

Original Research

Received 29 June 2026

Revised 14 Aug 2026

Accepted 28 Aug 2026

Natural Resources for Human
Health 2026, Vol. 6 (17s): 1593–1607

KEYWORDS:

Geopolymer concrete, Fly ash,
Bagasse ash, alkaline activators,
Curing type, Curing temperature,
Curing Hours, microstructure
analysis.

Mechanical and Microstructural Performance of Fly Ash Geopolymer Concrete Incorporating Sugarcane Bagasse Ash

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ABSTRACT: Today for the growth of a country, there is demand for sustainability. As there is increase in demand of infrastructure there is also increase in the sustainable development due to increase in the pollution. The construction sector is not only contributing to GDP of a country but also contributing the large amount of pollution. One of the major ingredients of the construction sector is the Cement because it acts as a binder to the concrete but manufacturing of cement contributing to the pollution due to emitting CO₂ in tonnes. CO₂ emission during manufacturing process contributes to the ozone depletion and also effecting surrounding environment. So to decrease this, there is need to have a material which will help to reduce this and a step towards sustainability can be taken. Geopolymer concrete is the one of solution to eliminate this pollution which uses waste products as the ingredients for manufacturing. These waste products are those which cannot dispose of easily and harm the environment such as agricultural waste, industrial waste, thermal power plant etc. Geopolymer concrete is a concrete which is showing good results for the 100% replacement of cement by fly ash. In this paper, investigation about the behaviour of geopolymer concrete for replacement of fly ash by the bagasse ash for different percentage is evaluated. Alkaline activators are used, NaOH and Na₂SiO₃ with 2.5 ratio. Compressive strength test had been done on different percentage replacement of fly ash by bagasse ash at different curing temperature and curing time for oven curing for 7 days. As per the research work finding maximum strength at 15% replacement of Fly ash by Bagasse ash at 100°C for 18hrs gives maximum strength up to 43.42Mpa. Microstructure analysis at the optimum percentage was performed using SEM, EDS and XRD to determine the crystalline phases and matrix morphology of the concrete.

1. INTRODUCTION

Today there is demand for sustainable infrastructure has become one of the important priorities. The demand for the green concrete is one of the methods for Sustainable development. From an ecological approach, this material should be such that it will not negatively impact the environment but enables to overcome from the waste material which cannot be dispose and negatively impacting the environment [2-15]. Due to this geopolymer concrete is one of the solutions which help to reduce the contribution of CO₂ emission and also increase the usage of the waste products such fly ash, bagasse ash, rice husk, GGBS etc. Geopolymer concrete is an alternative to the conventional Cement and results in about an 80% reduction in CO₂ emissions. [1-

20] Geopolymer is a new concept which was introduced by sir Joseph Davidovits [4]. Davidovits introduced a geopolymer technology which was used for the Geopolymer concrete by using Geopolymerization reaction so as to decrease CO₂ emission by cement manufacturing industries as it contributes to global warming [3].

As per the studies, Fly ash and agricultural waste by product can be used as additional cementitious material because it has alumina silicate composition and compatibility with the alkaline activators which are present in the geopolymer concrete. Geopolymer concrete shows good mechanical strength, decrease permeability and also improved resistance of chemical deterioration under ideal curing and alkali activator conditions. [3-19] There are different wastes by product which can be used as alternative binder materials which work effectively instead of cement with minimum degradation of environment. As there is reduction in availability of fly ash due to the restrictions on coal based power generation and hence creating need of the alternative binders which ensure sustainability and long term supply. [5] Most abundantly available waste by product is agricultural waste. One of the agricultural by product waste is sugar cane bagasse ash (SCBA) which is produce by burning bagasse in sugar mill cogeneration systems.[6] Tareg Abdalla Abdalla et.al .reviews shows that that global sugarcane production reached 0.012 billion metric tons of bagasse ash (BA) in 2018, with Brazil, India, and China as top three producers.[6] Disposing SCBA is hazardous for environment as it cause land pollution due the landfills and also contaminates the air and alkaline the soil .[7] SCBA content amorphous silica, which makes alternative for binder material for the replacement if it processed and ground in controlled way.[7-18]

As per the studies about the SCBA confirms that it possess the significant potential to be a binder material because it's high reactive silica content and favourable pozzolanic behaviour [8-21]. Using this industrial and agricultural waste as in concrete will help to not reduce CO₂ but also waste management and sustainable construction method. [9-10] According to study, SCBA participates in Geopolymerization under alkaline activation and helps to form C-S-H/N-A-S-H gels when SCBA used as partial replacement to the Fly ash, improving strength development within desired mix proportions [11]. As per findings of experiment 16M concentration of the NaOH offers better compressive strength in the partially replacement of bagasse ash in fly ash based geopolymer concrete. [11-22] The study investigated SCBA as a partial replacement for binder materials at varying proportions and demonstrated that optimum performance was achieved near 30% replacement, beyond which compressive, tensile, and flexural strengths showed a reduction for the elevated temperature [12]. The workability tends to decrease with higher percentage of SCBA content as its finer particle structure increased water absorption, although the use of super plasticizers can improve flow ability when required [12].

2. MATERIAL USED

2.1 Material

In the manufacturing process of the bagasse ash geopolymer concrete material used is fly Ash, bagasse ash, sand, coarse aggregate, alkaline solution of Na OH and Na₂SiO₃. As per Blaine's method fineness of Fly ash is 360m²/kg. Fly ash processed to low calcium class F, supplied as POZZOCRETE 60 by Dirk India Private Limited with specific gravity of 2.26.



Fig 1. Fly ash

Sugarcane bagasse ash (SCBA) is an agro-industrial waste generated after the combustion of sugarcane bagasse in cogeneration plant. Annually the production of the bagasse ash in sugar industry is in millions of tonnes in those countries where the sugar

production is high. Due to this disposal of this sugar cane bagasse ash is an environmental challenge; however, its high silica content and pozzolanic potential make it a valuable precursor for sustainable cementitious and geopolymer materials [14]. Sugarcane bagasse ash can be used as partial replacement of fly Ash geopolymer concrete by proper thermal and mechanical processing [15]. Sugarcane bagasse ash was acquired from Mula Sakar Karkana, Sonai, Ahilyanagar, Maharashtra in India. Sugarcane ash was sieved through 500 μ m sieve to eliminate the residue and collect the fine SCBA [13]. After the collection of fine SCBA it is calcined at temperature 700°C for 2hrs for promoting pozzolanic reactivity and the specific gravity of Bagasse ash is 2.56 [13-16].



Fig. 2 Untreated Bagasse ash collected from Mula Sakar Karkana, Sonai, Ahilyanagar, and Maharashtra in India



Fig. 3 Treated Bagasse ash

After calcination of SCBA, replacement of fly ash geopolymer concrete by 5%, 10%, 15%, 20%, 25% and 30% at different curing temperature and different curing time for 7days is done. The alkaline solution of NaOH and Na_2SiO_3 with the ratio of 2.5 is prepared [11]. NaOH in the pellets form is used. As per the studies, NaOH of molarity 16 is prepared a day prior to the casting.[11] Aggregate of 12.5mm and 20mm with specific gravity 2.7 for coarse and river sand as fine aggregate having 2.4 specific gravity is used.



Fig. 4 NaOH in pellets form



Fig.5 Na_2SiO_3 in gel Form

2.2 Mixing, Casting and Curing

For Bagasse ash Geopolymer concrete, mixing of all the ingredients is done in concrete mixer as per the conventional concrete [17]. For casting bagasse ash geopolymer concrete, 16M NaOH is prepared a day prior of casting. The need to prepare NaOH a day before is as it liberates heat when added to water for 16 Molarity and hence this liberated heat will not allow to bind the other material properly. Due to this, compressive strength will decrease. Bagasse ash geopolymer concrete is prepared by replacement of fly ash by 5%, 10%, 15%, 20%, 25%, 30% with the concentration of alkaline solution for 16M Na OH and ratio of NaOH/Na₂SiO₃ is 2.5.[11] The casting of cube of size 150 x150x150mm for different replacement of bagasse ash by 5%, 10%, 15%, 20%, 25%, 30% for the fly ash based geopolymer concrete are prepared. These casted cubes are oven cured for 60°C, 80°C, 100°C temperature at 6hrs, 12hrs, 18hrs and 24hrs curing hours. Compressive Strength test of cubes are done after 7 days of rest period.



Fig. 6 Mixing of material in concrete Mixer



Fig. 7 De-moulded Samples

2.3. Test Conducted

Compressive Strength testing of concrete is done as per IS516:1959. A compression testing machine with a 2000KN capacity was used to test sample. For every replacement of the fly ash by bagasse ash 03 cubes sample were tested which are oven cured for different curing temperature and curing hours. Flexural and split tensile test were also conducted for every replacement of the fly ash by bagasse ash, curing temperature and curing hours for 28 days according to IS516:1959.

3. RESULT AND DISCUSSION

3.1 Workability

On the freshly prepared concrete for every replacement of fly ash by 5%, 10%, 15%, 20%, 25%, 30% by bagasse ash workability test had been done. As per the workability test slump value for each percentage of replacement of fly ash by bagasse ash had been decreasing. It is also graphically represented in fig 3.1 for each percentage of replacement of fly ash by bagasse ash.

Table 3.1 Slump Test Result

Mix ID	%FA	%SCBA	Slump Value
95F5B	95%	5%	95
90F10B	90%	10%	86
85F15B	85%	15%	75
80F20B	80%	20%	69
75F25B	75%	25%	50
70F30B	70%	30%	38

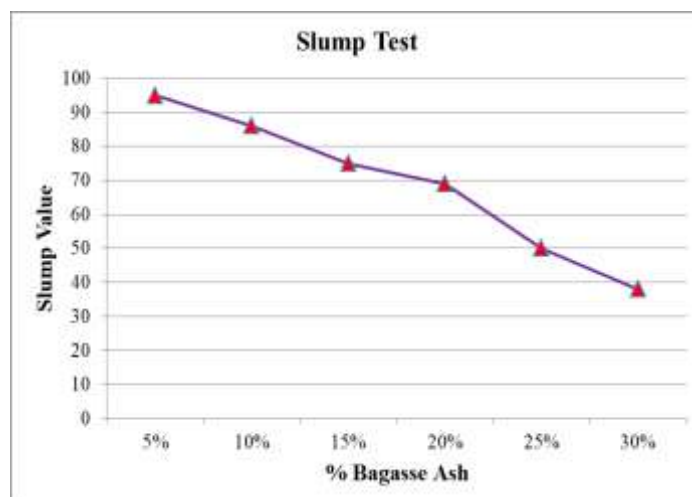


Fig.8 Slump Test

As per the above fig 8, it is observed that workability test by slump cone test shows decrease in the slump value as there is increase in the percentage replacement of bagasse ash in Fly ash Geopolymer Concrete.

3.2 Mechanical Properties

3.2.1 Compressive Strength

The oven cured cube of size 150x150x150mm is tested for compressive strength for every percentage replacement of bagasse ash for 7 days of rest period. In oven curing, optimum percentage replacement, temperature and curing hours are determined. To determine the optimum percentage of replacement of Fly ash by the bagasse ash compressive strength is evaluate at different curing hours and different temperature.



Fig. 9 Oven for oven curing



Fig. 10 Samples kept for Oven Curing

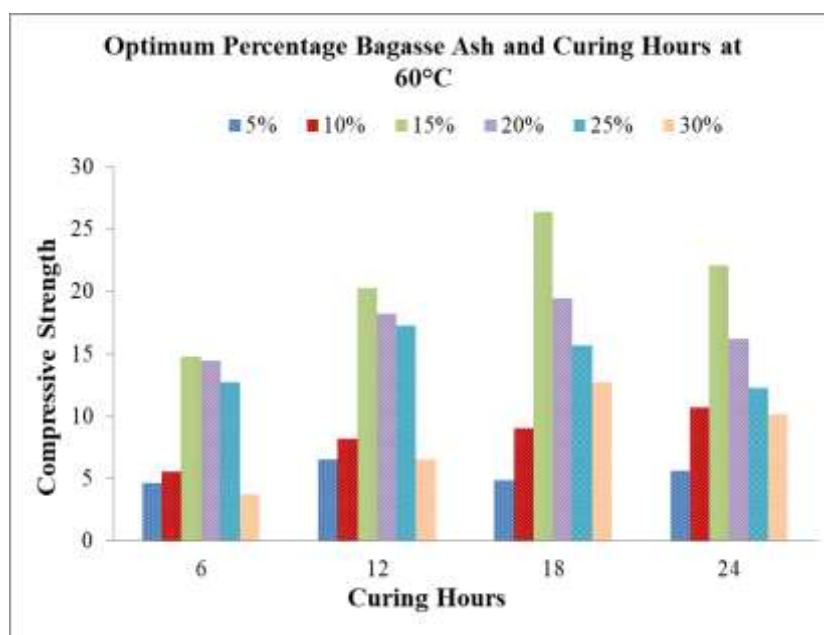


Fig.11 Optimum Percentage Bagasse Ash and Curing Hours at 60°C

In the above fig.11, it is observed that samples are oven cured at 60°C temperature for 5%, 10%, 15%, 20%, 25% and 30% for 6hrs, 12hrs, 18hrs, and 24hrs. As the curing hours are increasing the compressive strength also increase but it is observed maximum compressive strength for 18hrs of curing for 15% replacement of bagasse ash as after that there is decrease in the compressive strength. So it concluded from graph that, 18hrs is the optimum curing hours and 15% replacement of bagasse ash is optimum replacement for 60°C temperature.

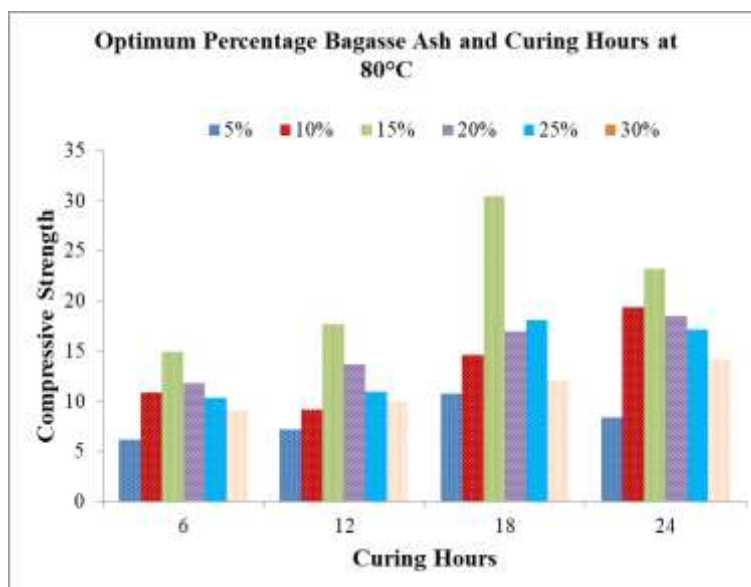


Fig.12 Optimum Percentage Bagasse Ash and Curing Hours at 80°C

In the above fig.12, it is observed that samples are oven cured at 80°C temperature for 5%, 10%, 15%, 20%, 25% and 30% for 6hrs, 12hrs, 18hrs, and 24hrs. As the curing hours are increasing the compressive strength also increase but it is observed maximum compressive strength for 18hrs of curing for 15% replacement of bagasse ash as after that there is decrease in the compressive strength. So it concluded from graph that, 18hrs is the optimum curing hours and 15% replacement of bagasse ash is optimum replacement for 80°C temperature.

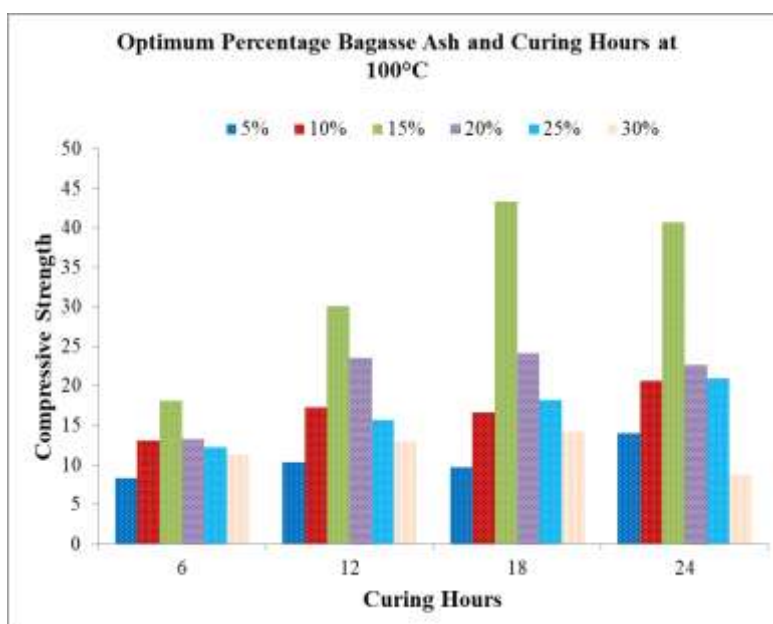


Fig.13 Optimum Percentage Bagasse Ash and Curing Hours at 100°C

In the above fig.13, it is observed that samples are oven cured at 100°C temperature for 5%, 10%, 15%, 20%, 25% and 30% for 6hrs, 12hrs, 18hrs, and 24hrs. As the curing hours are increasing the compressive strength also increase but it is observed maximum compressive strength for 18hrs of curing for 15% replacement of bagasse ash as after that there is decrease in the compressive strength. So it concluded from graph that, 18hrs is the optimum curing hours and 15% replacement of bagasse ash is optimum replacement for 80°C temperature.



Fig.14 Testing of Compressive Strength using 2000KN compression testing Machine

3.2.2 Flexural Strength

Flexural Strength is evaluate for every percentage replacement of bagasse ash, at 100°C curing temperature as maximum strength gain and 18hrs optimum curing hour's for the sample of beam having size 100x100x500mm at 28days rest period according to IS516:1959.



Fig. 15 Sample test of Flexural Strength test using UTM

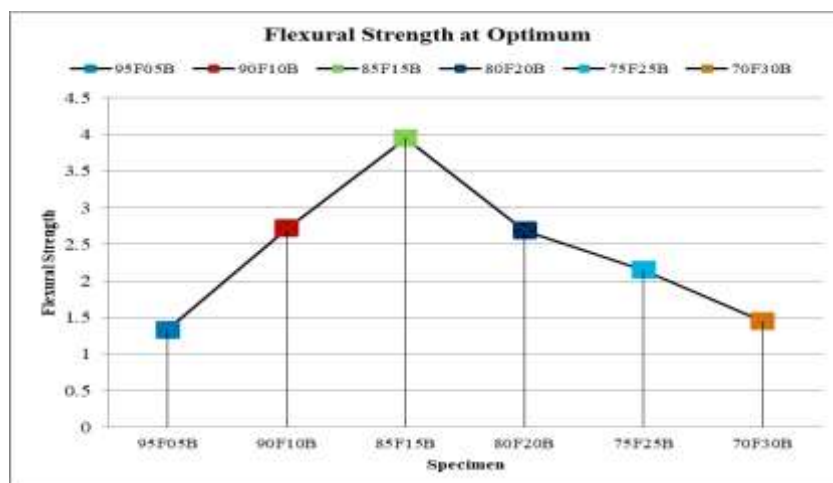


Fig.16 Flexural Strength at Optimum Condition

From above fig 16, it is observed that flexural strength for the beam sample are tested for different percentage of replacement of bagasse ash at 18hrs of optimum curing hours and at 100°C curing temperature. It is observed that at 15% replacement of bagasse ash flexural strength is increasing 20% when compare to ordinary Portland cement as per IS 456:2000.

3.2.3 Split Tensile Strength

Split tensile Strength is evaluate for the every percentage replacement of bagasse ash, at 100°C curing temperature as maximum strength gain and 18hrs optimum curing hour's for sample of cylinder of size 150x300mm for 28 days rest periods according to IS516:1959.



Fig. 17 Sample test on Split tensile test apparatus

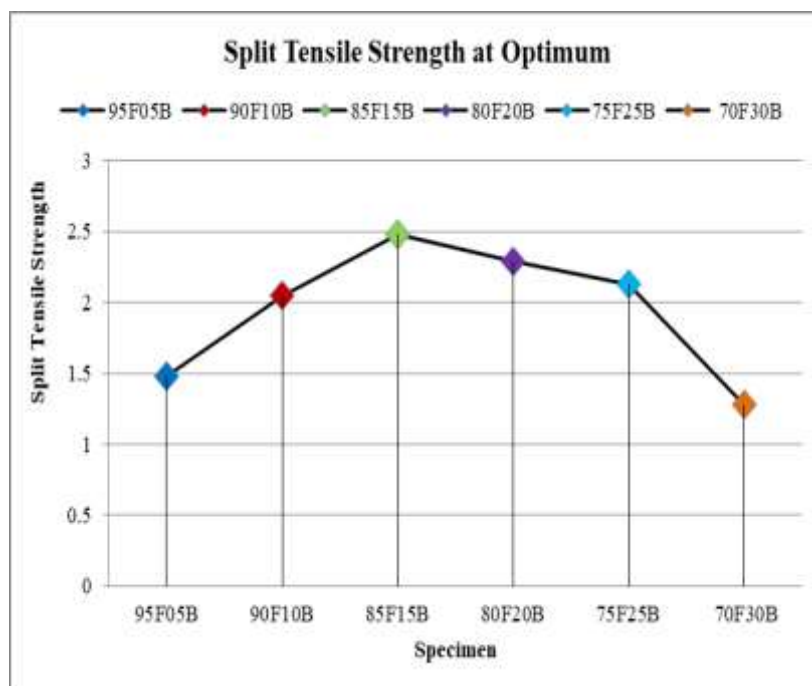


Fig. 18 Split Tensile Strength at Optimum Condition

From above fig.18, it is observed that split tensile strength for the cylinder sample are tested for different percentage of replacement of bagasse ash at 18hrs of optimum curing hours and at 100°C curing temperature. It is observed that at 15% replacement of bagasse ash flexural strength is increasing 11% when compare to ordinary Portland cement as per IS 456:2000.

3.3 Microstructure Analysis

3.3.1 Scanning Electron Microscope (SEM)

Sugarcane bagasse ash was characterized using SEM method to analyses the particle morphology for the bagasse ash material and 15% replacement of bagasse ash geopolymer concrete.

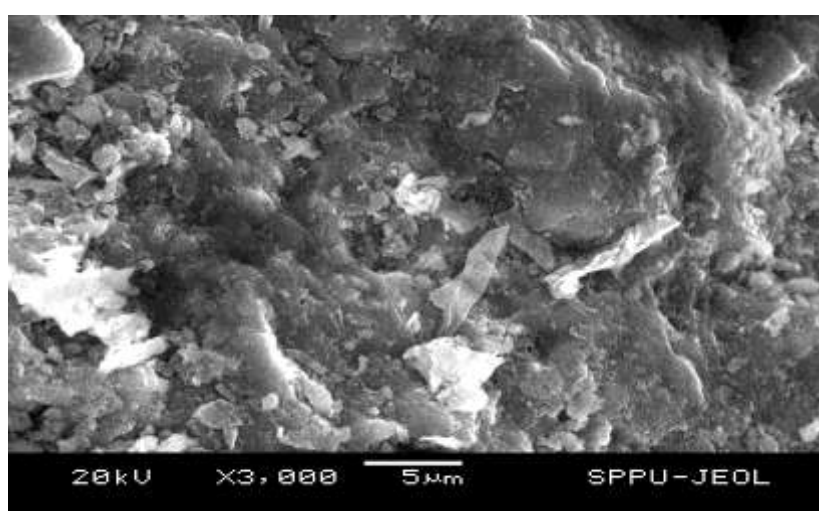


Fig. 19 SEM analysis of bagasse ash sample

In the above Fig.19 presents SEM micrographs of test results for the bagasse ash at 3000 magnification with a scale bar of 5µm. In this SEM image, particles appear irregular, angular and partly elongated. In this, central region contains a cluster of smaller

visible features among the larger particles. Particle size and shape vary across the examined fields indicating morphological heterogeneity. Particle agglomerations are observed.

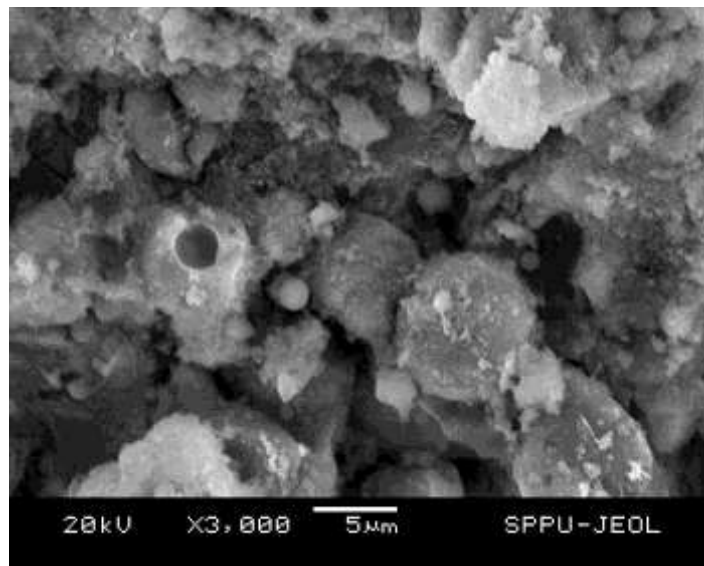


Fig. 20 SEM analysis of 85F15B cured at Bagasse Ash Geopolymer Concrete

In the Fig 20 shows SEM micrographs of test results for the 15% replacement of bagasse ash geopolymer concrete oven cured at 100°C for 18hrs of curing time at 3000 magnification with a scale bar of 5μm. In the SEM image, particles appear spherical shape with more continuous matrix and fewer larger visible voids.

3.3.2 X- Ray Diffraction (XRD)

X- Ray Diffraction is a microstructural scanning test which is performed on the bagasse ash and 15% replacement of bagasse ash geopolymer concrete which oven cured at 100°C for 18hrs to investigate and identify a materials atomic and crystallographic nature. The XRD analysis test the position of substance to identify its composition by irradiation of materials with the entrant X –rays and then counting the intensities and scattering angles. The figure 25 and 26 shows the materials atomic and crystallographic nature of bagasse ash and 15% replacement of bagasse ash geopolymer concrete which cured at 100°C for 18hrs.

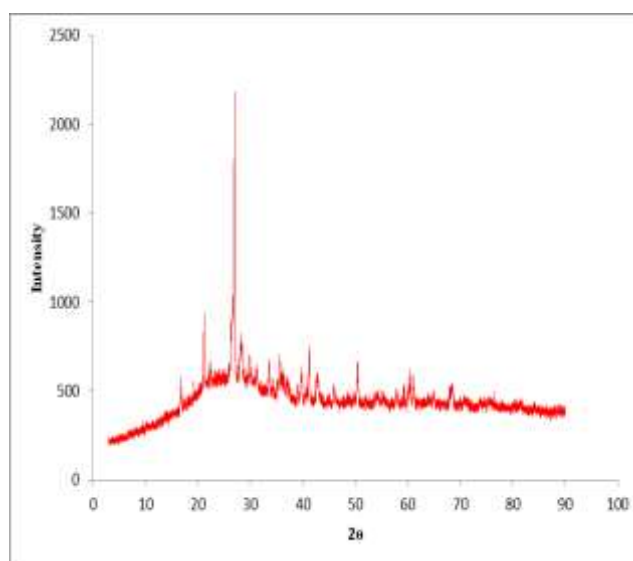


Fig 21 XRD of bagasse ash

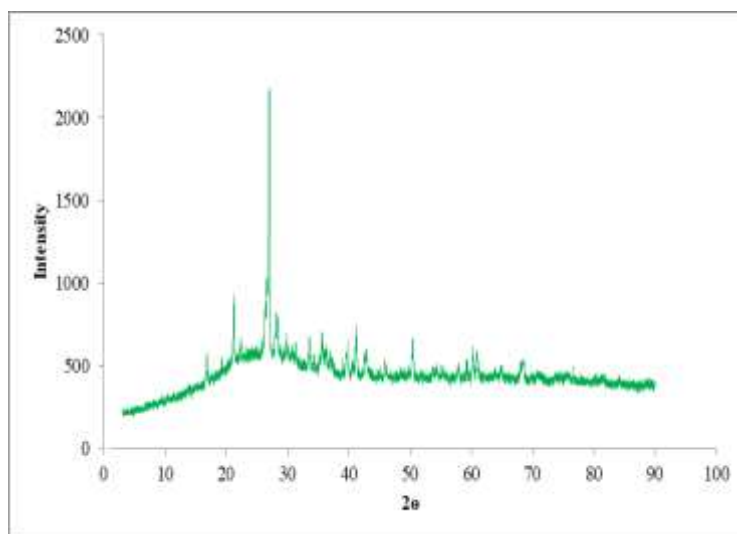


Fig 22 XRD of 85F15B Bagasse Ash Geopolymer Concrete

4. CONCLUSION

In this study, the impact of oven curing for different curing hours at different curing temperature for different percentage of replacement of fly ash by bagasse ash had been evaluate. Based on the above experimental work carried out, it observed that curing hours and curing temperature play a vital role in compressive strength of bagasse ash geopolymer concrete. From the above experimental work following can be concluded:

1. The workability of the bagasse ash geopolymer concrete decreases as we increase the percentage replacement of the fly ash by bagasse ash primarily may be due to its larger specific surface area. As the larger specific surface area which will increase the demand for alkaline activator solution for the proper mixing.
2. The experimental results demonstrated that oven curing of bagasse ash geopolymer concrete shows an increment as the percentage of the replacement of bagasse ash is increase from 5%, 10% and 15% for 60°C, 80°C, and 100°C temperature but as the percentage replacement increase from 20% -30% a decrement in the strength has been observed.
3. In this study, an increase in the percentage replacement of the fly ash by bagasse ash from 5%, 10% and 15% for 60°C, 80°C, and 100°C temperature for 6hrs, 12hrs, 18hrs and 24hrs shows an increment in the compressive strength up to 15% replacement of bagasse ash but after that from 20% -30% replacement shows decrement.
4. From above observation, it is concluded that 15% replacement of bagasse ash geopolymer concrete is optimum replacement for 18hrs of optimum hours of curing.
5. The flexural and split tensile strength test are carried out for the different replacement at 100°C for 18hours of optimum curing hours to determine the behaviour for each percentage. It is concluded that as the result of flexural and split tensile strength shows increment 20% and 11% respectively at 15% replacement of bagasse ash geopolymer concrete.
6. The bagasse ash geopolymer concrete containing 15% bagasse ash cured at 100°C temperature for 18hrs of curing hours exhibit the optimum flexural and split tensile strength at 28 days.
7. The microstructure analysis by SEM and XRD show presence of bagasse ash appear to be angular, partly elongated and presence of mineralogical phases in bagasse ash and 15% replacement of bagasse ash geopolymer concrete.

These experimental work conclude that bagasse ash can be used as replacement of fly ash up to 15% at optimum curing hours and temperature.

Acknowledgement

The author would like to express its gratitude towards the Mula Sakhari Sakhar Karkhana, Sonai, Ahilyanagar, Maharashtra, India for supplying raw Sugarcane bagasse ash for this experimental work. The author also thankful to the Civil Engineering

Department of Sandip University, Nashik, Maharashtra and Shri Chhatrapati Shivaji Maharaj College of Engineering, Nepti, Ahilyanagar, Maharashtra for providing the facilities for the experimental work.

Declarations of Conflict Interest

The author declares that there is no conflict of interest

Declarations of Funding

This research work not received any financial funding.

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