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Experimental studies on bagasse ash reinforced with GF and BF-slag in direction towards sustainable development

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ABSTRACT

To assess the appropriateness of the current by-product for application in building construction and to mitigate potential environmental risks in the context of environmental sustainability, a series of tests were conducted to determine the compressive strength properties of a material composed of glass fiber (GF) strengthened sugar cane bagasse ash (SCA). This material was made from SCA, blast furnace slag (BF-slag), and GF binding with cement. Cylinders were employed to measure the compressive strength of a mixture consisting of water and an SCA ratio of 50%. Cylindrical samples of 150 millimeters in length and 75 millimeters in diameter were utilized to evaluate the compressive strength across curing durations of 7, 14, and 28 days. The present study attempt utilizes mixture ratio percent of 0.15, 0.3, 0.45, 0.6, and 0.75 to perform compressive strength tests. The compressive strength of cylindrical samples ranges from 86.5-801.6 kPa. The density of a cylindrical sample containing 30% cement dropped from 900.1-865 kg/m3. The initial tangent stiffness of the sample ranges from 66-630 MPa. The findings suggest that it is possible to achieve a material with acceptable strength by using SCA ash in combination with BF-slag, strengthened with GF.

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1. INTRODUCTION

Large quantities of waste like agricultural and industrial waste are produced in very large quantity year to year basis which causes the problem of disposal and treatment. This large accessibility quantity of materials like sugar cane bagasse ash (SCA), rice husk ash, coal ash, and pond ash are another immense environmental challenging problem faced nowadays. These waste materials from time to time also disposed of in the river or channel nearby to the industry which causes the epidemic of diseases in the area near by industry. Hence there is a great extent is needed to utilize these waste materials without harming to environment. As an agricultural commodity grown in more than 100 countries, the sugarcane industry produces more than 500 million tons annually. About 10 million tons of SCA are produced annually in India, out of which 300 million tons are utilized overall. The remaining SCA is thrown away of as garbage within the surrounding area of nearby companies [1]. Approximately 45-50% of the leathery residue that was removed from sugar cane was recovered. Those fibrous components are utilized in the same sector as fuel for boilers for producing heat, leaving 8-10% ashes behind which is referred to as SCA [2]. Subsequently, SCA was utilized in companies to generate heat from the residual. The sugar cane was burned at high temperatures in a boiler to produce the sugar, the residues did not react. The material is referred to as bagasse ash, and it has difficulties with disposal. It is thrown away adjacent to industry in low-lying areas. An effort has been built to make use of SCA as a substitution to cement 0, 5, 10, 15, and 20% by weight and 100% substitution expanded polystyrene beads as for coarse aggregate. It was observed that compressive strength of materials increases up to 15% substitution of SCA and which is moderately less than ordinary Portland cement (OPC) at 28 days in light weight concrete [3]. The author carried out the experimental study on geomaterial, from the result, it was observed that density ranges from 350-720 kg/m^{3,} compressive strength varies from 150-760 kPa, and initial tangent modulus ranges from 15-42 MPa [4]. From the experimental result of lightweight fill material from the result, it was observed that density ranges from 700-1,100 kg/m^{3,} compressive strength varies from 100-510 kPa and Initial tangent modulus ranges from 79-555 MPa [5]. It was observed that with the use of SCA as a 10% replacement of cement, flexural strength was enhanced by 10.46% in self-compacting concrete [6]. SCA use as substitution of cement at 0, 10, 15, 20, 25, and 30% to the cement by weight and compressive strength of concrete was determined after 7, 28, 56, and 90 days. It was that observed the potential effects of bagasse ash as a substitution of cement and also the relative effects on the overall durability and strength of concrete after replacement cement with SCA [7]. The overall schematic diagram of sugar cane by products is displayed in Figure 1.

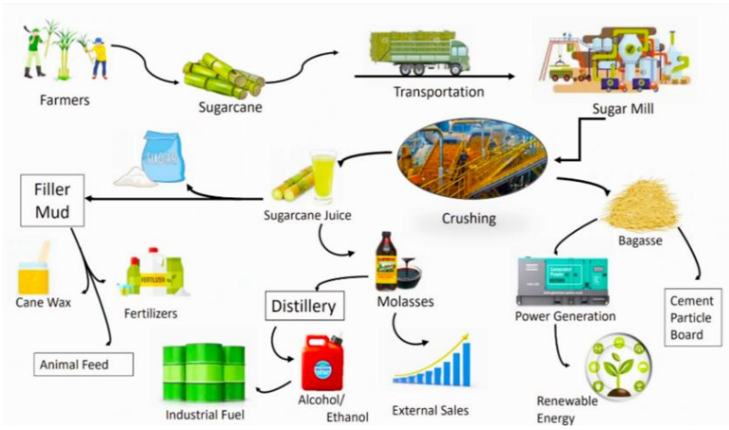


Figure 1. Schematic diagram of sugar cane by-products

Blast furnace slag (BF-slag), a waste product generated in the metals industry, consists largely of silicon dioxide, calcium oxide, aluminum oxide, and magnesium oxide by an iron production unit. It begins as a fluid and eventually cools to deposit off as a solid form [8]. ACI Committee 233, 1995 states that slag from BF is a non-metallic byproduct composed primarily of silicon dioxide and aluminum silicates of calcium and other bases that are specially formed in a melting condition at precisely the same time as iron in a combustion chamber.

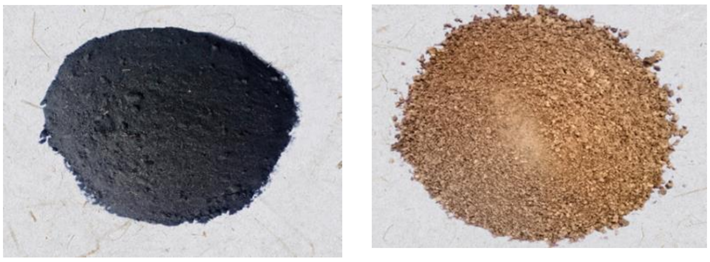
BS-slag is a minor product and usage as aggregates in concrete may provide an effective and environmentally amiable solution in local regions [9]. The potential of the use of granulate slag of BF in substitution of sand in cement matrix to minimize the environmental issue which relates to the mining of materials and deposition of waste [10]. Concrete characteristics are to be preserved with advanced mineral blends like BF-slag dust as a fractional substitution of cement up to 5-30% [11]. BF-slag was replaced with two different sources as partial substitution of fine partial to understand the behavior of concrete. The consequences procured stimulate the utilization of that material as a substitution material as fine-grained. It was observed that the usage of BF-slag will decrease the expense of concrete by 8-10% [12]. The potential of the use of granulate slag of BF in substitution of sand in cement matrix to minimize the environmental issue which relates to the mining of materials and deposition of waste. Depletion in feasibility is articulated as flow which is made by the addition of appropriate rates of super solvent. Also, as the rate of ground granulated blast furnace slag (GGBS) increased feasibility of the materials decreased. The reduction in flow up to 25%

was acceptable and for higher rates, the flow decreases significantly. Using an appropriate dosage of compositive, the feasibility was to be preserved [10].

E-glass fiber fails to withstand an alkaline treatment and becomes weaker. The alkali treatment was sustained on the alkali-resistant (AR) glass fiber but after undergoing wet aging, it was discovered that the AR glass fiber was brittle. The lack of versatility in AR glass fiber is a result of hydrated cement material depositing on each fiber filament [13]. The mix with a fiber proportion of 65 with 1% has the strongest compressive strength among all mix ratios, according to the examination of the results. When fiber insertion reaches a specific point, the compressive strength increases before progressively decreasing [14]. Glass fibers were added in increments of 0.5, 1, 2, and 3%, the highest compressive, tensile, and split tensile strengths obtained at 2% fiber inclusion; however, at 3% fiber addition, the strength of the concrete somewhat decreased. By adding glass fiber, concrete becomes more workable and is less likely to crack under various loads by incorporating 2% by volume of poly-vinyl alcohol (PVA) fiber of diameter 40 microns and length of 8 mm in a mix of Portland cement, limestone powder, and BF-slag composite. It was observed that engineering cementitious composite blend with 15% Portland cement by powder weight shows a maximum tensile strain efficiency of 3.3%, a tight fracture dimension of 57 microns, and an average compressive strength of 38 MPa, at 28 days of curing [15]. The effects on the mechanical properties and durability of M25 grade concrete that was made by adding steel fiber in amounts of 0.5, 1, 1.5, and 2% and glass fiber in amounts of 0.1, 0.2, 0.3, and 0.4%, and substituting GGBS for cement in amounts of 10, 20, 30, and 40% by weight. It was observed that compressive and flexural strength rises with a 0.2% glass fiber content [16]. A review of the literature shows the recommendations for using SCA in concrete in place of fine aggregate; yet, there is a gap in the literature about the use of SCA in the direction of sustainable development.

2. ANALYSIS OF THE COMPOSITION OF MATERIALS

The classification of materials was required to interpret the experimental data. Figure 2 shows the materials employed in this investigation comprised SCA as shown in Figures 2(a) and BF-slag as shown in Figures 2(b) glass fiber, and 53 grade OPC. The assessment of the performance of materials that incorporate glass fibers is of considerable significance in ascertaining their appropriateness for real-world applications.

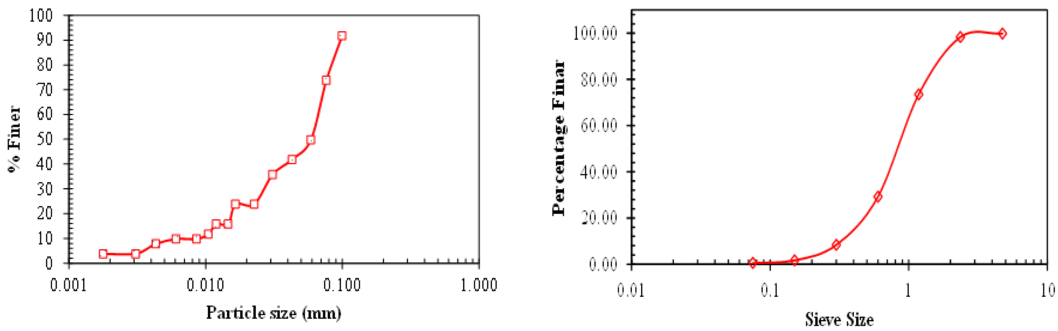


(a) (b)

Figure 2. Material of (a) SCA and (b) BF-slag

Figure 3 shows the particle size distribution curve. A hydrometer test as per IS 2720 (Part-4): 1985 [17] was conducted on SCA as shown in Figure 3(a) to determine the percentage of smaller particles. The SBA used in this study comprises 40% finely ground sand, 45% silt, and 5% clay. The aggregate of silica, ferrous oxide, and aluminum oxide proportions in the BF-slag amounts to 52.36%. The percentage of calcium oxide that's present is 34.8%. According to the American Society for Testing and Materials (ASTM) C618 [18] standard, BF-slag is categorized as a class C kind product due to its cementitious properties and the highest amounts of calcium oxide and magnesium oxide. The glass fibers used in this study are AR glass fibers, which are employed for material reinforcement.

According to the American Concrete Institute (ACI), BF-slag is a nonmetallic substance mostly composed of silicates and aluminum silicates of calcium. The BF-slag, weighing 500 grams, was obtained by the specifications outlined in IS 2386 (Part-I): 1963 [19]. Subsequently, a sieve analysis was conducted on the collected materials. The particle size distribution curve is shown in Figure 3(b). The determination of the modulus of fineness of BF-slag was conducted by the guidelines outlined in IS 383-1970 [20], resulting in a value of 2.93. Based on this measurement, the slag may be classified within the medium-density sand range. The glass fiber was employed in the study to enhance the structural integrity of the created material. The current study employed AR glass fiber. A glass fiber with an overall length of 12 millimeters with an outer diameter of 19 micrometers was utilized as a reinforcement to the material. The determination of the bulk density of glass fiber was conducted using the pychnometer technique as specified in ISO 10119 (2002). The average bulk density of a glass fiber is recorded as 780 kg/m^3.



(a) (b)

Figure 3. Particle size distribution curve of (a) SCA and (b) BF-slag

3. MATERIALS AND PROCEDURES USED

3.1. Experiments program

The mix ratios percentages that were used in this investigation were 0.15, 0.3, 0.45, 0.6, and 0.75% for cylinders, based on the methodology employed by Lal and Badwaik [4] the amounts of each component in the mix were computed. The dry weight of SCA is calculated using the formula W_{SCA}=γdmax X V_{SCA}, where γdmax maximum dry unit weight of SCA and V_{SCA} is the volume of SCA, V_{SCA}=V-V $_{BF\text{-}slag}$ –V_{GF}, V the total specimen volume (662.68 ccs), and V $_{BF\text{-}slag}$ is taken 78 ccs and volume of V_{GF} glass fiber is taken 1.1 to achieve the mix ratio 0.15 %. The mix proportion is defined as the weight of BF-slag to the weight of SCA ($W_{BF\text{-}slag}$/W_{SCA}) is taken at 10% for the investigational work. The cement to SCA ratio below 10% was insignificant and the materials used were observed to be segregated after one day of curing. Therefore, cement to SCA weight (C/SCA) is considered as 10, 20, and 30 %. For the 0.15 mix ratio and cement to SCA ratio of 20% the quantity of materials required for 1 m^3 are SCA 820 kg, BF-slag 81.48 kg, and cement 162.96 kg.

3.2. Preparation of cylinder

For the preparation of specimen SCA, BF-slag for reinforcing purposes, and glass fiber (GF) and cement were used for binding purposes. The components used for the mixing process are unable to be combined to produce a uniform mixture above the ideal moisture content of 20% obtained from the standard Procter test. Further, for research purposes, the water to SCA (W/SCA) was taken at 50% of the weight of SCA for cylinders (Figure 4). Cylindrical molds of 75 mm diameter and 150 mm long as shown in Figure 4(a) were used in experimental work and curing of the specimen shown in Figure 4(b). For each mixing ratio 3 cylinders were cast, total of 135 samples were tasted for 7, 14, and 28 days as shown in Table 1.

(a) (b)

Figure 4. Cylinder specimen for (a) cylindrical mold (b) curing of the specimen

Table 1. Mix ratios and quantities of components for a cylinder

S. No.	Mix ratio (%)	Weight of SCA W SCA (gm)	Weight of BF -slag W BF-slag (gm)	Weight of glass fiber W GF (gm) 10% Cement	Weight of cement 10% Wc(gm)	Weight of cement 20% Wc(gm)	Weight of cement 30% Wc(gm)	Water, Vw (ml) (50%)	Curing duration in days
1	0.15	544.08	54.40	1.09	54.40	81.61	108.82	272.03	7, 14, 28
2	0.3	542.77	54.27	2.18	54.27	81.41	108.55	271.38	7, 14, 28
3	0.45	541.50	54.15	3.24	54.15	81.22	108.30	270.75	7, 14, 28
4	0.6	540.21	54.02	4.31	54.02	81.03	108.04	270.11	7, 14, 28
5	0.75	538.93	53.89	5.38	53.89	80.83	107.78	269.46	7, 14, 28

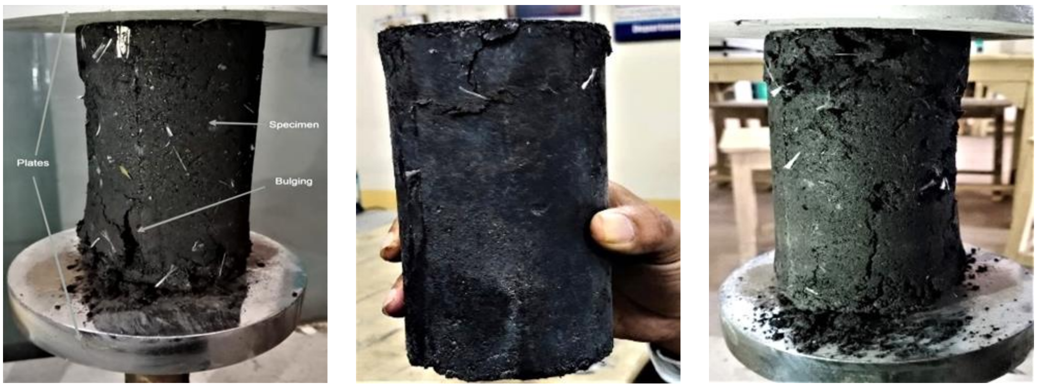
An unconfined compressive testing machine was used for compression testing on the specimens by IS 2720 (Part 10): 1991 [21] with a constant deformation rate of 1.0 mm/min on the specimen. A 5 kN capacity load cell was used to find out the specimen's compressive strength, and an axial displacement was measured using a linearly variable differential transducer (LVDT). The preparation of the SCA mixture is conducted using the technique used by Kaniraj and Gayathri [22]. Initially, the necessary quantities of SCA, BF-slag, and cement were accurately measured and then combined in a dry condition. Due to the tendency of the fibers to aggregate, a significant amount of caution and time was necessary to achieve a uniform dispersion of the fibers within the mixture. The dry ash of SCA, slag, and cement were then combined with the necessary quantity of water. The process of mixing was carried out manually, with meticulous attention given to ensuring the creation of homogenous mixtures at every step of the mixing procedure. In the study conducted by Kaniraj and Havanagi [23], it was shown that the incorporation of 20 mm polyester fibers with fly ash was more effective when performed in a wet condition as opposed to a dry one. Consequently, the fibers were incorporated into the moist mixture. This approach would facilitate the uniform dispersion of fibers inside SCA, hence preventing fiber agglomeration.

4. RESULTS AND DISCUSSION

A sequence of compression experiments was conducted on cylindrical specimens that were fabricated using various mix ratios while maintaining a constant water-to-SCA ratio of 50%. The investigation focused on analyzing the breakdown patterning, stress-strain behaviors, density, initial tangential modulus, and compressive strength of cylindrical specimens. The acquired data were then analyzed. The compressive strength of a material is often defined as the maximum axial compressive stress experienced by the material.

4.1. Failure patterns

The study examined the behaviors of SCA and BF-slag composites reinforced with glass fiber under axial compressive stress. The observed failure structures in cylindrical samples included a process of lateral stretching before the formation of fractures along separate planes, as seen in Figure 5. Figure 5(a) shows the bulging of the specimen, Figure 5(b) shows a crack in the specimen, and Figure 5(c) shows the crack and bulging of the specimen. In the current experimental investigation, a majority of the cylindrical samples exhibited a failure pattern characterized by conical deformation and subsequent splitting. All compression specimens experienced failure within an axial strain ranging from 0.77-1.00%.

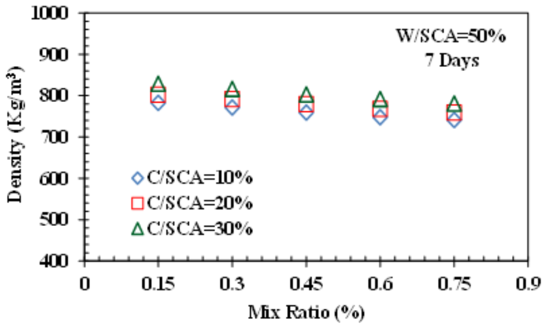


(a) (b) (c)

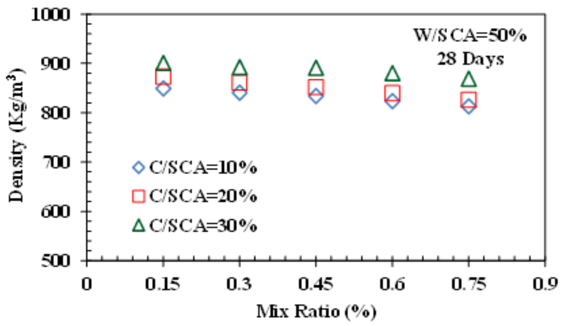
Figure 5. Cylindrical specimen inflation and crack development of (a) specimen inflation, (b) cracks in the specimen, and (c) cracks and specimen inflation

4.2. Density of cylindrical specimen

Before undergoing the crushing process, the cylindrical specimens were subjected to air drying. Subsequently, their weights were measured and their densities were calculated. The density of a cylindrical specimen is subjected to the cement percentage as, cement percentages raised from 10-30% for a certain mix ratio, density higher for 30% cement mix ratio. The impact on the density of the specimens has been seen to be associated with the water-to-cement ratio, the density of the constituent materials, and the proportion of SCA as shown in Figure 6. Additionally, it was determined that there exists a linear relationship between density and the percentage of cement ratio. A linear correlation was seen between the mixture ratio and density for a 50% cement-to-SCA content by weight ratio. Sample density ranges from 740.10 kg/m^3-900.1 kg/m^3 when the amount of water to SCA is 50%, Figure 6(a) shows the material density for 7 days, and Figure 6(b) 28 days.



(a)



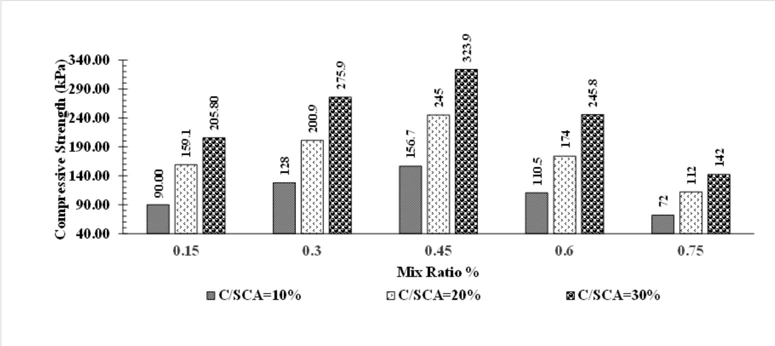
(b)

Figure 6. Density of materials for (a) 7 days and (b) 28 days

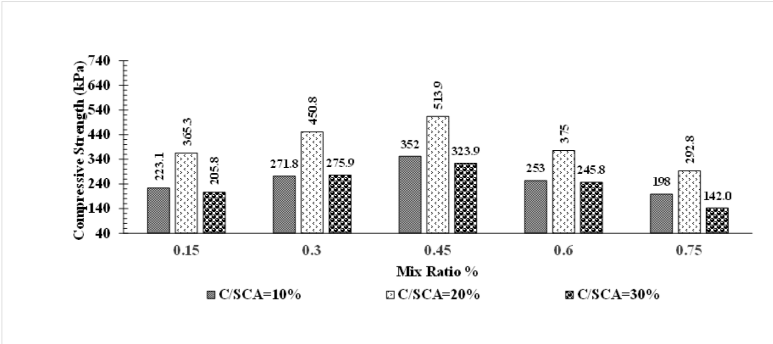
4.3. Compressive strength of the cylindrical specimen

The compressive strength of specimens supplemented with glass fiber and BF-slag is substantially influenced by the duration of the time it takes to cure, the mixture's ratio, and the proportion of cement to SCA ratio. The compressive strength has been established by evaluating the peak compressive stress magnitude as shown in Figure 7. Figure 7(a) shows the changes in compressive strength of SCA augmented with GF about the proportions of BF-slag and cement to SCA at levels of 10, 20, and 30% for 7 days of curing and Figure 7(b) shows 28 days curing. These variations are seen throughout various cure durations, with water proportions of 50%. The laboratory findings indicate that the incorporation of glass GF into SCA enhances the compressive strength of the mixture. The samples having a mixture ratio of 0.45% demonstrated the highest compressive strength across all mix ratios and cure times.

The compressive strength after 28 days exhibited a somewhat greater value compared to the findings obtained at 7 and 14 days for every combination ratio. The compressive strength of the cement to SCA ratios of 30, 20, and 10% was compared, and it was observed that the 30% ratio exhibited a greater compressive strength than the other two ratios. The compressible strength for the SCA mixture varies between 801.6 kPa-86.5 kPa. The compressive strength values of the materials produced in this investigation are found to be in between those reported for EPS geofoam blocks, which range from 44-200 kPa according to previous studies conducted by Hovarth [24], Padade and Mandal [25], Nikhade and Lal [26], Nikhade and Lal [27], and Nikhade *et al.* [28].



(a)



(b)

Figure 7. Compressive strength of materials for (a) 7 days and (b) 28 days

4.4. Regression model

The use of response surface technique (RSM) is being used for developing a (1) regression that estimates the compressive strength of newly discovered geomaterials. To construct the regression model, an overall of thirteen possibilities were chosen, which includes a range of ratios of mixture between 0.15-0.75 with various amounts of cement ranging from 10-30%. The use of center composite design (CCD) is prevalent in RSM. Figure 8 shows the Pareto Chart of SCB.

$$616.2 - 33.9747 \text{ X A} + 117.0 \text{ X B} - 150.5\text{XA2} - 55.08 \text{ X B2} - 17 \text{ X AX B} \tag{1}$$

Where A and B are coefficients.

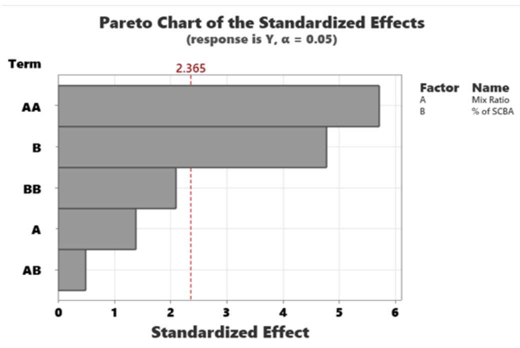


Figure 8. Pareto chart of SCB

Display the graphs illustrating the relationship between the residuals and the fittings for both compressive strength and mixing percentage. The purpose of these charts is to confirm that the residuals exhibit a random pattern and maintain a consistent level of variation. Ideally, the data points should be distributed randomly on each side of the zero point, without displaying any noticeable patterns. In both graphical representations, the residuals exhibit a random distribution and maintain a consistent level of variation. Figure 9 shows residual vs observation of SCA.

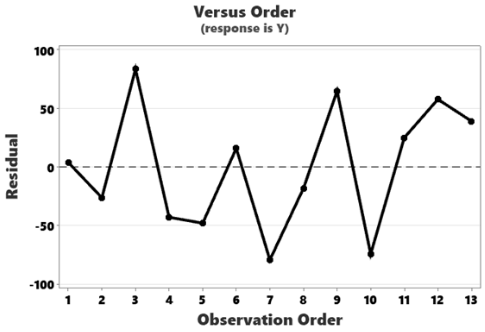
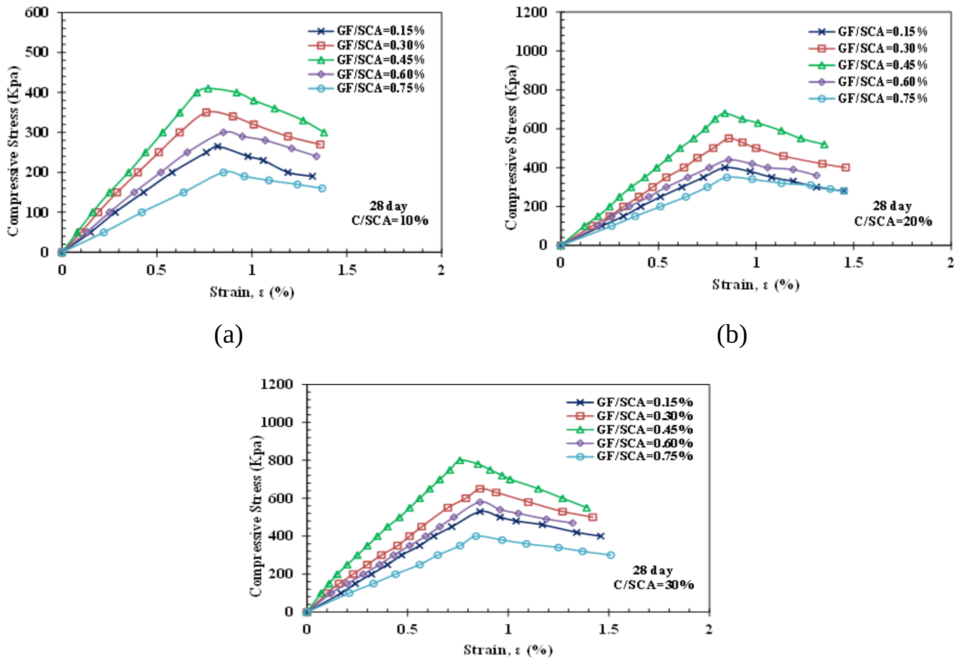


Figure 9. Residual vs observation of SCA

4.5. Stress-strain curve

The stress-strain graph has relevance in that it allows for the determination of the elastic modulus, which is computed at a certain position along the ascending portion of the representation. The stress-strain graph is significantly impacted by several factors, including the circumstances of testing, the form and dimension of the sample, intensity and time spent being loaded, quantity and placement of strain gauges, as well as the age and nature of the material being tested. The stress-strain graphs for rocks and hardened cement pastes subjected to uniaxial loads exhibit a mostly linear relationship up to the point of final stress. According to Popovics [29], the diagram for mortars and concretes has a curved shape. Figure 10 depicts the stress-strain diagrams for various mix ratios ranging from 0.15-0.75% at 28 days, Figure 10(a) shows C/SCA=10%, Figure 10(b) shows C/SCA=20%, and Figure 10(c) shows C/SCA=30%. These diagrams were obtained at an unchanged strain rate of 1.25 mm/min. An irregular correlation exists between stress and strain across all of the samples.



(a) (b) (c)

Figure 10. Stress-strain curve of SCA and BF-slag under compressive stress for 28 days of (a) C/SCA=10%, (b) C/SCA=20%, and (c) C/SCA=30%

4.6. Initial tangent modulus

The initial tangent modulus (Ei) has considerable importance in the produced material. The term "E_i" refers to the property of rigidity exhibited by a substance. The slant of the tangential lines at the first point of the strain-stress curve was calculated. There is a positive correlation between compressive strength and the greatest early tangent modulus. The Ei values of the SCA and BF-slag reinforced with glass fiber vary from 66-630 MPa. Figure 11 illustrates the correlation among compressive strength (σ) and initial tangent modulus (Ei) for the examined material. Figure 11 shows that there is a significant linear correlation between Ei and σ.

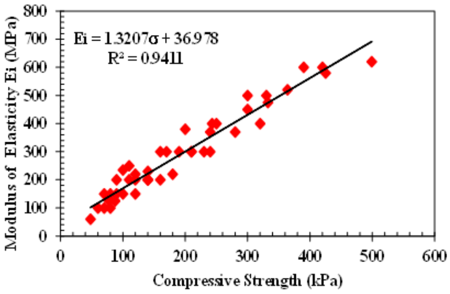


Figure 11. Correlation between initial tangent modulus and compressive strength

5. CHEMICAL COMPOSITION

The X-ray fluorescence (XRF) analysis is conducted on SCA and BF-slag at the Indian Bureau of Mining in Nagpur, which uses an X-ray fluorescent spectrophotometer. The procedure aims to ascertain the elemental composition of SCA. According to the ASTM C 618 standard, SCA is categorized as a grade F kind of material and BF-slag is a grade C type.

5.1. Mineralogical composition

The phases and ratios of SCA were determined via the use of X-ray diffraction (XRD) testing. This testing took place at the Metallurgical Engineering and Mineral Science departments at VNIT, via an XRD spectrophotometer that has an examining frequency spanning from 5-120º. The radiation source Cu-K was employed throughout the testing process as shown in Figure 12.

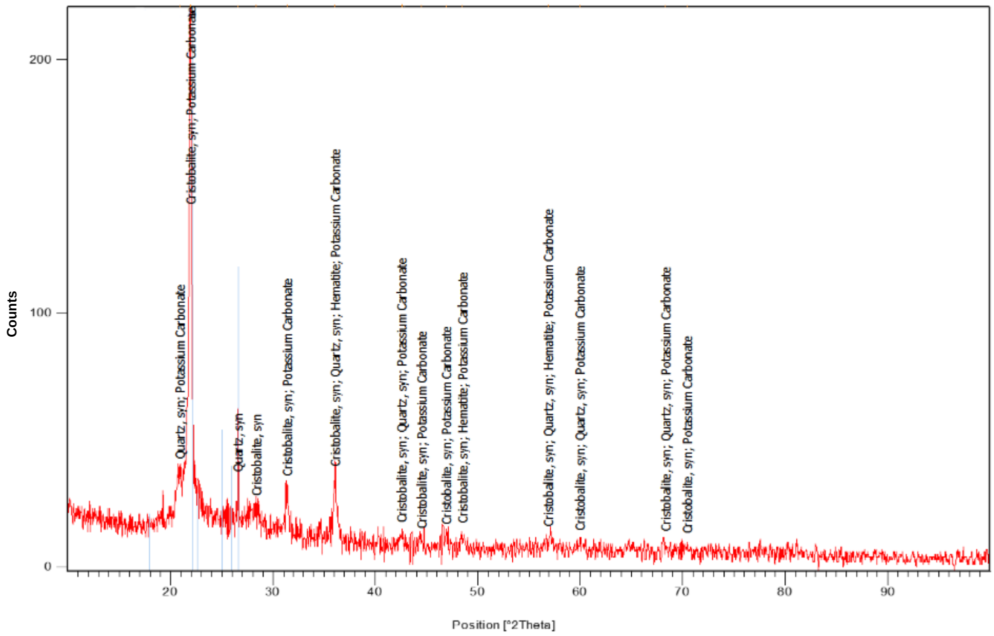


Figure 12. XRD of SCA

5.2. Morphology

The scanning electron microscope (SEM) experiment was carried out by the Division at VNIT Nagpur. Research using an SEM was conducted to investigate the structure of SCB. The scanning electron micrographs of the SCA are shown in Figure 13. The SCA utilized during the study consists of particles that exhibit coarse as well as uneven sizes.

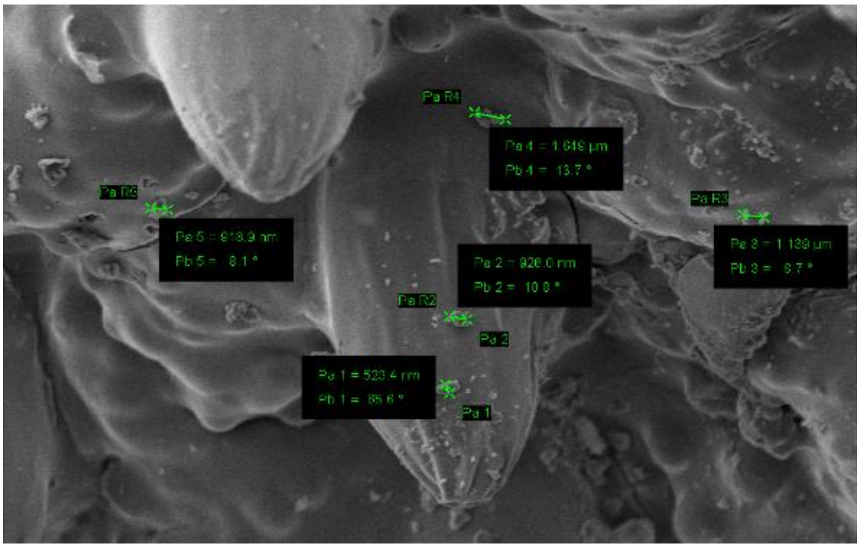


Figure 13. XRD of SCA magnification factor 1,000

6. CONCLUSION

A research investigation was conducted to examine the compressive strength, density and stress-strain nature of specimens composed of SCA along with BF-slag base materials, which had been reinforced using GF. The density of a cylinder composed of prepared components exhibits a decrease when the mixture ratio values grow within the range of 0.15-0.75 %. The average density of the compressed specimen, consisting of 30% cement and a water-to-cement-to-SCA ratio of 50%, was seen to fall from 900.1-865 kg/m^3. The observed drop in percentage amounts to around 3.56%. The experimental results indicate that the density of all produced material specimens had a positive correlation with the percentage of cement, regardless of the mix ratio.

The greatest compressive strength of the cylindrical sample was determined to be 801.6 kPa after 28 days, using a mix ratio of 0.45% and a C/SCA ratio of 30%. Conversely, the smallest compressive strength of 86.5 kPa was observed at 7 days, using a mix rate of 0.75 % and a W/SCA rate of 50%. The beginning tangent modulus was seen to have a linear relationship with compressive stress. The relationship between compression stress and mix ratio is nonlinear, resulting in a corresponding nonlinear variation in the initial tangent modulus. The possible range of initial tangent modulus values for cylindrical specimens is seen to be between 66 and 630 MPa.

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