Strength and Durability Studies on Ternary Blended Concrete Containing GGBS and Bagasse Ash

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Abstract— **Sugarcane bagasse is a byproduct of sugar industries found after extracting the sugar cane juice. The disposal of bagasse is causing serious environmental problems in and around the industries. Bagasse ash (BA) which is obtained after burning and grinding the bagasse has found to have pozzolanic properties. Using sugarcane bagasse ash as a cement replacement material is both environmentally and economically viable, since it reduces the problems of waste disposal and cement price hike. In this paper the properties of ternary blended concrete with bagasse ash and Ground Granulated Blast furnace Slag(GGBS) has been studied. The bagasse ash replacement levels were 0,5,10,15,20,25 and 30% by weight of cement and the GGBS replacement level was fixed as 30% for all mixes. For comparison purposes normal concrete with 100%OPC(Ordinary Portland Cement) was also tested. After studying the strength and durability properties, it was found out that the ternary blended concrete with 10% bagasse ash and 30% GGBS has showed greater improvement in the properties than all other mixes. Flexure and impact tests were done on TBC (Ternary Blended Concrete) beams with optimum dosage of bagasse ash and are compared with the control mix beams.**

Keywords— Bagasse ash, Ternary blended concrete, strength, durability

I. INTRODUCTION

Concrete is certainly the most important construction material in the world. The main component of concrete is the binder that normally is composed of Portland cement, and in some cases, the presence of mineral additions, such as fly ashes or silica fume, can also be observed in its composition. Portland cement is the conventional binding material that, actually, is responsible for about 5%–8% of global CO_2 emissions. Hence, several research groups, and even the Portland cement industry, are investigating alternatives to produce green binding materials. Nowadays, several studies have been performed in order to reuse industrial and/or agricultural wastes abundantly generated in society: this approach is in agreement with sustainable development principles. Among the waste materials generated bagasse ash, which is a byproduct of sugarcane industries is abundant and possess the required pozzolanic property. With the country's plan to boost the sugar production to over 3 million tons by the end of 2015, the disposal of the bagasse ash will be of a serious concern. The disposal of this material is already causing environmental problems around the sugar factories. The boost in construction activities in the country created shortage in most of concrete making materials especially cement, resulting in an increase in price. Using sugarcane bagasse ash as a cement replacement material is both environmentally and economically viable, since it reduces the problems of waste disposal and cement price hike.

To utilize materials more effectively and reduce the cost in construction industry, Ternary Blended Concrete (TBC) that made with Portland clinkers and other two admixtures may be a better option because it presents several advantages over binary cements. The mostly used supplementary materials in ternary blends are silicafume, metakaolin, flyash, Ground Granulated Blast furnace Slag (GGBS) etc. Among these GGBS is a better option since it has a higher proportion of the strength-enhancing calcium silicate hydrates (CSH) and is routinely specified in concrete to provide protection against both sulphate attack and chloride attack. So this study examined the potential use of sugarcane bagasse ash and GGBS as a partial cement replacement material.

II. EXPERIMENTAL PROGRAMME

A. *Materials*

Detailed tests were conducted in the laboratory to evaluate the required properties of the individual materials. Properties of the constituent materials were tested as per the methods prescribed by the relevant IS codes.

Cement: Ordinary Portland cement confirming to IS 12269 (53 Grade) was used for the experimental work. Fineness was 4%. Specific gravity was 3.13.Initial and final setting times were 140 and 480 minutes respectively.

GGBS: GGBS was supplied by Quality Polytech, Manglore. Specific gravity of GGBS was determined as 2.90 and fineness as 385 m^2/kg.

Bagasse ash: Bagasse ash was collected from Sakthi sugar mills, Erode. The specific gravity of bagasse ash was determined as 2.16 and the fineness as 18%.

***Fine aggregate*:** Manufactured sand having fineness modulus 2.87 and specific gravity 2.63 was used as fine aggregate. Tests are conformed to IS: 383-1970[12].

***Coarse aggregate*:** Crushed stone aggregate of size between 20mm and 4.75mm and specific gravity 2.80 and fineness modulus 7.09 was used as coarse aggregate. Tests are conformed to IS: 383-1970[12].

***Water*:** Clean drinking water available in the college water supply system was used for mixing.

Superplasticizer: The superplasticizer used was Ceraplast300 of specific gravity 1.24.

B *Mix Proportion*

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance. The mix design is done as per IS 10262-2009. Percentage dosage of superplasticizer (high range water reducers) is an additional parameter to be considered for designing an OPC mix. Percentage dosage of super plasticizer was fixed as per the mix design method described in IS 10262-2009.The super plasticizer dosage was fixed as 0.5% by weight of binder. Mix proportion was arrived through various trial mixes. The grade of concrete prepared for the experimental study was M_{30}. The cement: fine aggregate: coarse aggregate ratio is fixed as 1:1.68:3.02 and the w/b ratio were fixed as 0.43. The experimental investigation consists of two phases. These phases include determining the optimum dosage of mineral admixture and the flexure and impact tests on reinforced cement concrete (RCC) beams. The phases are as follows:

- Phase I – Determination of optimum dosage of bagasse ash
- Phase II – Casting and testing of RCC beams

In the first phase 8 mixes were prepared. Control sample consists of 100 % OPC only and one with 30% cement replaced with GGBS and other mixes were developed by varying the bagasse ash dosages as 5, 10,15,20,25 and 30% by weight of cementitious material in order to get an optimum level. The designations for the different mixes with varying bagasse ash dosages are as shown in Table.1. The fresh and hardened properties of each mix were studied. The tests conducted to determine the workability are slump test and compaction factor test. The compressive strength was tested after 3, 7, 28, 56 and 90 days of water curing. The impact test, modulus of elasticity, split tensile strength test and flexure tests were carried out after 28 days of water curing. The durability tests such as sulphuric acid attack test, sulphate attack test and bulk diffusion tests were conducted after 56 and 90 days. Optimum value for bagasse ash was determined from compression test, flexural test, impact test and durability tests on hardened concrete.

In phase II the study consisted of casting and testing TBC beams with optimum proportion of bagasse ash obtained from phase I. For comparison purpose, control mix beams were also cast and tested. The tests conducted were flexure test and impact test. The beams of length 1650mm, height 200mm and width 150mm were used for the present study.

Table 1. Mix Designation

Mix No	Designation	Cement (%)	GGBS (%)	BA (%)
1	OPC	100	0	0
2	BA0	70	30	0
3	BA5	65	30	5
4	BA10	60	30	10
5	BA15	55	30	15
6	BA20	50	30	20
7	BA25	45	30	25
8	BA30	40	30	30

C. *Methods*

Workability: The workability was assessed by determining the slump and compacting factor as per the **IS 1199:1959** [13] specification.

***Compressive Strength*:** In the present study, compression tests were carried out on 150mm cube specimens at ages of 3, 7, 28, 56 and 90 day as per **IS:516-1959** [14]**.** The reported strength values are average of three test results.

***Flexural Strength Test*:** Flexural strength test was conducted as per **IS: 516-1959**.The standard beam specimens of size 500 x 100 x 100 mm were used for this investigation. Two-point loading was applied and breaking load was noted at 28th day.

Split Tensile Strength: The split tensile strength was carried out on concrete cylinder of size 150mm×300mm as per IS 5816:1999 specification. The split tensile strength was determined for various mixes after 28 day water curing.

Impact Resistance: The impact resistance test was carried out as per the ACI 544-2R-89, Concrete samples of size 150 mm diameter and 50 mm thickness were used and was tested after 28 days of water curing.

Modulus of Elasticity:The modulus of elasticity was determined by subjecting cylinder specimen having 150 mm diameter and 300 mm height to uniaxial compression as per IS 516:1959 specification. The modulus of elasticity was determined for all the eight mixes with mineral admixtures after 28 day water curing.

***Sulphate Resistance Test*:** The test was conducted based on ASTM C 452-02[15] test method. After 56 days and 90 days of 20000ppm magnesium sulphate exposure, 150mm cube specimens were tested for compressive strength.

Sulphate Attack: The sulphate attack is tested on 150x150x150 mm cubes. The cubes are immersed in magnesium sulphate solution at a concentration of 20000 ppm and are tested for its loss in co mpressive strength after 56 and 90 days.

Bulk Diffusion: The bulk diffusion tests are conducted to determine the chloride ion permeability of various concrete mixes. This test is conducted on 100m diameter, 200mm height cylinders. The cylinders are immersed in a solution sodium chloride at a concentration 105 g/litre. At the end of 56 and 90 days the chloride penetration depth are measured by spraying $AgNO_3$ solution at the inner surface. Chloride penetrated depth is visible by the white precipitate formed on spraying the $AgNO_3$ solution.

Flexure Test on Beams: Flexure test was performed under two point loading with pure bending at central zone of 50cm. The beams were supported on two rollers of which one was fixed and the other was free to rotate. The effective span was kept as 150cm. Beams were tested after 28 days.

Impact Test: Impact test on beams were performed by drop test. The parameter selected for the study was total energy absorption. Loading was continued till spalling of compression zone occurred. Beams were tested after 28 days.

II. RESULTS AND DISCUSSIONS

This session provides a summary of the experimental results and endeavours to draw some conclusions. The test result covers the workability, mechanical properties and durability properties of concrete with and without admixtures.

Workability: Slump test was done to measure the workability of various mixes. The compacting factor test is more appropriate tests. The workability of various mixes was assessed as per the IS 1199:1959 specification. The values of compacting factor vary from 0.95 to 0.84. Both compacting factor and slump showed same pattern of variation with BA30 mix having minimum workability and OPC mix having maximum workability. BA30 mix showed 27.9% loss of workability when compared with the OPC. The minimum workability for BA30 mix may be due to the lesser fineness of bagasse ash particles which can result in higher water consumption thereby reducing workability. OPC mix has high workability compared to other mixes which may be due to the absence of mineral admixtures containing in it. So in short, mixes with high percentages of bagasse ash is less workable than the control one. Fig.1 and Fig.2 show the variation of slump and compacting factor for various TBC mixes.

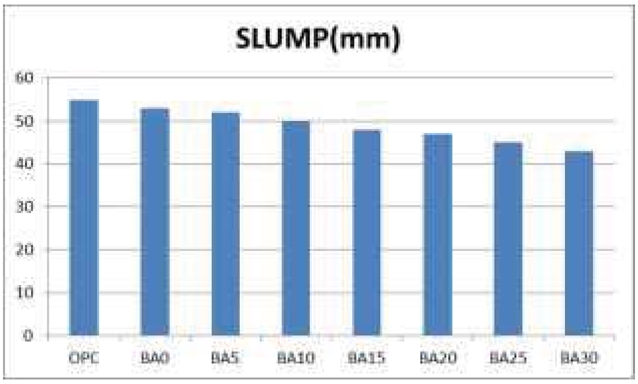

Fig.1. Slump for various mixes

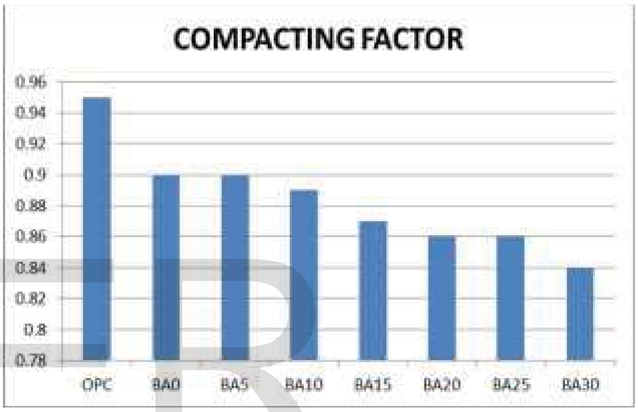

Fig.2. Compacting factor for various mixes

Compressive Strength Test: For each mix, three cube specimens of size 150mm×150mm×150mm were tested for compressive strength. Cubes were tested after 3, 7, and 28, 56 and 90 days of water curing. Fig.3 shows the cube compressive strength for various mixes at different ages.

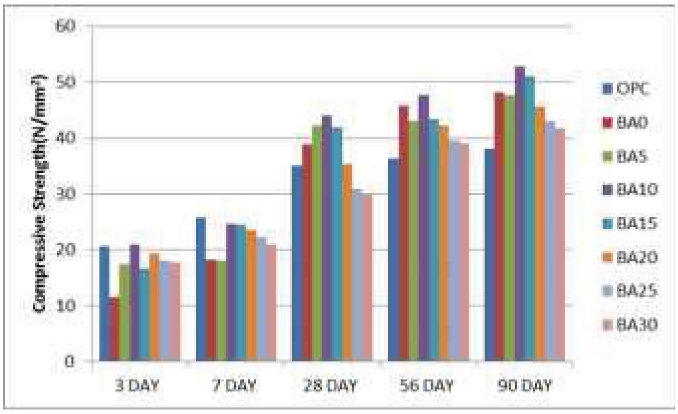

Fig.3. Compressive strength variation for different mixes

From figure it is clear that BA 10 mix has greater strength than other mixes at all ages due to the optimum amount of bagasse ash and faster pozzolanic reaction.BA10 shows an increase of 25.72% higher strength than the control one at the 28th day. The greater strength for BA10 mix can be attributed to densely packed structure owing to the higher specific surface area of GGBS along with BA.The reduction at high percentage levels may be due to the high replacement of cement by bagasse ash, reduces cement content of the mixture which in turn results in reduction of the hydration reaction. In addition to this, the high content of bagasse ash resulted in a higher water requirement, making the water unavailable for the hydration of the cement and thus reducing hydration and compressive strength development. Thus mix BA10 shows the optimum value when compared with other mixes.

Flexural Strength Test: Beam specimens of size 100mm×100mm×500mm were tested for determining the flexural strength of various mixes. Fig.4 shows the variation of flexural strength for mixes. The flexural strength is tested after 28 days of water curing.

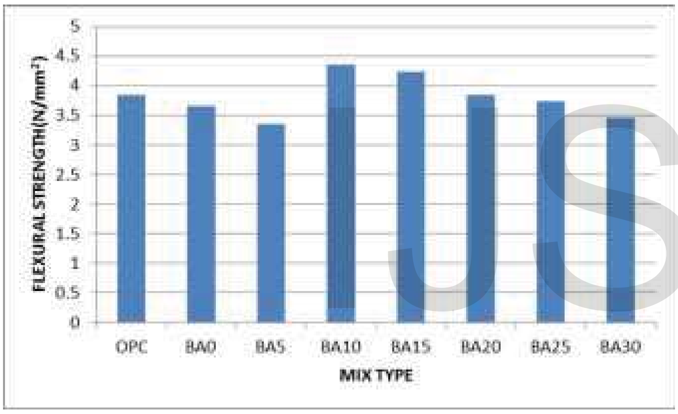

Fig.4. Flexural strength for various mixes

Impact Resistance: Dynamic energy absorption or strength is called as impact resistance and is one of the major attributes of concrete. Here the repeated impact test or drop weight test was conducted to determine the number of blows to achieve a prescribed level of distress of the specimen. To determine the impact resistance of concrete the first crack and ultimate failure of specimens are determined. The resistance offered by the concrete was found out using this test. Fig.5 shows the variation of impact resistance for different mixes. It can be seen that the pattern of variation of impact resistance for various mixes is similar to that of the variation of compressive strength. Compared to all other mixes BA10 mix has a higher impact resistance .This may be due to the pozzolanic reaction imparted by bagasse ash and additional binding property due to the presence of GGBS resulting in a denser concrete mix with finer pore structure thereby increasing the dynamic energy absorption capacity of the mix. The results of impact resistance test are presented in fig.5.

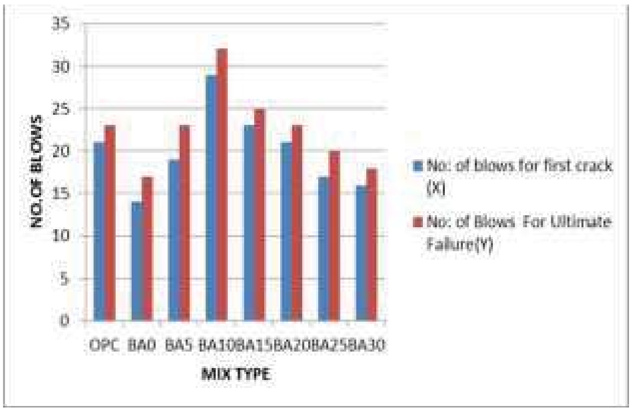

Fig.5. Impact resistance for various mixes

Split Tensile Strength: For each mix, cylinder specimens of size 150mm×300mm were tested for determining the split tensile strength. Split tensile test was done after 28 days of water curing. Fig.6 shows the variation of split tensile strength for various mixes. Split tensile strength also showed a similar variation as that of compressive strength. The highest splitting tensile strength value is obtained for BA10 mix. This may be due to the pozzolanic reaction of bagasse ash which resulted in better bonding.BA10 mix showed an increase of 30.89% higher strength than the control mix. At high replacement levels the strength dropped.

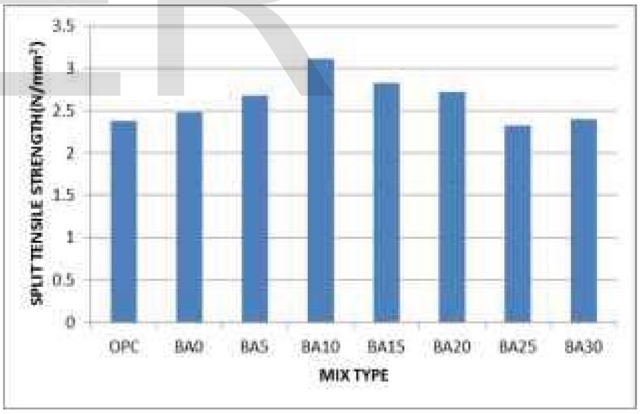

Fig.6. Split tensile strength for various mixes

Modulus of Elasticity: The Young's modulus values are obtained from stress-strain diagram obtained by carrying out the test on 150mm×300mm cylinders. Fig.7 shows the variation of modulus of elasticity for various mixes. From figure it can be seen that OPC mix has lower modulus of elasticity than other mixes. But for TBC mixes with bagasse ash the value decreases with high replacement levels.

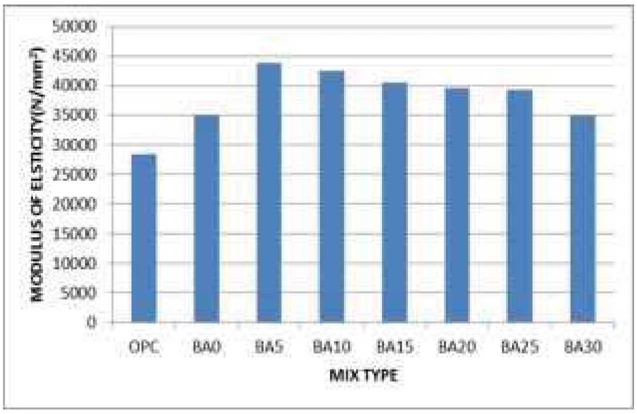

Fig.7. Young's modulus for various mixes

Sulphate Attack: The sulphate attack test was conducted on 150x150x150 mm cubes. The cubes are immersed in $mgso_4$ at a concentration of 20000 ppm and are tested for its compressive strength after 56 and 90 days. The results are plotted in fig.8.The loss in compressive strength is minimum for BA10 mix than all other mixes both at 56 days and at 90 days.

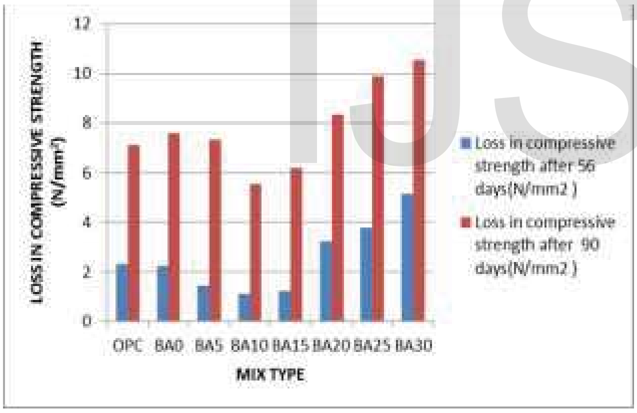

Fig.8. Sulphate Attack on Various Mixes

Sulphuric Acid Attack:The sulphuric acid attack test was conducted on 150x150x150 mm cubes. The cubes were immersed in 0.1N sulphuric acid at a concentration 3%. The loss in compressive strength is noted after 56 and 90 days after casting. The results are plotted in fig.9.The loss in compressive strength after acid attack is found to be lesser for the control mix than the other mixes. But for BA10 and BA15 the values are almost similar to the control one and hence it is comparable.

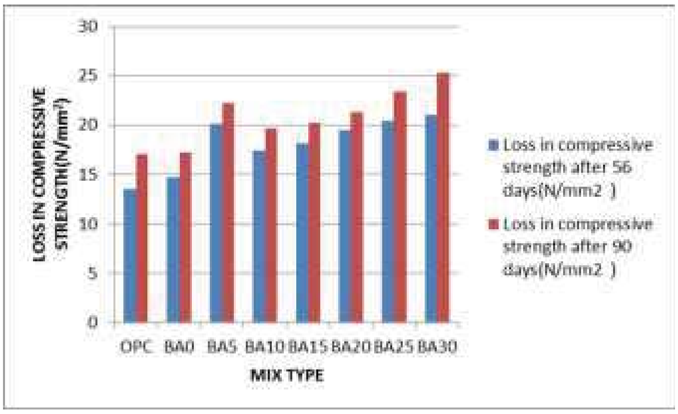

Fig.9. Sulphuric Acid Attack on Various Mixes

Bulk Diffusion Test:The bulk diffusion test was conducted on 100mm diameter; 200mm height cylinders. The cylinders were immersed in NaCl solution at a concentration of 105 mg/l and are tested after 56 and 90 days. The chloride penetration depth is noted the variation is plotted in Fig.10.

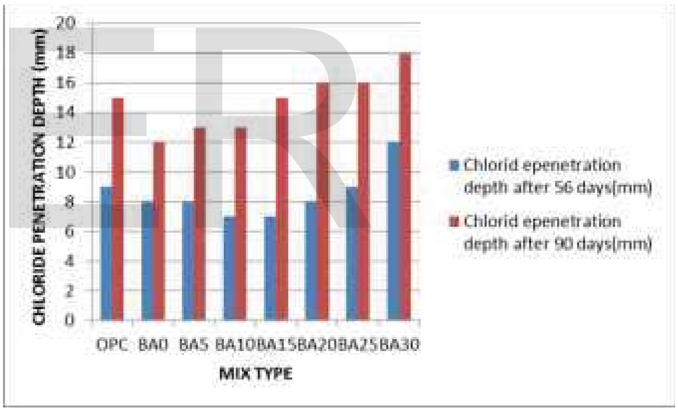

Fig.10. Chloride penetration depth of various mixes

From the results we can see that the BA0 mix provides more resistance to chloride penetration than the OPC and TBC mixes. At high percentages of bagasse ash the chloride penetration depth increases. This may be due to the porous structure of bagasse ash particles and their chemical composition. But the chloride penetration depth of BA5 and BA 10 mixes are lesser than the other TBC mixes.BA0, BA5 and BA10 mix shows high resistance to chloride penetration than the normal OPC concrete.

***Flexure Test Results on Beams*:** The objective of the test is to study the flexural properties of OPC, BA0 and BA10 beams subjected to static loading. Static loading was performed under two point flexural loading with pure bending in central zone. Deflection at the centre and 1/3rd points were measured during the experiment. During the testing, the load at which the first crack appeared was noted and the ultimate load was determined as that load beyond which the beam cannot take any more load and undergoes spalling. Load-deflection graphs were plotted based on the observations. Pre-cracking stiffness and Post-cracking stiffness were calculated from the Load-deflection graphs. Fig.11 shows the comparison of Load Vs Deflection plots for the different series of beams at midspan.

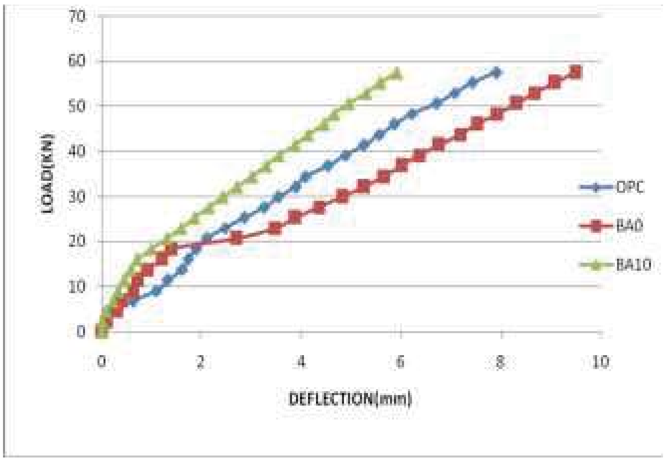

Fig.11. Variation of Load Deflection Graph of Various Mixes at Midspan

The variations for cracking and ultimate loads are shown in Fig.12.From the results it is clear that, load at first crack and ultimate load are greater for the BA10 mix than the other mixes.

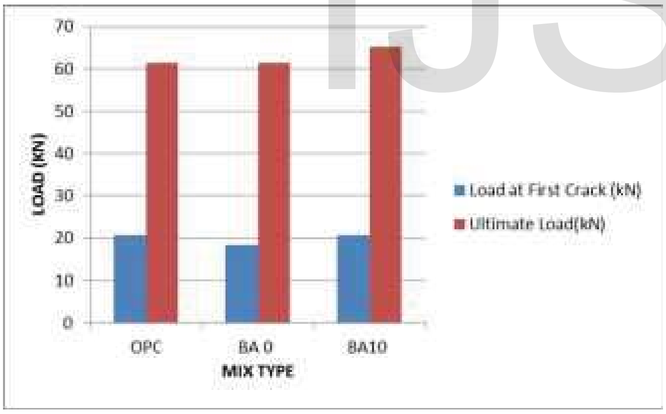

Fig.12. Variation of cracking load and ultimate load

The variation of pre-cracking and post-cracking stiffness is shown in Fig.13.

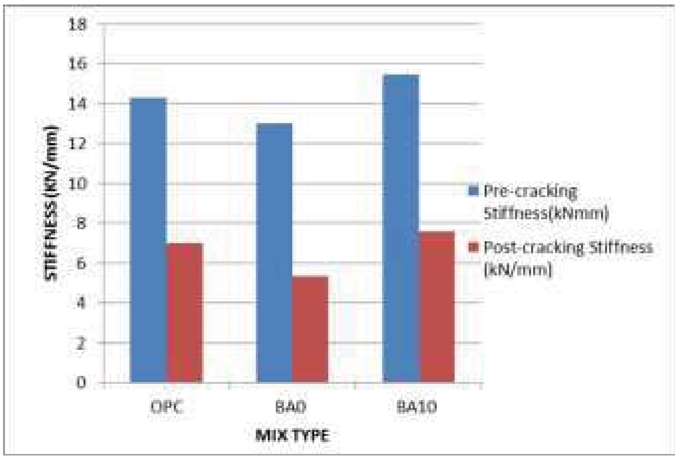

Fig.13. Variation of pre-cracking and post-cracking stiffness

The results show that the precracking and postcracking stiffness are greater for the BA10 mix than for all other mixes. The pre cracking and post cracking stiffnesses of BA10 beam shows an increase of 27.78 and 8.71% greater than the OPC respectively.

Impact Test Results on Beams: Dynamic loading was conducted by drop test. All the specimens subjected to impact loading failed by spalling of concrete at the vicinity of point of impact.Number of blows required for the first crack and spalling is noted. Energy absorbed for the first crack and failure was determined from the equation connecting number of blows and drop height. The equation is as below:

$$Energy\ absorbed = mg(h_1 + h_2 + h_3 + \cdots h_n)$$

Where, m - mass of drop weight

g - acceleration due to gravity

h - drop height of weight

n - total number of blows

Fig.14 shows the comparison between the beam specimen OPC, BA0 and BA10 beams for total energy absorption.

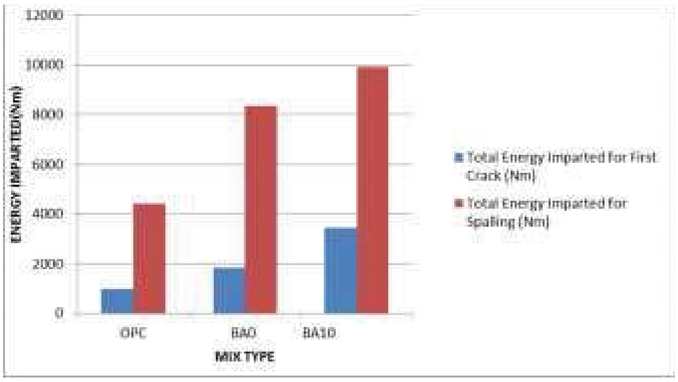

Fig.14 Total energy absorption for beam specimen OPC, BA0 and BA10

Fig.14 shows the graphical representation of total energy absorbed by each specimen. From the graph it can be seen that the energy required forming first crack in OPC is slightly less than BA0 beams. The total energy absorbed by the beam BA10 is greater than that for other beams. It is noted that the percentage of increase in total energy for BA10 beam is 124.9% higher than that of OPC beams.

IV. CONCLUSIONS

From the present experimental investigation the following conclusions are arrived:

- The addition of bagasse ash has decreased the workability of concrete. Workability of concrete is reducing at high replacement levels of bagasse ash.
- The compressive strength, flexural strength, split tensile strength and impact strength has reached greater values when cement is replaced with 30% GGBS and 10% bagasse ash. So the optimum value of bagasse ash replacement was taken as 10%.
- The modulus of elasticity of TBC mixes is high when compared to the control mix. But it founds to be decreasing at high replacement levels of bagasse ash.
- The durability tests showed that the durability properties of BA10 and BA15 mixes are almost same as that of the control mixes.
- The load-deflection behaviour of OPC, BA0 and BA10 beams under flexure can be assumed to be bilinear.
- In the post cracking and pre-cracking region, BA10 beam undergo less deflection for same load compared to OPC and BA0 beams. This shows that the BA10 beam is stiffer than the control beams due to the increased bonding effects of GGBS and bagasse ash.
- The total energy absorbed at spalling by BA10 beam under impact is greater than those for control beams.
- Bagasse ash is a by-product material, when used as a cement replacing material to an optimum dosage of 10% improves the properties of concrete, saves a great deal of waste disposal problems and also reduces the cement price hike and levels of CO_2 emission by the cement industry.

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