Role of Physical, Chemical, and Mineralogical Characteristics of Bagasse Ash as Supplementary Cementitious Materials in Sustainable Concrete

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Abstract: - Using sugar cane bagasse ash as a pozzolanic material has shown qualities that make it an ideal choice for replacing cement in concrete. This study examined the effects of adding bagasse ash (BA) and ultrafine bagasse ash (UBA) to concrete in incremental proportions ranging from 5% to 30%. The aim was to increase reactivity and the rate of hydration through the grinding effect. The concrete's mechanical properties were examined, such as compressive, flexural, and tensile strengths. The study found that incorporating up to 5% of BA and 15% of UBA into the concrete mix significantly improved compressive strength, flexural strength, and tensile strength. The optimal content of UBA was found to be 30%. The inclusion of UBA also notably enhanced the strength of the concrete, mainly due to the improved utilization of available free lime, which reacts with the reactive silica of BA to generate larger quantities of pozzolanic compounds. This enhancement was not primarily attributed to an increased heat of hydration resulting from the mixture of cement and BA.

Key Words: Bagasse ash, Compressive strength, Flexural strength, Pozzolanic compounds, Hydration.

1.   Introduction

The global construction industry is currently experiencing rapid expansion, driven by the world's increasing population. Notably, concrete stands as the second most extensively used material worldwide, trailing only water in consumption as of the year 2021. Within this context, the construction sector consumed a staggering 4.37 billion tons of cement globally. This consumption rate is projected to sustain an annual growth rate of 8%, potentially reaching an impressive 4.8 billion tons by the year 2027.

Central to the formulation of concrete is cement, which serves as its principal ingredient. Cement's preeminence in the construction domain can be attributed to its unique properties and binding capabilities. With global cement production already surpassing the 4.5-billion-ton mark, estimates suggest this figure could surge to a remarkable 6 billion tons by the year 2050, as indicated by reputable sources [1,2]. However, the once revered status of cement has been overshadowed by mounting concerns regarding its environmental impact, specifically its role in carbon dioxide emissions. Notably, the production of a single ton of cement contributes to the release of approximately one ton of carbon dioxide into the atmosphere, a revelation that has significantly shifted

perceptions surrounding this material [1,2].In the current context, there exists a pressing imperative to identify an alternative cementitious material that is both environmentally sustainable and economically viable within the cement industry. This pursuit presents a formidable challenge given the prevailing circumstances. To address this challenge, the incorporation of supplementary cementitious materials (SCMs) emerges as a pertinent strategy, capable of yielding substantial benefits. Specifically, the utilization of SCMs has the potential to curtail CO_2 emissions by a noteworthy 30-40% and concurrently reduce energy consumption by up to 30%, as outlined in established sources [3-5]. To effectively diminish the reliance on traditional cement, an avenue that warrants exploration involves the integration of alternative or substitute cementitious materials. Among these, industrial and agricultural by-products, such as fly ash, silica fume, rice husk ash, and BA, emerge as compelling candidates with considerable potential to replace conventional cement. Notably, a growing body of research has been dedicated to harnessing agricultural waste, including BA, as supplementary materials for cement augmentation [6].

Sugarcane cultivation stands as a substantial agricultural activity in regions like South America and Southeast Asian countries, including India, where it ranks as the second largest producer globally [7-9]. In the sugar extraction process, the residual fibrous matter, referred to as bagasse, finds utility as a fuel source for incineration in boilers [10-11]. This incineration yields BA as a residual by-product. During combustion, BA undergoes fusion in suspension and subsequently gets transported away from the combustion chamber using specialized trolleys. This residue holds the potential for repurposing in cementitious applications. The substantial accumulation of BA raises significant apprehensions regarding its disposal. The sheer volume of this ash has given rise to an issue of notable importance, compounded by the fact that its deposition over extensive tracts of valuable land has triggered environmental concerns. The potential for groundwater and soil contamination stemming from this deposition has been underscored as a major cause for alarm [13].

In this context, recognizing BA as a supplementary cementitious material (SCM) holds multifaceted advantages. Notably, its adoption serves a dual purpose: not only does it contribute to the reduction of CO_2 emissions, but it also plays a pivotal role in abating environmental pollution [14]. The research conducted by Fairbairn et al. delves into the inherent potential of bagasse ash as a viable solution to the quandary posed by solid waste generation. Specifically, this waste, which takes the form of bagasse ash, exhibits promising prospects for repurposing as a construction material. This exploration opens up new avenues for sustainable waste management practices and innovative applications within the construction domain [15].Previous investigations have extensively examined the impact of bagasse ash on concrete properties. For instance, in a study, it was observed that the density of concrete samples containing untreated BA experienced a decline with increasing quantities of BA incorporated into the mix [16]. Additionally, this study revealed a slight increase in air content as BA content rose and further highlighted that the slump value of concrete diminished with rising proportions of BA[11]. This reduction was attributed to the low specific gravity of untreated BA, leading to an increase in powder content and subsequently hampering flowability [17]. The underlying factors for this reduced workability include the rough surfaces, irregular shapes, and porous nature of BA particles [18,19].

In a related vein, it was documented that the initial and final setting times of concrete extended due to decreased cement content resulting from BA substitution [20]. This adjustment was attributed to the diminished presence of tricalcium aluminate (C_3A), a compound pivotal for the initial hydration process [20-25]. Multiple researchers have concurred that the utilization of BA as a cement substitute leads to a reduction in the heat of hydration [9,26,17]. Particularly noteworthy is a finding that concrete with a 20% replacement of bagasse ash exhibited a substantial reduction of approximately 23% in total heat [26]. In an experimental work, it was demonstrated that concrete featuring a 20% replacement of BA exhibited an early strength development. This phenomenon was attributed to the elevated silica content present in the amorphous phase of BA, in conjunction with its enhanced fineness and specific surface area [20]. These collective insights shed light on the intricate relationship between BA incorporation and the diverse aspects of concrete behaviour and performance.

Several researchers have demonstrated a noteworthy trend in processed BA-infused concrete, revealing a consistent enhancement in compressive strength, tensile strength, and flexural strength with increasing bagasse

ash content within the concrete mix. Additionally, the modulus of elasticity exhibited improvement in the context of processed bagasse ash-replaced concrete. These advancements can be attributed to a combination of factors. In particular, the formation of hydration phases contributes to the heightened strength characteristics observed in BA-blended concrete. Moreover, the process of pore refinement plays a crucial role in improving the microstructure of the concrete matrix, further contributing to its overall strength enhancement. This phenomenon indicates that the incorporation of BA triggers beneficial alterations within the concrete's internal structure, resulting in improved mechanical properties.

In contrast, the scenario is different when considering raw bagasse ash mixed concrete. Here, the modulus of elasticity has shown a decrease, primarily attributable to the reduction in cement content due to the presence of bagasse ash. This reduction in cement content can lead to altered mechanical properties in the resulting concrete. In essence, these findings underscore the significance of processing bagasse ash to harness its positive impact on concrete performance. The careful manipulation of bagasse ash content and its incorporation into the concrete mix presents a potential avenue for optimizing the material's structural and mechanical qualities, contributing to more resilient and efficient concrete compositions.

Numerous researchers have extensively explored the potential incorporation of BA into concrete, leveraging its inherent pozzolanic attributes. These investigations have primarily focused on evaluating both the fresh and mechanical properties of concrete blends containing BA [27, 28, 29]. While these endeavours have significantly contributed to our understanding, it's worth noting that much of the previous research has predominantly centered on investigating the integration of various agro-based industrial by-products, such as fly ash and rice husk ash, in concrete formulations that include BA.

However, it's imperative to approach the utilization of BA judiciously, as an excessive addition of BA can lead to undesirable consequences, including reductions in concrete strength and workability. Despite the substantial body of work delving into the fresh and mechanical properties of BA-infused concrete, it's important to recognize that several influential factors that impact the behavior of concrete with bagasse ash, such as fineness, chemical composition, and lime content, have often been overlooked.Consequently, the present study seeks to address these gaps by focusing on comprehensively understanding how the properties of bagasse ash exert a transformative effect on both the mechanical robustness and durability of concrete blends containing it. Central to this endeavor is the exploration of the intricate interplay between the physical, chemical, and mineralogical attributes of bagasse ash and how these factors collectively shape the performance and longevity of concrete when employed as a partial substitute for cement.

To gain a deeper comprehension and validate the underlying mechanisms at play, this study also delves into the role of various aspects, including the impact of different forms of BA, such as ground BA, as well as the potential enhancement resulting from the introduction of lime. By investigating this broad spectrum of factors, this research endeavour to provide a comprehensive foundation for optimizing the integration of bagasse ash in concrete mixtures, thereby contributing to the development of sustainable and high-performance construction materials.

2. Materials and Methods

2.1 Materials Used

Cementitious binders (CB) used for the production of concrete consists of ordinary Portland cement (OPC)-grade 53 confirming to IS 8112-1995, BAwas obtained from Nirani Sugars located in Mudhol, Bagalkot, Karnatakaand natural hydrated limewas used.This study focuses on BA grounded in a ball mill around 6000 cycles at 150 rpm to produce UBA. The physical properties of BA and UBA as given in Table 1.

2.2.1 Physical and Chemical Characteristics

The particle size analysis of binders was characterized by using the Malvern laser instrument (MSS + Hydro MU model) conforming to ASTM B822-14(20) and the specific surface area of binders was tested by using Blaine's air permeability apparatus with ASTM C204-11(21). The particle size distribution of binders is shown

in Figure 1 whereas the physical properties of binders are presented in Table 1 The particle size distribution (PSD) of CB presents that OPC, BA and UBA are almost similar particle sizes. Particularly UBA shows a similar trend of OPC whereas BA shows a coarser PSD among CBs as shown in Fig. 1. As was expected BA has a coarser distribution than UBA as it distinguishes between as received and grounded form. However, both BA and grounded BA have D_{50} values higher than Portland cement. the specific surface area of BA and grounded BA is higher than cement.

Table 1-Physical properties of materials

| Properties		OPC	BA	UBA	HL	M-Sand
D50(µm)		19.56	37.87	25.01	14.67	-
Specific Gravity	3.15	1.90	2.10	-	2.57	
Specific Surface Area		357	220	495	851	-
Moisture Content (%)		0.18	0.83	0.59	0.13	3.35
Bulk Density (kg/m3)		-	-	-	-	1430
Fineness Modulus		-	-	-	-	3.52
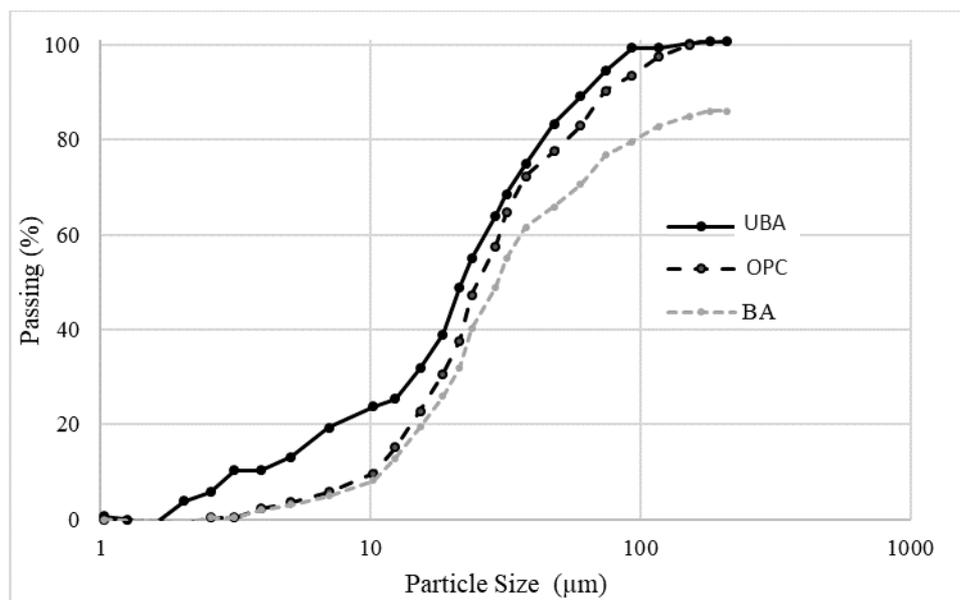
Fig. 1 Grain Size Distribution of Cement, Bagasse ash and grounded Bagasse Ash.

The X-rays, test was conducted to determine the oxide composition of binders using Panalytical (Axios-FAST) spectrometer according to ASTM D4326-04 (23). The chemical composition of binders and accelerator is presented in Table 2. The oxides composition of CB shows that BA is primarily containing 73.18 % of silica, 3.65% alumina, 1.78% of iron, 3.56% calcium, and 1.11% of magnesium. Minor constituents are sodium and potassium, and LOI is 14.78%. Additionally, crystalline compounds are in small amounts as can be seen in Fig. 6. Also, can see the chemical composition of OPC and HL. Sum of SiO_2, Al_2O_3 and Fe_2O_3 is more than 78% that shows BA is a pozzolan material on the basis of ASTM C618-14 (25). Based on the oxide composition of BA, it can be classified as class-F pozzolan materials (less than 10% of CaO and LOI is between 5-10%) according to guidelines stated in ASTM C618-14. Particularly, the oxide composition of BA was found to be almost in the range as reported in previous studies. Additionally, BA showed that the amorphous silica and alumina contents of BA were within requirement ASTM C618-14 (25). The expected chemical composition of OPC and BA as per linear law is shown in Table 2. The morphology of CB's observed using the Phenom table

SEM's based on ASTM E986-04 (22). In addition, loss of ignition (LOI) was determined using a furnace conforming to ASTM C114-04 (24).

Table 2. Composition of OPC and Bagasse ash

| Oxide composition	OPC	BA	5% BA	10% BA	15% BA	20% BA	25% BA	30% BA
SiO_2	20.90	73.18	23.51	26.13	28.74	31.36	33.97	36.58
Al_2O_3	4.90	3.65	4.84	4.78	4.71	4.65	4.59	4.53
Fe_2O_3	4.21	1.78	4.09	3.97	3.85	3.72	3.60	3.48
Ca O	58.21	3.56	55.48	52.75	50.01	47.28	44.55	41.82
MgO	0.89	1.11	0.90	0.91	0.92	0.93	0.95	0.96
K_2O	0.29	0.98	0.32	0.36	0.39	0.43	0.46	0.50
Na_2O	0.21	0.96	0.25	0.29	0.32	0.36	0.40	0.44
LOI (%)	2.01	14.78	14.14	13.50	12.86	12.23	11.59	10.95

(a)

(b)
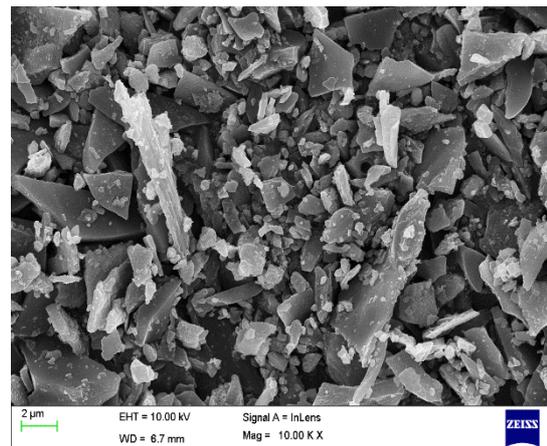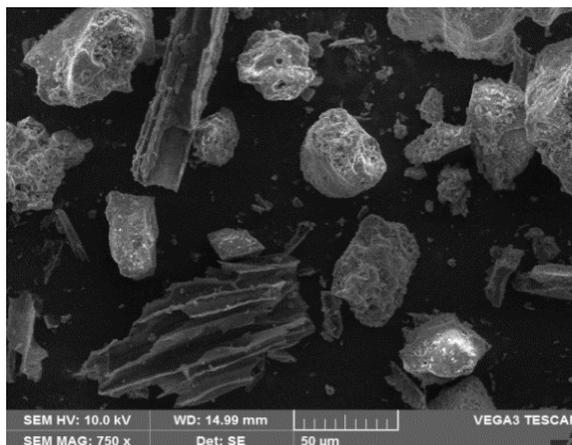
Fig. 2 SEM patterns of a) BA and b) UBA

Fig. 2a and 2b shows the SEM images of cementitious binders. Most of BA or UBA particles were found to be partially regular or angular, tubular-shaped particles with small pores and hollow cenospheres with conical sharp edges whereas ground materials OPC and HL (90% of CaO) had amorphous solid angular particles. As discussed in the previous section, BA particles were finer and coarser in some portions, which indicates the presence of cellular structure with irregularity is the reason for micro-voids and mesosphere of porous zones within the BA particles. Since BA is partially regular in shape, some flaky particles can also be seen in Fig 2 Similar characteristics were noticed in the previous studies [11].

X-Rays diffraction (XRD) test was conducted in accordance with ASTM C1365-19. This technique is used to identify the mineralogical composition of the material to identify the amorphous phase compounds' presence in BA. The XRD pattern of the BA is presented in Fig. 3a. Substantial silicon oxides (SiO_2) present within BA showed up as prominent peaks of cristobalite and quartz crystalline phases as part of SiO_2 or sub-components observed at angles (2Θ) of 15° to 55°, respectively. BA also contained considerable amounts of amorphous SiO_2

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shown by a hump ranging from 15° to 35° which could be actively participate in hydration to react with portlandite. However, BA has limited amounts of crystalline SiO_2 at 15° and 55°. Similar results was reported in a previous study that the amorphous materials comprised about 39.9% .

(a)

(b)
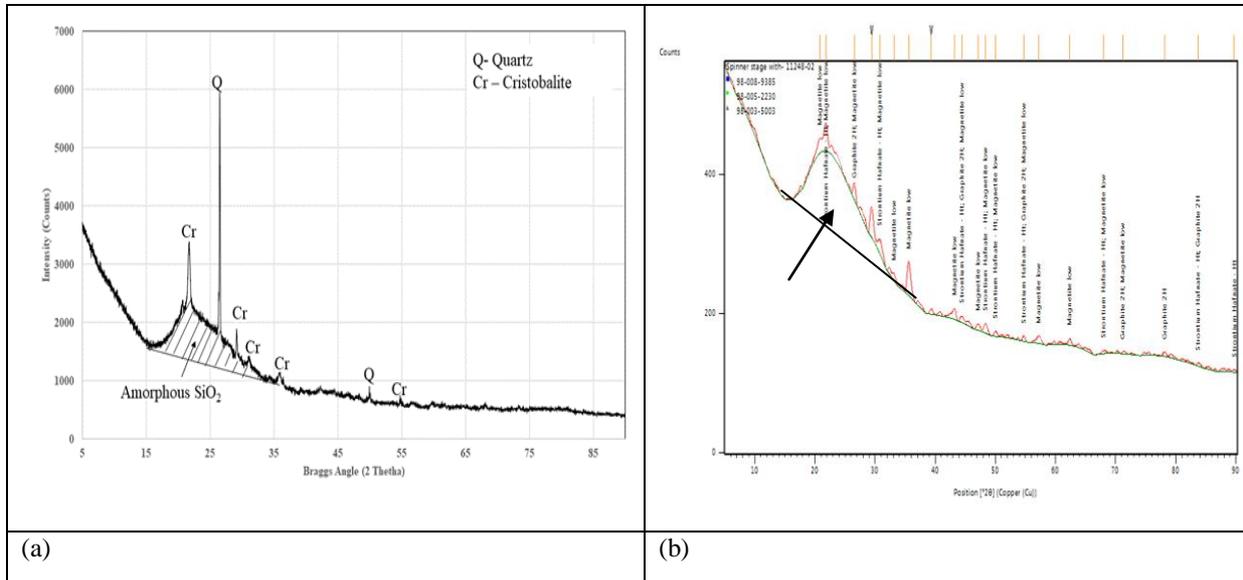
(c)

Fig.3 Microstructure studies of XRD a)BAb) UBA and c) DSC of BA

The DSC measurements were performed on BA and presented in Fig. 3c. From the DSC results of BA, it can be noticed that a major temperature around $110^{o}C$ of reaction. It was observed that at least reaction happened before the peak temperature and leads to weight loss due to presence of moisture. Further beyond the peak temperature led to thermal decomposition of cellulose and hemicellulose presence in BA. The lignin peak is quite wider and appears between $200^{o}C$ to $500^{o}C$ in BA.

2.3 Water and Superplasticizer

Portable tap water was used for mixing concrete. The superplasticizer (Sika Visco Crete–2055) was used as an admixture and purchased from the local market in Bengaluru, Karnataka. The superplasticizer (SP) used in this

research is a polycarboxylate-based third-generation SP for concrete products, which had high workability with slump retention of 0.3% by weight of the binder.

Testing Methods

2.4   Mix Design of Concrete

M25 grade of concrete was selected in this research as it is widely considered for all kinds of construction, and design of mixes were determined in accordance with IS10262. Total twelve batches (7 from phase I and 7 from phase II) consisting of plain, BA and UBA mixed to concrete in the increasing range of 5% from one batch to other in phase –I & II. Further, research was conducted by incorporating 1% lime in M25 grade of concrete mixes containing 25%, 30% and 50% of BA to study the influences of lime on enhancement of mechanical and durability properties. The cement content for the production of M25 grade concrete was calculated and used for reference and concrete with different levels of replacement of cement with BA and UBA up to about 30% were used. In this study, BA and UBA are used to blend the cement in proportions of 5-30% and for the 25,30,35 and 50% bagasse ash blended concrete, addition of natural hydrated lime having slaked lime being used.

Binder, fine and coarse aggregates were dry mixed thoroughly then water was constantly added into the mixture until a homogenous and consistency mixture was obtained in concrete mixer (see in Fig.). Mixing process took approximately 8 to 10 minutes. The method of production of concrete followed was simple blending and compacted by table vibrator however excess concrete removed. Further, the BA measured and added to into the mixture and blended with varying percentage as mentioned in the earlier section. Slump test of fresh state concrete performed to determine required slump for M25 grade to be added to workable concrete accordance with ASTM C143-18.The fresh state of concrete was placed into cubic steel molds with dimensions of 150 mm^3, prismatic molds with dimensions of 150 x 150 x 700 mm and cylindrical molds with dimensions of 150 mm dia. x 300 mm height used for flexural and splitting tensile strength, respectively. The specimens were dismantled after 24 hours of age. The curing method followed for all Specimenswere immersed in water. The ambient condition of laboratory at the air temperature and relative humidity were in the range of 20°-25^oC and 60-70%, respectively. In addition, an adiabatic calorimeter was used to find out the total heat of hydration for varying percentages of BA blended concrete mixtures. Hydration of cement producing calcium hydroxide is an exothermic reaction is a major mechanism of formation of pozzolanic reaction compounds by reaction with calcium hydroxide formed and calcium silicates of cement and/or reactive silica present in any supplementary cementitious materials added. Since pozzolanic reactions are endothermic reaction the amount heat of heat liberated by hydrations reactions are favorable for pozzolanic reactions.

The hardened state of concretes was tested for mechanical properties. The mechanical properties include compressive strength, flexural strength and split tensile strengths as per IS/ASTM standards. The details of tests and relevant standards are presented in Table 3.

Table 3. Tests carried out and the method adopted

Properties	Tests	Relevant Standard	Parameters
	Heat of Hydration	IS 4031-(Part 9)-1988 (RA 2014)	
	Slump cone test	IS:456-2000	Medium(50mm-100mm)
Hardened Properties	Hardened Density	IS:456-2000	24.00 kN/m^3 (Present Mix:23.54 kN/m^3)
	Compressive Strength	IS:456-2000	25 MPa

| Flexural Strength | IS:456-2000, IS 516, IS 5816 | 0.7*sqrt(fck) |
| Tensile Strength | IS:456-2000, IS 516, IS 5816 | 0.7*sqrt(fck) |

3. Results and discussion

### 3.1. Influence of BA and UBA on Fresh Properties

3.1.1 Heat of Hydration

Heat of hydration of control concrete and all SCBA blended concrete with different amounts of replacement of cement with bagasse are measured and presented in Fig. 4b. It was observed that the heat of hydration of Cement with Baasse is lower than cement heat of hydration. The heat of hydration is also measured at higher amount of bagasse ash replacement along with 1% lime are also measured. The heat hydration substantially reduced with an increase in replacement of pozzolanic material. Numerous studies have reported that the specific surface of cement greatly influences the heat development rate in concrete. From the results as shown in Fig.4b, it is observed that the heat of hydration of the control mix is 332.8KJ whereas the value of heat of hydration is substantially decreased by about 27.25%. Subsequently with increase in the percentage of bagasse ash in the cement as SCM the value of heat of hydration shows a decreasing trend. This may due to the decrease in the cement content due to lower cementitious phases in bagasse ash or may not be as effective as that of cement. However, the heat of hydration is increased by 37%, with theaddition of the lime of 1% to 25%BA mix and further increment can be observed in Mix of 30% BA, 35% BA and 50% BAwith 1% lime. This may be due to hydration of lime[30].
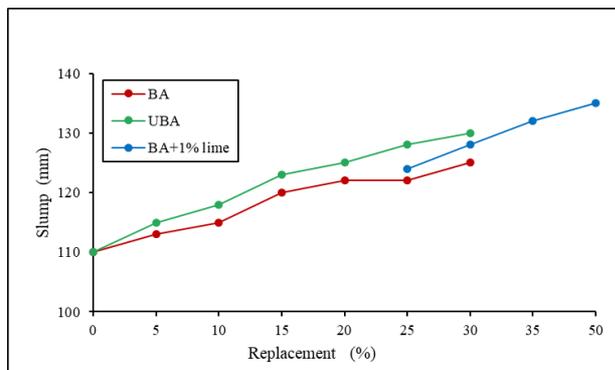
3.1.2. Slump Value
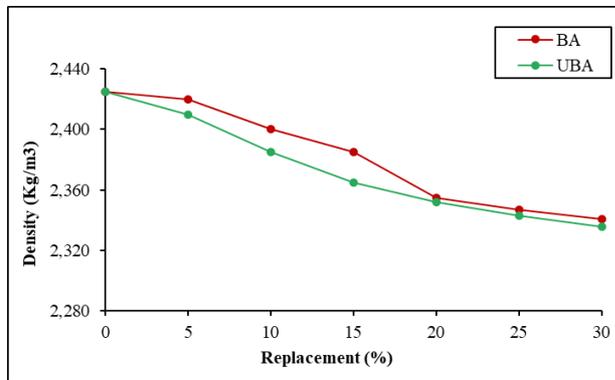
(a)
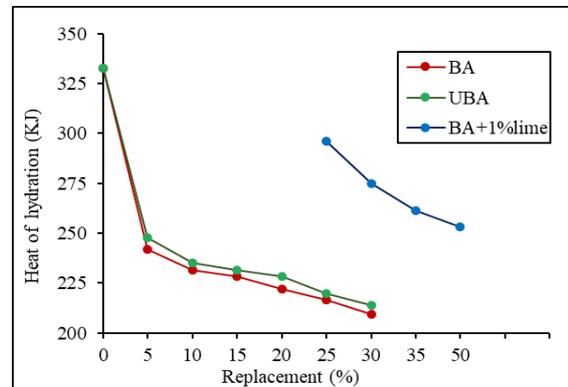
(b)

(c)

Fig.4 Fresh properties of BA and UBA blended concrete with different replacement levels: a)Density b) Heat of hydration, c) slump

Fig.4c shows the slump values for all samples with different levels of replacement of bagasse ash in cement are plotted and it is observed that the slump values are increasing linearly as replacement of BA increases, as the water content and volume of superplasticizer are maintained constant. Even though the microstructure of bagasse ash shows prismatic tubular structure it holds water in the tubular pores. The control mix shows the slump value of 110mm and it is increasing with increase in bagasse ash content in all the mixes i.e.,bagasse ash and ultrafine bagasse ash blended concrete. These trends indicates that the water demand is decreased as the quantity of bagasse ash is increased in the concrete. As the   particle size of bagasse ash is finer than the cement it gives more workability. There is no significant variation in workability is seen by addition of lime in bagasse ash concrete[20].

### 3.2. Influence of BA and UBA on Mechanical Properties

3.2.1 Density:

Fig. 4b shows thehardened density of concrete with varying percentage of BA. It is noticed that the density of concrete mixes decreases as the replacement percentage increases.In the ultra-fine bagasse ash concretealsosimilar trendof decrease in density with increase in percentage of bagasse ash content. The slight variation in both the types of blended concrete is due to the difference in specific gravity of the powder due to presence of pores in the BA as it originates as cellulose structure. Although the density of concrete decreased by 3- 5% which might not very significantlyinfluence on the reduction of density of concrete.
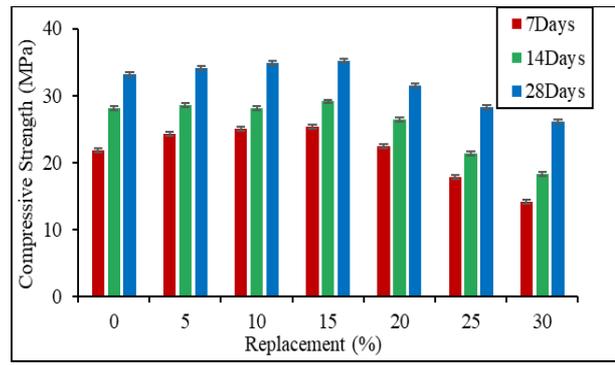
3.2.2 Compressive Strength:

Fig. 5a and 5b shows the compressive strength values corresponding to replacement of BA and UBA, respectively. Compressive strength for different levels of replacements of bags ash after curing for 7, 14, 28 days of curing period of 5% replacement were higher than the control mix and there is a marginal reduction in strength with 10% replacement of BA for cement as shown in Fig. It is observed that strength was gradually increased up to 5% replacement level and then the decreasing trend of compressive strength is observed. Up to 15% replacement level the strength is considerably matching the criteria of a satisfactory level for M25 grade of concrete. The reduction in strength may be due to dilution effect due to higher replacement level of cement with bagasse ash blended cements. Furthermore, it is observed that the strength criteria is satisfied as per code provisions and it can be opined that, the BA blended concrete may be produced with BA replacement level up to 15%, unlike the general problems of strength development in early age of fly ash concrete. The compressive strengths of different levels of grounded BAblended concrete are increasing till 15% level of replacement of bagasse ash. Strength gain behavior of BA concretewas relatively better compared to that of opt concrete as shown in Fig.5 The same trends were observed for a curing period of 28 days[29]. The increase in strength is due to formation of more pozzolanic compounds with replacement of cement by BA.This can be attributed to the additional pozzolanic reaction of reactive silica of BA and lime liberated with hydration of cementitious compounds of cement.

$2C_3S + 6H_2O = C_3S_2H_3 + 3CaOH,$.................(1)

$Reactive\ Silica + CaO = CSH$........................(2)
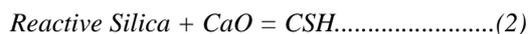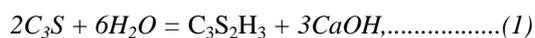
On Similar lines, the grounded bagasse ash blended concrete was also casted with different levels of cement replacements with grounded BA blended cement, in this case the trend of incremental development of strengths was observed up to a replacement level of 15%. Thereafter the decrease in strength occurs. However, the value of compressive strength is more than that of the control mix up to 15% replacement. The values of compressive strength up to 30% replacement level satisfied the strength requirement.
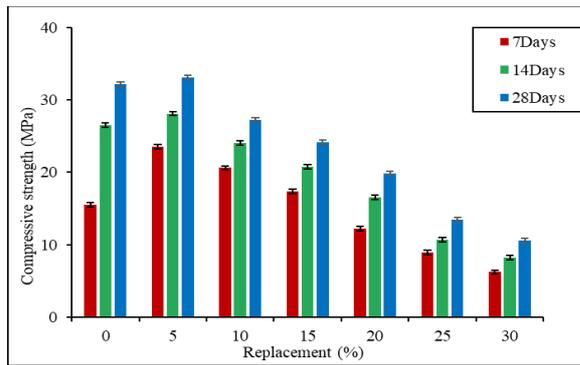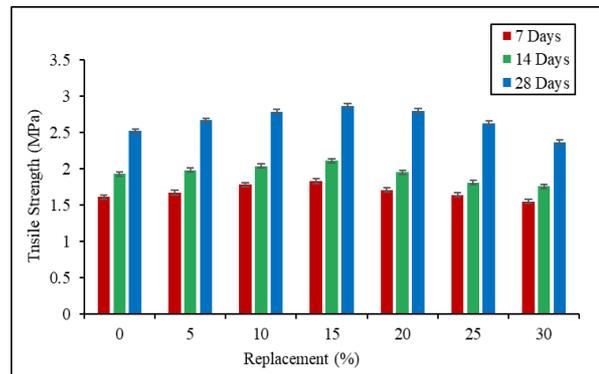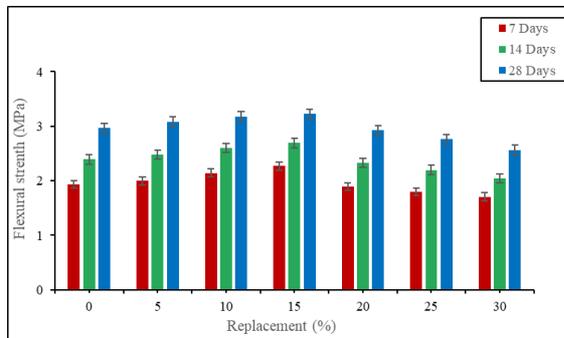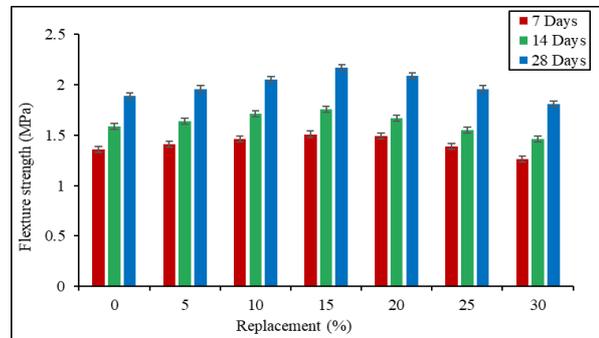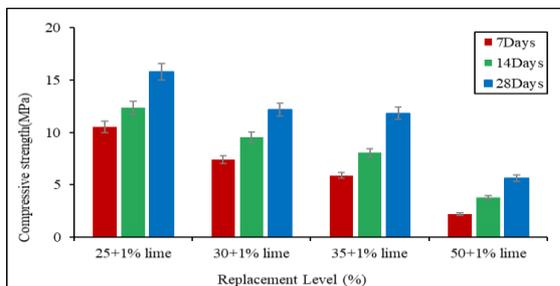
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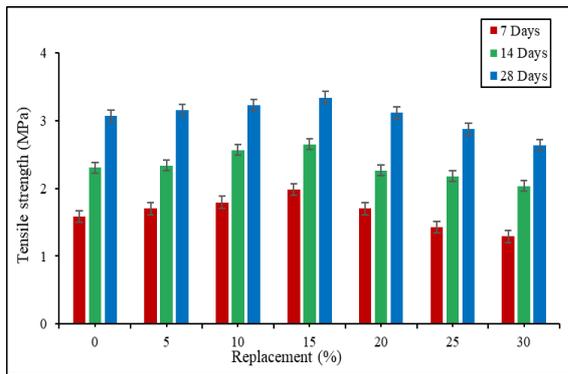
(c)

(d)

(e)

(f)

(g)

Fig.5 a)compressive strength of BA concrete, b) compressive strength of UBA concrete, c)Tensile strength of BA concrete,d) Tensile strength of UBA concrete, e) Flexural strength of BA concrete, f)flexural strength of UBA concrete, g)Compressive strength of concrete with 1% lime

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3.2.3 Flexural Strength:

Fig. 5e and 5f shows the flexural strength with respect to varying percentage of BA and UBA respectively. The flexural strength of concrete found to be 1.80 MPa to 2.25 MPa. The replacement level of BA increases the flexural strength increases up to 15% then decreases because the bonding develops between binder and aggregates was noticed relatively strong bonding up to 15% due to presence tubular shape particles act as fibres in concrete. Nevertheless, the trend was declined after 15% of BA due to insufficient amount of CaO which retards the bond strength development in the concrete. the development of flexural strength at 28 days of curing ages is highly appreciable than the early ages of concrete.

3.2.4 Tensile Strength:

Fig. 5c and 5d shows the relationship between tensile strength and replacement level of BA and UBA respectively. The tensile strength of control 1.5 MPa, 1.80 MPa and 2.50 MPa for curing ages of 7, 14 and 28 days, respectively. Tensile strengths of BA replaced with cement was observed the increases in the strength up to optimum mix of 15% then trend was followed descending pattern. The reason found be similar like flexural strengths. Nevertheless, the tensile strength of concrete with BA up to 15% attained the requisite strength.
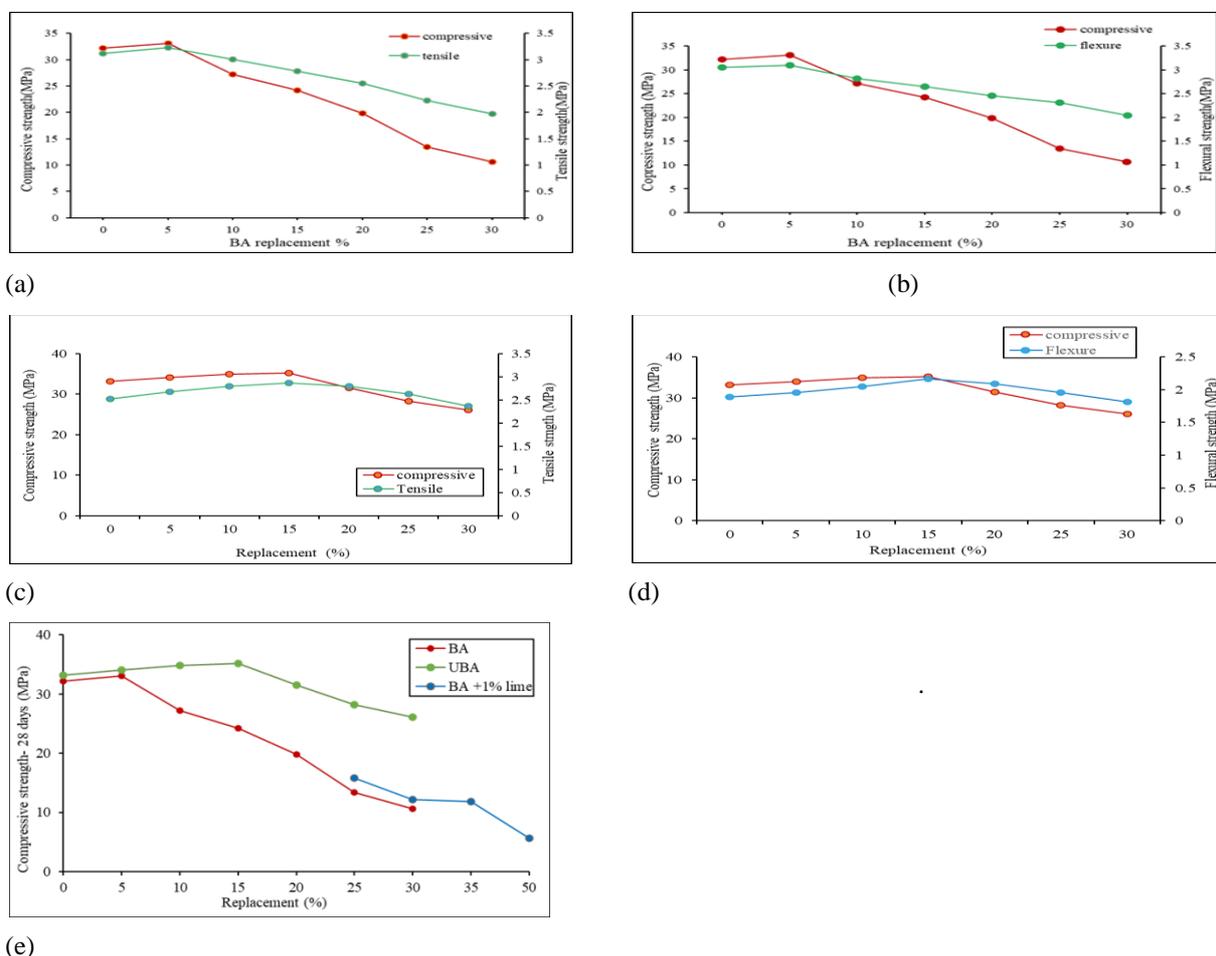

(a)

(b)

(c)

(d)

(e)

Fig. 6 a) Compressive strength and Tensile strength of BA concrete, b) Compressive strength and Flexure strength of BA concrete, c) Compressive strength and Tensile strength of UBA concrete, d) Compressive strength and Flexure strength of UBA concrete e) Comparison of strength of BA, UBA blended concrete

3.2.5 Correlation between compressive, tensile and flexural Strength of Concrete

Fig. 6e shows the correlation of compressive strengths of BA and UBA also adding lime. Comparative values of flexural and tensile strengths with respect to replacement of BA in the concrete are shown in fig 6a, 6b, 6c, 6d respectively. it was observed thatall the strengths were followed similar trend corresponding to replacement

level of BA which indicates that BA at 15% gave the better compressive strength and on contrary, not compromise on the flexural and tensile strengths that shows the contribution of BA in terms of better resistivity against the toughness and ductility.

3.3 Optimal Dosage of BA for replacement of cement in concrete from consideration of strength

Further investigation reveals that the optimum level of replacement of bagasse ash is 15% in normal bagasse ash obtained directly from the cogeneration boiler without processing further. The grounded bagasse ash with finer material we got the optimum compressive strength of M25 at 30% replacement level. This is due to the more reactive silica available in the grounded bagasse ash.

3.3.1   Influence of free lime on mechanical properties

The compressive strength of concrete was tested for the concrete cubes with the bagasse ash blended concrete having bagasse replacement level of 30%, 35% and 50% and 1% Lime. The values are plotted in a graph shown in fig 5g and 5h respectively. it can be observed that the compressive strength is increased.

4.   Mineralogical changes in BA and UBA blended concrete

The increase in compressive strenth in spite of decrease in heat of hydations shows that the effect of liberated lime reactions with reactive silica is very effective in producing pozzolanic compounds. However, with higher replacement of this production of cementitious compounds cannot compensate the lower amounts of CS with decreased cement content. The mineralogical changes for BA and UBA blended concretes are shown in XRD Patterns in Fig. 7a and 7b respectively.
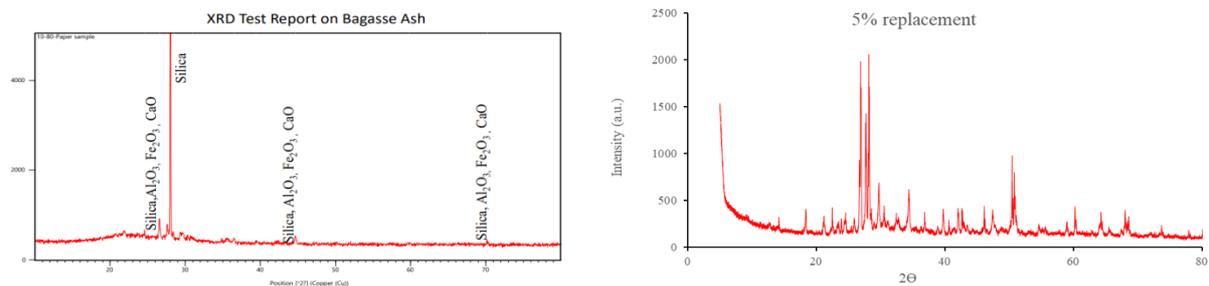

Fig. 7 XRD patterns of (a) BA blended concrete   (b) UBA blended concrete

5.   Conclusion

This paper studied on role of physical, chemical and mineralogical properties of BA on concrete and corresponding conclusions that,the physical properties of UBA found be more reactive than BA due to enhancement in specific gravity, specific surface area and grain size distribution. The chemical composition of BA found to be rich in silica (S) and requisite amount alumina (A) and iron (F)presence and that summed value obtained is 76.09% which falls under class-F pozzolanic materials as per ASTM C618-19.

The particle size of BAis slightly coarse than Portland cement and that of grounded bagasse ash is very similar to Portland cement. Carbon content of Sugarcane ash is higher at about 10%. SCBA contain high amount of oxide of silica but has reactive silica which is useful for production of cementitious compounds by reaction with free lime. BA produced higher amounts of cementitious compounds indicating that it has insufficient lime content to completely react and utilize its reactive silica. The mechanism changes in hardened properties and durability are explained based on the changes in the changes in pozzolanic reactions, changes in density and structural changes.It is observed that the improvement compressive strength and tensile strength of BA concrete upto about 15% of replacement of cement with BA but decreases with higher replacement of cement with BA. The increase is due to production of higher amounts pozzolanic compounds due to reactions between reactive silica of BA and lime produced by hydration of calcium silica hydrate. But with further higher replacement of cement with BA lime produced by hydration of CSH reduces both for production cementitious phases as well as reactive lime reactions.It is very interesting to note that though both compressive strength and tensile strength

increase with BA the percent improvement in tensile strength with BA is higher than the increase in compressive strength at the same amount BA.Fine BA improved the properties better than BA due to production of pozzolanic compounds due to increased specific area.

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