and durability tests. The results from static bending test showed that the resistance load of a sleeper with 50% of 6 M aggregate is 238 and 230 kN for conventional concrete. Electrical resistivity and durability of a sleeper with 6 M was found better than conventional concrete sleeper. The predic- tion of self-compacting concrete properties with artificial geopolymer aggregate and natural aggregate was investigated by using MATLAB.

Keywords Geopolymer aggregate · Railway sleeper · Durability · Electrical resistivity · RCPT · Bond strength

8.1 Introduction

Natural river sand and coarse aggregate have caused rapid depletion of this nat- ural source due to widely used in the production of cement mortar and concrete [1]. According to Freedonia, World Construction Aggregates Report, the global demand for construction aggregates exceeded 48.3 billion tons in the year 2015 and is expected to grow 5.2% annually. In India, the consumption of aggregate was about 2.2 billion metric tons in 2010, and further, the demand is going to be more than 5 billion metric tons by 2020 [2].
Since aggregate is the main occupants of concrete (about 65–75% of total concrete volume), type of aggregates have a significant influence on the fresh and hardened property of high-strength concrete [3]. The replacement of cement by GGBS not only increases the compressive strength but also reduces the cement content which even- tually leads to the decreases in emission of CO_2. Current standards allow only 50% of total binder content GGBS to be used in the production of concrete. The remain- ing GGBS goes unused and disposed as landfills [4]. Geopolymer is ceramic-type inorganic polymers produced at low temperature, generally below 100 °C. The raw material is mainly minerals of geological origin, and hence, the name is geopolymer. Creating geopolymer cement requires an alumina silicate material, a user-friendly alkaline reagent, sodium- or potassium-soluble silicates [5]. Geopolymer possesses excellent mechanical property, fire resistance and acid resistance [6]. The geopoly- mer product with fly ash and GGBS shows considerable resistance to chemical attack compared to the Portland cement product [7]. The property of geopolymer concrete with a fly ash aggregate mainly depends on the type of method of curing of aggregate [8]. Aluminosilicate network having Si–O–Al–O bonds in polymeric form, which are formed by dispersion of a precursor material such as fly ash or metakaolin (which has silica and alumina) in an alkaline solution which contains reagents such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) or potassium hydroxide (KOH) and potassium silicate (K_2SiO_3) [9].

8.2 Mix Design

Designing an appropriate mix proportion of SCC using geopolymer aggregate was challenging task. EFNARC method of mix design was adopted using different sizes of graded aggregates making suitable adjustments (Table 8.1).

Table 8.1 Mix design of self-compacted concrete

Sl. No.	Volume (m^3)	Proportion	Cement (kg)	Fly ash (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (l)	Superplasticizer (kg)
1	1	1:1.47:1.42	300	240	796.5	767	175	5.4
2	1	1:1.42:1.7	350	210	796.5	767	175	5.6
3	1	1:1.37:132	400	178	796.5	767	175	5.78

8.3 Experimental Investigations

Table 8.2 shows various properties of natural and GPA aggregate. From the table, it is observed that elongation index, flakiness index and angularity index are absent as coarse aggregate developed is round in nature.
Concrete cubes were cast with aggregate sizes varying from 10 to 20 mm. Fresh and hardened properties were found for the design mix. Natural aggregates were replaced in the range of 0–100% by geopolymer aggregates as shown in Table 8.3. Same investigations have been carried out for both 350 and 400 kg of cement. Figures 8.1 and 8.2 reflect the data

Table 8.2 Physical characterization of geopolymer aggregate

Sl. no.	Tests	Geopolymer aggregate	Conventional aggregate
1.	Fineness modulus	6.28	7
2.	Flakiness index (%)	0	19.2
3.	Elongation index (%)	0	15
4.	Angularity index	1.17	11
5.	Specific gravity	2.67	2.72
6.	Water absorption (%)	0.66	0.3
7.	Bulk density (kg/m^3)	1463	1542
8.	Aggregate crushing value (%)	26	24
10.	Aggregate impact value (%)	21	20
11.	Aggregate abrasion value (%)	20	18

Table 8.3 Fresh and hardened properties of SCC

Sl. no.	Cement content (kg/m^3)	Aggregate size (mm)	Percentage of replacement	Slump flow (mm)	*V* funnel (s)	*J* ring (mm)	*L* box ratio	*U* box (mm)	Compressive strength (N/mm^2)
1	300	10	0	700	8.5	2	1	12	42.04
			25	712	8	2	1	11	43.06
			50	730	7.9	1	1	10	47
			75	742	7.1	0	1	8	46.5
			100	760	7.1	0	1	6	43
2	300	12.5	0	678	9.9	4	0.89	16	49.46
			25	682	9.2	4	0.9	16	56.6
			50	700	8.8	3	0.95	15	58.2
			75	710	8.9	2	0.98	14	51.25
			100	724	8.1	2	1	12	48.9
3	300	20	0	666	11.5	8	0.8	22	37.5
			25	682	11.1	8	0.84	21	41.2
			50	695	10.5	7	0.87	18	46.1
			75	702	10.2	6	0.88	18	44.2
			100	714	10.2	6	0.91	16	39.3

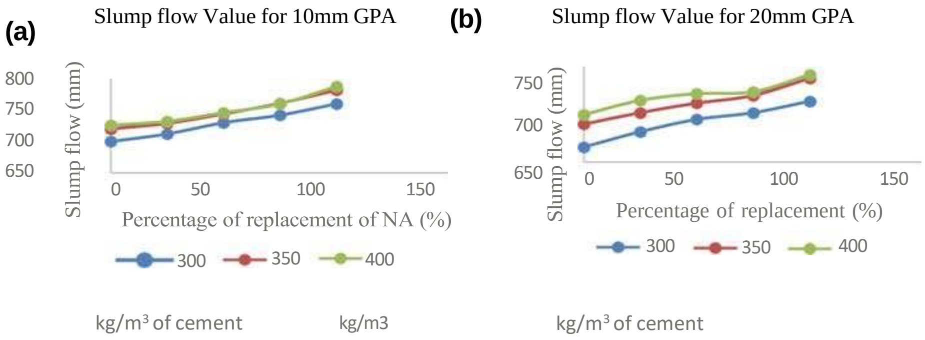

Fig. 8.1 Slump flow value of GPA

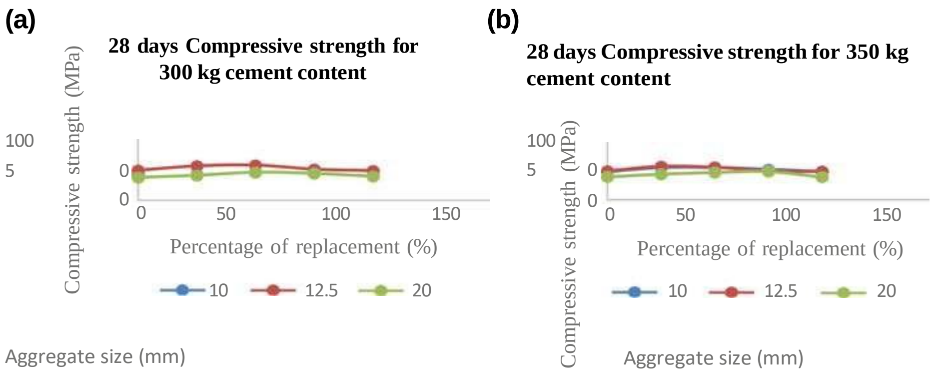

Fig. 8.2 Compressive strength value of GPA

8.4 Results and Discussion

8.4.1 Flow Characteristics

Figure 8.1a, b shows the slump of SCC for 10 mm and 20 mm aggregate, respectively. It is observed from Fig. 8.1 that higher the cement content higher is the slump. It is also seen that with increase in aggregate size slump also decreases.

From Table 8.3, it is also observed that *V* funnel, *L* box and *J* ring test show increase in flowability of SCC. However, the *U* box values have decreased with increase in aggregate size. This could be due to the filling ability of geopolymer aggregate.

8.4.2 Compressive Strength

The compressive strength was observed to be high for SCC mix with 350 kg cement content and 10 mm aggregate with a value of 56.9 N/mm^2. From Fig. 8.2a, b, it

Table 8.4 Rapid chloride penetration and bond stress of SCC

Sl. No.	Cement content (kg/m^3)	Percentage of replacement	RCPT (C)			Bond stress (MPa)		
			Aggregate size (mm)					
			10	12.5	20	10	12.5	20
1	300	0	3500	3500	3560	12.15	12.37	11.71
		25	3650	3700	3750	12.37	12.81	12.37
		50	3800	3820	3900	12.81	13.04	12.59
		75	4000	4020	4010	13.04	13.48	13.14
		100	4250	4300	4215	12.59	12.81	12.90

is observed that as the aggregate size increases compressive strength is reducing. Further studies need to be carried out to study the size effect of the aggregate.

8.4.3 Rapid Chloride Penetration Test (RCPT)

From Table 8.4, it is observed that penetration of chlorine increases with increase in aggregate size as well as cement content. The aggregates being round in nature increase the voids.

8.4.4 Bond Strength

Concrete cubes were cast with rods inserted with 200 mm projections. These were tested in UTM to find the bond strength. It is observed from Table 8.3 that bond stress is in the range of 12–14 N/mm^2 which is satisfactory.

8.4.5 Microstructure Analysis

Figure 8.3a, b is SEM images of natural aggregate and GPA. It is observed the natural particle size varies from 1.2 to 9.28 μm and geopolymer particle size from 2.98 to 4.70 μm. Geopolymer particles are more densely packed as compared to natural aggregate.

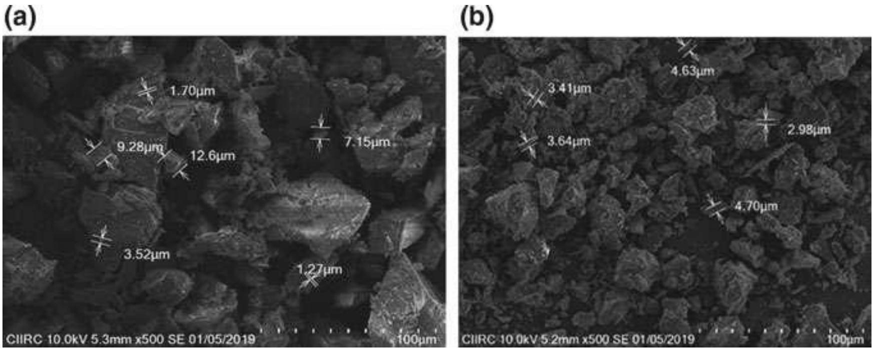

Fig. 8.3 SEM images of natural and geopolymer aggregate

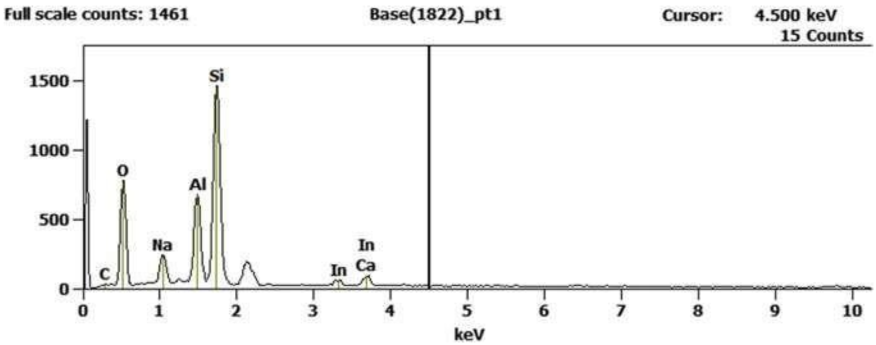

Fig. 8.4 EDS image of natural aggregate

8.4.6 Energy Dispersive Spectroscopy (EDS)

EDS is an analytical technique used for the elemental analysis or chemical charac- terization of a sample. It is found that silica content is higher in natural aggregate as compared to geopolymer aggregate. Calcium content is high in geopolymer aggregate as shown in Figs. 8.4 and 8.5.

8.5 Regression Analysis

It is of interest to predict strength of compressive strength of concrete for different percentage replacements of natural aggregates with GPA for varying cement con- tent. Regression Analysis is carried out in MATLAB. Figure 8.6 shows graphical representation of predicted values for various percentage replacements of natural aggregates with geopolymer aggregate. Figure 8.7 represents surface plot of the

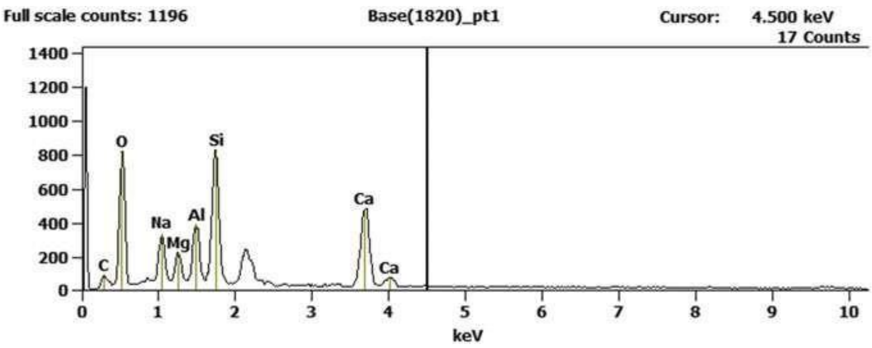

Fig. 8.5 EDS image of geopolymer aggregate

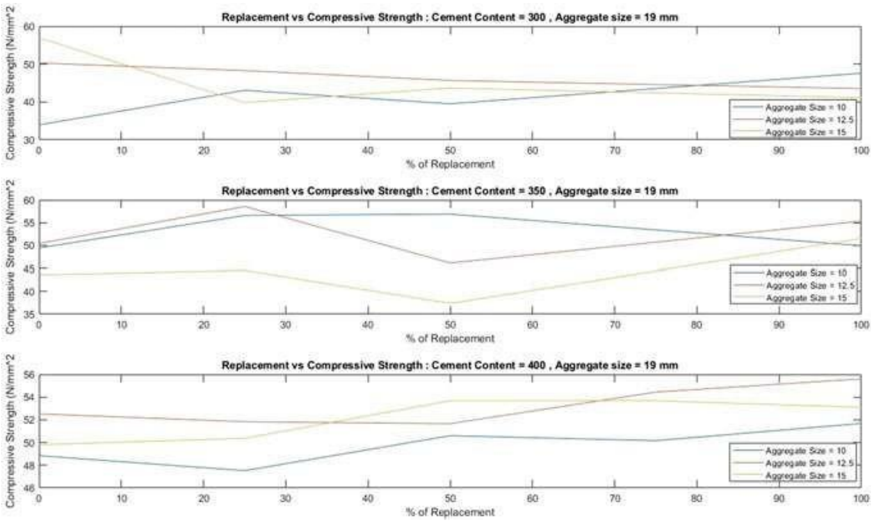

Fig. 8.6 Compressive strength for different sizes of aggregates

predicted values.

8.6 Application of Geopolymer Aggregate

Further investigations were carried out to check the suitability of geopolymer aggre- gate in sleepers. The sleepers were cast in Malu sleepers Pvt. Ltd., who are one of the suppliers for Indian Railways. The bending and electric resistivity tests of sleepers were carried out in yard. It was found that the bending strength of sleepers cast by

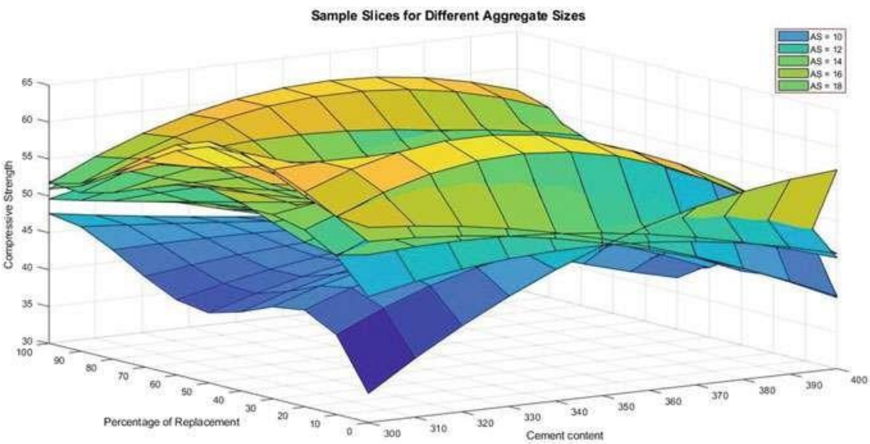

Fig. 8.7 Surface plot

Table 8.5 Static bending and electrical resistivity test results

Sleeper	Center top in (kN)	Center bottom in (kN)	Rail seat				Electrical resistivity (V)
			Resistance load (kN)		Failure load (kN)		
			R.H.S	L.H.S	R.H.S	L.H.S	
Sleeper (GPA)	70	65	238	236	380	378	160
Standard value as per RDSO	60	52.50	230	230	370	370	Max. 240

6 M GPA with 50% replacement met with standards prescribed by Indian railways. It was also found that electrical resistivity was also within the limits from Table 8.5.

8.7 Conclusions

Geopolymer aggregate is indigenously developed in KSSEM Laboratories. It was observed from the studies that with increase in aggregate size slump decreases. It was found that V funnel, L box and J ring test show increase in flowability of SCC. However, the U box values have decreased with increase in aggregate size. This could be due to the filling ability of geopolymer aggregate. The compressive strength was observed to be high for SCC mix with 350 kg cement content and 10 mm aggregate with a value of 56.9 N/mm^2. The penetration of chlorine increases with increase in aggregate size as well as cement content. The aggregates being round in nature increase the voids. The bond stress is in the range of 12–14 N/mm^2

which is satisfactory. SEM and EDS show the morphological properties as well as chemical properties of the aggregate. It is of interest to predict the compressive strength for intermediate values. Regression analysis has been carried out using MATLAB. However, the values should be validated by testing these mixes.

References

1. Sethu Parvathy, S., Sharma, A.K., Anand, K.B.: Comparative study on synthesis and properties of geopolymer fine aggregate from fly ashes. Constr. Build. Mater. **163**, 428–437 (2018)
2. Saint-Gobain and Bosch.: Fredonia, World Construction Aggregates—Industry Study with Forecasts for 2015 and 2020. The Freedonia Group, USA (2012)
3. Vishalakshi, K.P., Revathi, V., Sivamurthy Reddy, S.: Effect of type of coarse aggregate on the strength properties and fracture energy of normal and high strength concrete. Eng. Fract. Mech. (2018)
4. Oner, A., Akyuz, S.: An experimental study on optimum usage of GGBS for the compressive strength of concrete. Cement Concr. Compos. **29**, 505–514 (2007)
5. Davidovits, J.: Geopolymers: ceramic-like inorganic polymers. J. Ceram. Sci. Technol. **8**(3) (2017)
6. Davidovits, J., Davidovits, M.: Geopolymer room temperature ceramic matrix for composites. Ceram. Eng. Sci. Proc. **9**(842), e853 (1988)
7. Sakkas, K., Nomikos, P., Sofianos, A., Panias, D.: Fire resistant geopolymer for passive fire protection. Fire Mater. (Special issue) D (2014)
8. Venkata Suresh, G., Pavan Kumar Reddy, P., Karthikeyan, J.: Effect of GGBS and fly ash aggregates on properties of geopolymer concrete. J. Struct. Eng. **43**(5), 436–444 (2017)
9. Menon, S.U., Anand, K.B., Sharma, A.K.: Performance evaluation of alkali-activated coal ash aggregate in concrete. Waste Resour. Manage. **171**(1), 4–13 (2018)