

Strength Development Properties Of Sugar Cane Bagasse Ash Blended Geopolymer Concrete Containing Waste Steel Fibers



V.M. Sounthararajan, T.L. Ramadasu, S. Sivasankar

Abstract: This research paper deals the two different mixture of GGBS/SCBA have been used for preparing the geopolymer alkali-activated concrete, by using NaOH (12 M solution), sodium silicate (12 M solution in Na⁺ and SiO₂/Na₂O molarity ratio of 0.3) and KOH (12 M solution) as activating solutions. Replacements of 10%, 20% and 30% of GGBS by SCBA were carried out for various mixes. It is observed that 20% replacement of GGBS showed better strength enhancement in the range 25-40 MPa at 3 days curing. However, the addition of waste steel fibers up to 1.5% by volume fraction (V_f) showed a reasonable improvements on the compressive strength and split tensile strength of geopolymer concrete. Further test results showed drastic improvement in flexural strength of geopolymer concrete for various mixes. The various comparative assessments were made for different geopolymer mixtures and the reinforcing effects of steel fibers were investigated in different concrete matrix.

Keywords: Accelerated curing, Alkali activators, Blast furnace slag, Geopolymer, Hot air oven curing, Sugar cane bagasse ash, waste steel fibers.

I. INTRODUCTION

Now days very widely used non-flammable and non-combustible resins type of geopolymer act as binding materials in structural concrete and completely avoid the Portland cement. The main chain link reaction of polymeration occurred in geopolymer concrete due to alkali activator; sodium hyorixde produced the alumina-silicate components, which is rich in silica and alumina content. The major construction industries have been utilized the natural available materials in worldwide and facing the serious issues on the shortage of the natural resources. One of the waste by-product materials like sugarcane bagasse ash is a low carbon binding materials and suitable to improve the

hardened properties thus resulting to reduce the Portland cement and it will resolve the environment issues. This type of SCBA ash contains approximately 50% of cellulose, 25% of lignin and 25% of hemicellulose and used in the farms as a fertilizer in the sugarcane harvests.

The several research studies on geopolymer concrete have shown better strength gain results on the improvement of the hardened properties. In this direction many fruitful investigations had produced this wonderful material with different types of industrial waste materials such as silica fume, fly ash, blast furnace slag, rice husk ash and bentonite. Many studies by then had proved the advantageous properties of geopolymer concrete [1-4].

The addition of waste steel fibers up to 1.5% by weight of binder along with different percentage of cementitious materials (slag/sugarcane bagasse ash) exhibited the good fracture properties of matrix densification [5]. In this author concluded that the addition of cotton fibers up to 0.5% by weight of binder content were greatly improved the hardened properties of geopolymer concrete and also the density of the geopolymer composites were found to decrease with the increase in the fiber content [6]. The geopolymer chain reaction of concrete mix depends on the molarity/concentration of alkali activator such as sodium hydroxide, sodium silicate, potassium hydroxide, potassium silicate etc. It was noted that the alkaline activation of aluminosilicates mortars and concrete made from geopolymeric binders with respect to fresh and hardened states, interfacial transition zone between aggregate and geopolymer, bond with rebar and resistance to eminent temperature. It was also stated that durability of geopolymer pastes and concrete is highlighted in terms of their deterioration in various aggressive environments [7]. The mix containing 8-Molarity of sodium hydroxide at room temperature with steel fiber 0.5 to 1.0% by weight of mortar volume produced the maximum strength attainment and less amount of drying shrinkage at later age curing [8-10]. Several works had been focused on the careful selection of silica to alumina ratio and sodium hydroxide/sodium silicate ratio exhibited the higher strength during the hydration process occurred in geopolymer concrete. Limited study focused on the cuing period of time in hot air curing provided in the rapid geopolymerisation in environmental conditions. Also, the formation of alumina-silicate compound occurred very rapidly at elevated temperature curing and also was found to stable chain formation at high concentration level of alkali activator.

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* Correspondence Author

Dr VM Sounthararajan*, Professor, Department of Civil Engineering, CMR Technical Campus, Kandlakoya, Medchal Road, Hyderabad – 501401, Telangana, India. Email: researchsoudar@yahoo.in

Dr TL Ramadasu, Professor, Department of Civil Engineering, CMR Technical Campus, Kandlakoya, Medchal Road, Hyderabad – 501401, Telangana, India. Email: ramadasjntu@gmail.com

Dr S. Sivasankar, Associate Professor, Department of Civil Engineering, CMR Technical Campus, Kandlakoya, Medchal Road, Hyderabad – 501401, Telangana, India. Email: drssspdh@gmail.com

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Further, the additions of steel fibers provide the toughness of the composites materials in slag based alkali activator geopolymer concrete [11-13]. Several research works had been indicating that the excellent potential effect on the geopolymerized product while testing the various properties of concrete in hardened and durability and also structural properties of geopolymer concrete had reveal that the various polymer reaction was depended on the concentration of alkali reactor thus results to improve the micro structural densification [14-16]. This research work concluded that the good bonding strength in geopolymer concrete while proper selection of alkali react were act as a main reactor and also alumina-silicate sources aided with alkali- silicate resume during the polymersation [17].

In their research work focused on the usage of alkali activator content had considerably reduce the degree of deterioration in geopolymer concrete than exposed to sulphuric acid. However, the specimen having more alkali content showed lesser reduction in weight and also less severe attack than compared to less amount alkali content present in geopolymer concrete and showed there was nothing visible sign in structural disintegration but under the optical microscope observation in the surface deterioration was clearly visible [18].

This author concluded that the usage of sodium hydroxide to sodium silicate concentration in geopolymer concrete has consecutively reduce the mortar flow in the range of 110 ± 5 to $135 \pm 5\%$ thus resulting to produce the maximum strength attainment in geopolymer concrete [19].

II. RESEARCH SIGNIFICANCE

The main focus of this study is striving to produce the quality of high strength concrete by utilizing the waste by-product materials of slag/sugar cane bagasse as a pozzolanic material in geo-polymer concrete and check the suitability of materials towards the mechanical and durability properties of mass concrete.

III. MATERIALS

A. Slag

The slag is more alternate binder material to production of geopolymer concrete. The composition of slag 31.73%, alumina of 11.50% (Al_2O_3), magnesium oxide of 7.30% (MgO) and calcium of 42.50% (CaO).

B. Sugarcane bagasse ash (SCBA)

The sugarcane bagasse was collected during the cleaning operation of a boiler operating in sugar mill and burnt up to 6000C in hot air oven after that naturally cooing the particle up to 24 hours and consists approximately 51% of cellulose, 25% of hemicellulose and 24.5% of lignin. It generates approximately [16-17] 27% of bagasse (at a moisture content of 50%) and 0.61% of residual ash and also a high concentration of silicon dioxide (SiO_2) up to 78.35%, which promises to use as a binder material in Ordinary Portland cement. However, to produce the aluminosilicate gel formation due to the presence of silica and alumina react with the alkaline solution.

C. Alkaline solutions

Sodium-silicate A53 type of solution is a basic alkali activator used for the production of geo-polymer concrete up

to 12-Molarity for concentration level of solutions were made by dissolving 480 grams of sodium hydroxide pellets in 1000 ml of distilled water. The sodium silicate and sodium hydroxide solution were mixed 24 hours for concrete batching to allow the exothermic heat reaction with constant room temperature.

D. Fine aggregate (FA)

Natural type of river sand (fine aggregate) passing through 4.75 mm IS sieve was used and conformed to zone II in accordance with IS 383: 2016 [21]. The specific gravity value of 2.67, water absorption up to 1.0%, fineness modulus value of 7.20 and bulk density value of 1392.16 kg/m^3 (loose state).

E. Quarry dust (QD)

Quarry dust replaced in river sand used as a fine aggregate having a test value of specific gravity of 2.52, fineness modulus of 2.71 and water absorption up to 1.80% and conforming to Zone-II grade as per guideline are given in Indian standard 383-2016 [21].

F. Coarse aggregates (CA)

Machine crushed rough stone well graded angular type of aggregate used for averaged size 12.5 mm for different mixes. The specific gravity value of 2.74, water absorption of 0.62 % at 24 hours and satisfied the all the aspects as per the code.

G. Steel slag (SS)

Sintered earth steel slag is the main problem where the excessive amount of free and unburnt oxides of calcium and magnesium are present in the slag this react with the moisture in the formation of air or with water and swells, this leads to volumetric instability. This excessive lime which meets the metallurgical requirements will produce the sintered earth steel slag as shown in Figure 1. It is suitable for conventional concrete and partially replaced in coarse aggregate from 0%, 10%, 20% and 30% for various mixes.



Fig. 1. Image of sintered metal steel slag

H. Waste steel fibers (WSF)

The waste steel fibers are in scrap form called steel scrap or elongated chips as shown in Figure 2. The usage of steel fibers in concrete to improves the bending stress in flexural rigidity and mechanical characteristics of waste steel fibers are presented in Table 1.



Fig. 2. Image of waste steel fibers

Table- I: Details for mechanical characteristic of waste steel fibers

Length (mm)	Width (mm)	Thickness (mm)	Displacement (mm)	Strain	Force (N)	Strength (MPa)
21.4	1.7	0.5	2.31	0.11	950	640
21	1.4	0.8	0.95	0.05	820	670
21.2	2.4	0.65	1.23	0.08	1200	770
21.1	3	0.7	1.3	0.06	1200	560
21.5	2.5	0.56	1.3	0.05	900	849
22	1.8	0.45	1.5	0.07	950	672

I. Polycarboxylate ether super plasticizer (SP)

This study used for high range water reducer of chemical admixtures was constant dosage level up to 1.5% by weight of binder content to drastically improved the gel formation during the hydration process and avoid the excess of bleeding as well as particle segregation (gravel, coarse and fine sands).

IV. EXPERIMENTAL PROGRAM

A. Curing method

Initially required accelerated curing for all the specimens were cured in a Hot air oven at 100°C for 6 hours followed by normal curing for various mixes [22].

B. Concrete Testing details

All the concrete specimen size details are represented in Table 2 and calculated the compressive, split tensile and flexural strength of concrete by destructive method.

Table- II: Various specimen size details

Specification	Sample size (mm)	Formula	IS code
Compressive strength	100 x 100 x 100	load/Area	IS 516:1959 (Reaffirmed 2004) [23]
Split tensile strength	100 diameter x 150 height	$2P/\pi dl$	
Flexural strength (Third point loading method)	100 x 100 x 100	Pl/bd^2	

C. Acid Attack Test

The acid test was performed on the concrete specimen size of 150 x 150 x 150 mm cast and tested for different mixes. All the concrete specimens are initially cured with normal curing after that dry weight was taken and followed by 5% of sulfuric acid solution immersed and tested for 56 and 90 days to measured the weight loss and strength gain loss for different mixes.

D. Mix Details

From Table 3 shows the mix details for different materials used in concrete, The active binding material is slag along with different percentage of sugar cane bagasse ash replaced in slag up to 0%, 10%, 20% & 30%, fine aggregate replaced 50% of quarry dust and coarse aggregate replaced 0%, 10%, 20% & 30% in steel slag and also addition of a constant percentage of waste steel fibers up to 1.5% of volume fraction for all mixes of concrete.

Table- III: Various mixes of geopolymers concrete

Mix proportions	B/TA	Relative composition in volume (%)			Mix id	Slag - GGBS	SCBA	Fine-aggregate	Quarry dust	Coarse-aggregate	Steel slag	Water	Waste steel fiber (%)
		Slag	Fine aggregate	Coarse aggregate									
		(kg/m ³)											
1:1.56:2.63	0.3	28	18	46	V1	670	0	420	0	1095	0	216	1.5
					V2	603	67	210	210	1095	110	216	1.5
					V3	536	134	210	210	1095	219	216	1.5
					V4	469	201	210	210	1095	329	216	1.5

Note:

V1 mix = 100% GGBS+100% FA+100% CA+1.5% WSF + 1.5% SP
 V2 mix = 90% GGBS+10% SCBA+50% FA+50%QD+90% CA+10% SS+1.5% WSF + 1.5% SP
 V3 mix = 80% GGBS+20% SCBA+50% FA+50%QD+80% CA+20% SS+1.5% WSF + 1.5% SP
 V4 mix = 70% GGBS+30% SCBA+50% FA+50%QD+70% CA+30% SS+1.5% WSF + 1.5% SP

WHRE B/TA IS THE BINDER-TOTAL AGGREGATE RATIO

V. MECHANICAL PROPERTIES INVESTIGATED

A. Density of Geopolymer Concrete

The different percentage replacement of aggregate in concrete for various mixes to produce the quality of concrete, it is noted that the density of concrete increases at 3 and 28 days, which were cured for 6 hours at 100⁰C (oven curing). The various mixes of the density of geopolymer concrete value starts ranging from 2359 to 2493 kg/m³ as shown in Figure 3. It is clearly observed that there is a reliable increase in the density of concrete (V3 mix), which showed a remarkable weight gain and improves the strength gain, when compared to all other mixes.

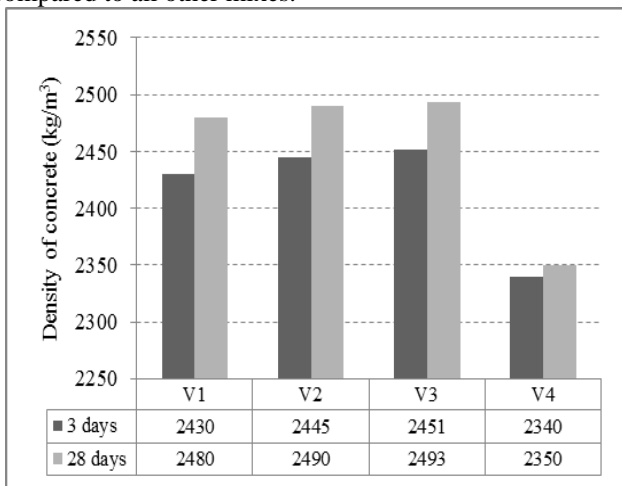


Fig. 3. Various mix id vs Density of geopolymer concrete

B. Compressive strength

The laboratory test results exhibited the higher compressive strength of geopolymer concrete was 35.1MPa and 40.1 MPa (V3) for 3 and 28 days respectively (V3-mix id) as shown in Figure 4. It was clearly proved there is a reliable increase trend in compressive strength of geo-polymer concrete due to the presence of SiO₂ content and best mixes consisting of 80% of slag with 20% of SCBA and 50% of natural sand is replaced in quarry dust along with 20% of steel slag replaced in coarse aggregate which exhibited the good bonding effect on the binder content during the hardening process. However, another combination in V4 mix is likely affected the early curing due to the effect of the polymerization reaction. Further, It was also noted that the test results for 3 days of strength attained earlier up to 90 % than compared to 28 days of geopolymer concrete.

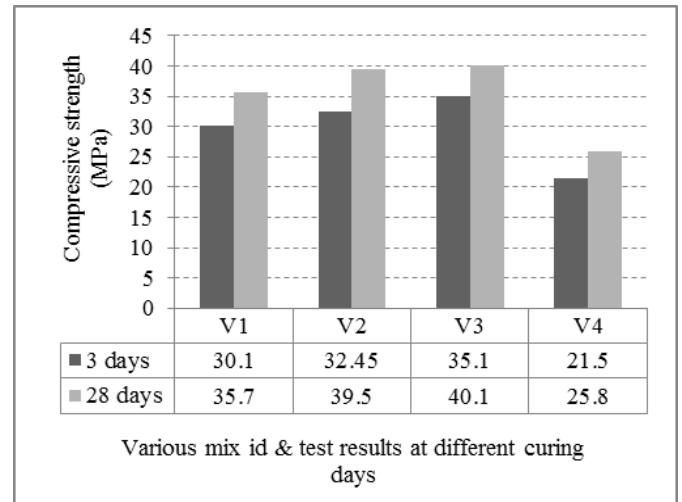


Fig. 4. Various mix id vs Compressive strength of geopolymer concrete

C. Split tensile strength

The similar trend was noted in the indirect measurement of the tensile strength of concrete consisting of 1.5% of waste steel fiber by volume fraction exhibited the higher strength (V3-mix) was 4.5 MPa at 3 days and 6.27 MPa at 28 days as shown in Figure 5. Since the failure of concrete has diametrically split into two pieces along the beam axis proved the excellent load-carrying capacity of geopolymer concrete while usage of steel fibers. As per the test result, if the fiber dosage level increases automatically increased in split tensile strength for various mixes.

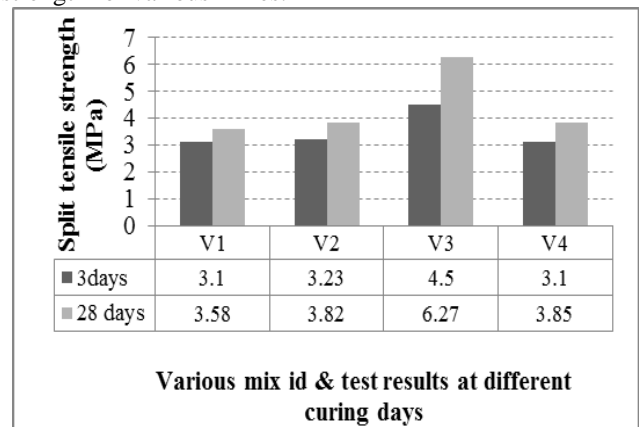


Fig. 5. Various mix id vs Split tensile strength of geopolymer concrete.

D. Flexural strength

The usage of waste steel fibers to promulgated a drastic improvement in the flexural rigidity of geo-polymer concrete mixes as shown in Figure 6. It was proved the addition of waste steel fibers up to 1.5% produced the maximum flexural strength was 5.10 MPa at 3 days (V3 mix) and 7.25 MPa at 28 days when compared to plain cement concrete (V1 mix). Also, it is noted that the irregular shape of steel fibers exhibited the best anchorage effects in matrix densifications of composite materials and also increases the post crack toughness in bending than compared to crimped steel fibers.

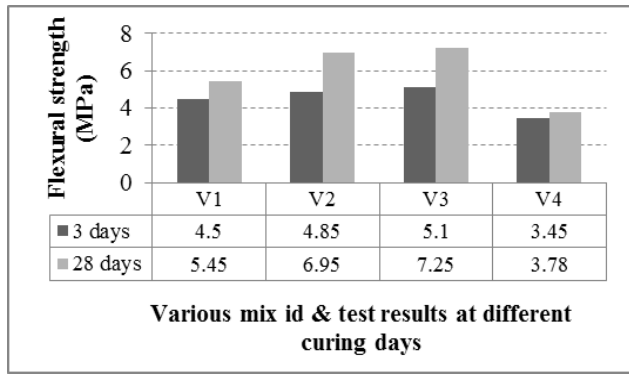


Fig. 6. Various mix id vs Flexural strength of geopolymer concrete.

E. Acid attack test

For all mixes of geopolymer concrete specimens where cured in sulfuric acid solution for different curing days and the same sample has been tested by compressive testing machine, it has been observed that the conventional concrete is highly prone to the acid attack. However, the outer surface of concrete after 90 days of the Acid immersion is completely eroded and the aggregates starts peeping out of the concrete and the severity of acid attack is more in the conventional concrete. It has been screened that there is a loss in strength gain in conventional concrete up to 29.45% and 35.07% for 28 and 90 days respectively. The V3 mix containing 80% GGBS with 20% sugarcane bagasse ash showed better performance, when compared to all types of concrete considered as shown in Figure 7.

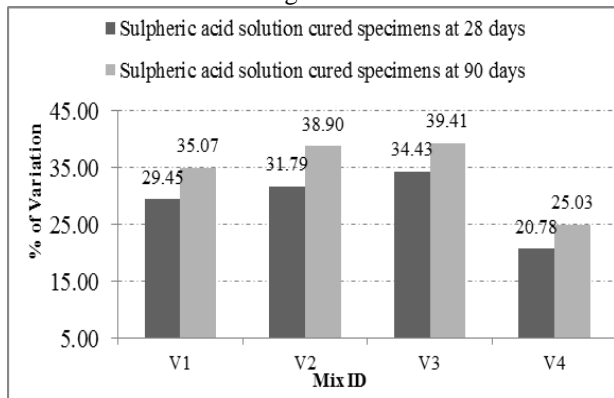


Fig. 7. Acid tests for sulfuric acid solution cured at different curing days

VI. CONCLUSION

From the above experimental works following conclusions could be drawn: The slag/SCBA based concrete exhibited better performance in mechanical properties for various mixes of concrete. The higher percentage of replacement of bagasse ash by slag there will be a decrease in compression, tension and flexural strength gaining properties of geopolymer concrete for various mixes of concrete. The alkali activator depends on the chains link formation in polymerization reactions. The multi-stage of polycondensation reaction leads to polysialate components during the formation of cross-network structures. The test results possess up to 50% of quarry dust replaced in river sand produced the maximum strength in geopolymer concrete thus resulting to decrease the CO2 emission.

Coarse aggregate with replacement of 0% to 30% of steel slag showed that the better mechanical properties for various mixes of geopolymer concrete. The ratio of GGBS: SCBA (80:20) with 12-M sodium hydroxide exhibited higher compressive strength than compared to plain cement concrete. Also, it was noted in the split tensile strength and flexural strength was 6.27 MPa and 7.25 MPa at 28 days (V3 mix) respectively. The major role of waste steel fibers addition showed remarkable improvement in bending stress through bridging the gap between them and both sides of a crack opening of the beam axes. As the percentage replacement of GGBS by SCBA increases the concrete becomes impermeable concrete. The better resistance to Acid attacks is observed in V3 mix concrete of lower percentage of strength loss. Use of supplementary cementitious materials at higher volumes in concrete is found to be beneficial not only for the structural concrete but also for environmental safety.

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AUTHORS PROFILE



Dr VM Sounthararajan working as a Professor in the Department of Civil Engineering at CMR Technical Campus, Hyderabad, Telangana. He has 9.5 years teaching as well as research experience. Also, eight years of Industrial experience. He is a reviewer for more than four reputed journals. He is a Member of Indian Society for Technical Education. He has received

the best research awards at VIT University in the year of 2012 and 2013. He has published more than fifty-two research papers in various National and International journals and conferences.



Dr. T.L. Ramadasu, working as a Professor in Department of Civil Engineering, CMR Technical Campus, Hyderabad, Telangana, India. He has 16 years of teaching experience and one year in industry. He has published 24 research papers in various National and International Journals and conferences. He is a life member in various chapters like ISTE, IGS, IEI and Chartered engineer.



Dr. S. Sivasankar is presently working as an Associate professor in the Department of Civil Engineering, CMR Technical Campus, Hyderabad, Telangana. He has eight years of teaching experience and one year industry experience. Also he has four years of research experience. He published ten research articles in national and international journals. His research area includes steel-concrete composites, strengthening and retrofitting of steel and concrete structures and corrosion assessment in steel and concrete. He is a life member in ISTE, IAE and IE chapters.