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Potential of Bagasse Ash as Alternative Cementitious Material in Recycled Aggregate Concrete

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Abstract: ***The experimental study deals with assessing the potential of bagasse ash (SBA) as alternative for cement in recycled aggregate concrete. The natural coarse aggregate in concrete is partially replaced with 20%, 30% and 40% of the recycled coarse aggregates (RCA) and the cement is partially replaced with 10%, 15% and 20% SBA. The fresh properties of recycled aggregate concrete are assessed by conducting slump test. The slump increases with increase in the percentage of replacement of SBA and reaches 115mm in recycled aggregate concrete as compared to without SBA in recycled aggregate concrete. The hardened properties like compressive strength were assessed at 7 & 28 days, split tensile, flexural strength and modulus of elasticity were carried out at 28 days respectively. Compressive, split tensile strength, flexural strength and modulus of elasticity of recycled aggregate concrete decreased with increase in the percentage of replacement of RCA but with the partial replacement of cement with 10% SBA compressive, split tensile strength, flexural strength and modulus of elasticity of recycled aggregate concrete strength increases. The microstructural analysis revealed that interfacial transition zone of recycled aggregate concrete containing 10% SBA is better than recycled aggregate concrete without SBA. Based on test results, it can be inferred that 30% replacement of the RCA with NCA and cement with 10%SBA can be considered as optimum replacement level, considering its fresh, hardened and micro structural properties.***

Keywords: ***Controlled mix; Recycled aggregate concrete; Sugarcane Bagasse ash (SBA); Fresh properties; Hardened properties; micro structural analysis.***

I. INTRODUCTION

The use of recycled aggregates in concrete mixes has become more common in recent times as it conserves depletion of natural resources but also minimizes environmental pollution. The consumption of construction and demolition (C&D) waste in India from 2005–2013 was 165–175 million tonnes per annum [1, 2].However, these waste was dumped as landfill resulting in environmental pollution. India has promoted policies for the use of recycled aggregates as a partial replacement for natural aggregates. Researchers around the world have extensively studied the properties of recycled coarse aggregates (RCA) as well as the behavior of recycled aggregate concrete (RAC) at various replacement level.

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In general, it was noted that with an increase in the replacement level of RCA tends to reduce workability, strength and durability characteristics of RAC mixes. Several studies are performed to improve the properties of RAC mixes. Dhir et al (1999) have performed experiments on RAC mixes (M30 and M35) and have inferred that some of the deficient attributes of RCA can be mitigated by using a filler material to improve the fresh properties. The strength reductions with RCA can be overcome by a adjustment in water/cement (w/c) ratio [3]. Limbachiya (2004) has demonstrated that strengths similar to NAC can be achieved with RCA by either modifying the water content or cement content [4]. Tam et al (2006) have explored the possibility of improving the property of RAC by dividing the mixing procedure into two stages. The authors have concluded that special mixing procedures can also circumvent the inherent deficient strength of RAC [5].. Corinaldesi and Moriconi (2009) have found that RAC with fly ash or silica fume (15% and 30% by weight of cement) can yield strengths comparable to NAC or can even exceed it [7]. Saravanakumar and Dhinakaran (2012) have made RAC mixes with fly ash (20%) and SP to achieve the compressive strength of NAC even with 100% CRCA as a replacement [8]. They have concluded that 20% use of CRCA in concrete mixes didn't show a prominent effect on the properties of concrete. In view of above observations outlined in the literature, the present study aims to improve the properties of RAC mixes, using sugarcane bagasse ash (SBA) in concrete mixes. SBA is obtained by burning sugarcane bagasse in boilers during the cogeneration process. SBA exhibits characteristics of supplementary cementitious materials because it is rich in amorphous silica. It also contains unburnt fibrous carbon particles, a small amount of aluminum, iron, and alkalis are also present. A.Bahurudeen and Manu santhanam have observed that the presence of coarse fibrous particles in raw bagasse ash demands more water for achieving required consistency and same in the case of processed bagasse ash but it demands lesser water as compared to that of raw bagasse ash and the compressive strength of concrete for different percentage of baggase ash blended cements at various ages was concluded that up to 20% replacement level of bagasse ash were higher as compared to controlled concrete and the durability performance of concrete with and without replacement of bagasse ash and observed that resistance against chloride penetration and gas penetration increased with increase in replacement of cement with bagasse ash due to improvement in pore structure[9-10] and K. Ganesan et.al, revealed that the water requirement for normal consistency of blended cement increases with increase in replacement.

level due to ashes are hygroscopic in nature and the specific surface area of bagasse ash is higher than the cement and setting time of
bagasse ash was found to be higher than that of ordinary Portland cement and compressive strength of bagasse ash blended concrete increases up to 20% at early ages as compared to controlled concrete due to silica content, fineness, amorphous and pozzolanic reaction and also the splitting tensile strength of bagasse ash blended concrete were increased when cement is replaced up to 20% bagasse ash content [11].

II. OBJECTIVE OF THE STUDY

1. To ascertain the properties of bagasse ash and recycled coarse aggregates.
2. To assess the fresh and hardened properties of the concrete mixes prepared by replacing NCA with 20%, 30% and 40% RCA.
3. To ascertain the optimum replacement of RCA in the concrete mix, so as to study its fresh, hardened and microstructural characteristics.
4. To determine the performance of RAC mixes with the optimum replacement of RCA, and cement is replaced with 10%, 15% and 20% SBA.
5. To analyze the micro structural characteristics of a particular RAC mix containing both RCA and SBA at an optimum level.

III. MATERIALS AND METHODS

Concrete mixes are produced using NCA, RCA, manufactured sand, water, cement and SBA. Crushed granite is used as NCA; crushed laboratory concrete specimens are used as RCA.

A. Physical Properties of Cement and SBA

The physical properties of ordinary Portland cement of 53 grade and SBA passing through 90 microns (recovered after removing unburnt carbon-rich fibrous particles) are determined as per IS: 4031 (part1)-1996[12] and IS: 1727-1967[13] respectively. The physical properties of cement and SBA are given in Table 1 and 2.

Table 1: **Physical properties of cement and SBA+OPC**

Sl no.	Attributes	Cement	SBA +OPC
1	Specific gravity	3.1	2.2
2	Normal Consistency (%)	29	33
3	Initial setting time(mins)	150	180
4	Final setting time(mins)	210	290
5	Soundness(mm)	1	1
6	Fineness (%)	4.88	6.50
7	28 Days Compressive Strength (MPa)	55.5	

The physical properties of SBA are determined as per IS: 1727-1967[13]. The physical properties of sugarcane bagasse ash are listed in Table 1. The physical test is done as specified in IS:4031-1996[12] except that in place of cement, a mixture of pozzolana and cement in the proportion 0.2 N : 0.8 by weight, blended intimately shall be used. The results are listed in Table 1

B. Chemical Properties of bagasse ash

The test results highlighted in Table2 are based on the test reports of chemical analysis furnished by an ISO certified laboratory. The SBA is tested in three different forms viz., in the raw state (collected SBA directly tested), SBA sieved through 300 microns (µ) sieve and ground SBA sieved through a 90µ sieve.
The chemical analysis of SBA reveals, more than 70% of silica content in all three samples. The carbon content in the raw sample is marginally high as compared to other samples. As per IS: 3812(part1)-2013[14] specifications the combined chemical composition of $SiO_2+Al_2O_3+Fe_2O_3$ should be ≥ 70% which satisfies the pozzolanic nature of SBA, and the aforementioned code provisions.

C. Microstructural Properties of bagasse ash

1. X-ray diffraction (XRD) Analysis

This analysis is performed to assess the mineralogical properties of bagasse ash as depicted in Fig.1. The bagasse ash essentially consists of an amorphous silica structure with a wide scattering peak (hump) centered at 2Θ values in the range of 15 - 40^0.

Sample	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	Loss on Ignition (LOI) %
Raw	70.16	0.26	6.67	1.78	11.25
Passing 300µ	88.80	0.18	3.45	1.38	7.88
Grinded SBA Passing 90µ	87.45	0.22	2.98	1.25	2.21

Table 2: Chemical properties of SBA

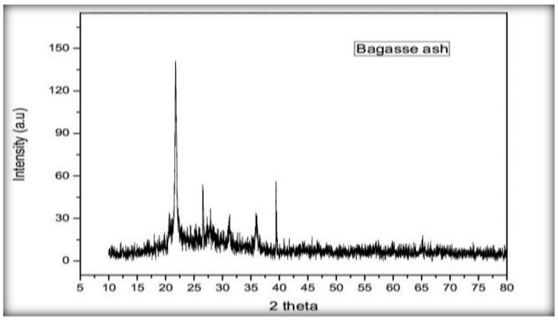

Fig. 1. X-Ray diffraction (XRD) analysis of sugarcane bagasse ash

2. Scanning Electron Microscope (SEM) Analysis

Morphology study of bagasse ash is carried out by SEM (Scanning Electron Microscope) is shown in Fig 2. It reveals that SBA samples are composed of grains with the different shape they are spherical, prismatic, fibrous and irregular. Prismatic particles consist of Si & O, spherical particles contain Si & O as well as some other minor compounds, fibrous particle consists of only carbon and particles with irregular shape are rich in silica.

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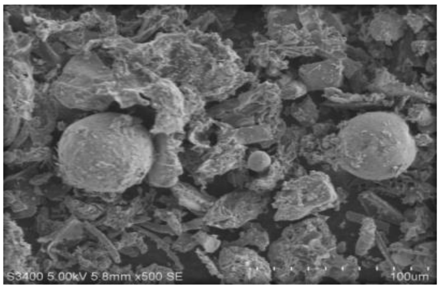

Fig. 2. SEM analysis of sugarcane bagasse ash

D. Physical Properties of Aggregates

The physical properties of manufactured sand, NCA and RCA were assessed with reference to procedures mentioned in IS: 2386 Parts (1 to 4)-1963 [15]. RCA is recovered by crushing tested concrete specimens that are stacked in the laboratory. The process of crushing is carried out using a hammer, and the aggregates are separated using IS sieves. The physical properties of manufactured sand and coarse aggregates are listed in Table 3 and Table 4 respectively.

Table 3: Physical Properties of Manufactured Sand

Sl. no	Tests	Results
1	Specific gravity	2.65
2.	Fineness modulus	2.70
3.	Silt content (%)	5%
4.	Water Absorption (%)	1%
5	Bulk Density(Kg/m^3)	1599

Table 4: Physical Properties of NCA and RCA

Sl no.	Attributes	NCA	RCA
1	Specific gravity	2.65	2.3
2	Water absorption (%)	0.5	2.5
4	Flakiness Index (%)	17.54	4.58
5	Elongation Index (%)	24.53	11.76
6	Crushing value (%)	25.75	32.72
7	Angularity Number	7.12	3.11

E. Mix proportions and mixing methods

The concrete mix is designed as per IS 10262-2009[16] by considering the properties of manufactured sand, NCA, and cement. The mix corresponds to 1: 2.18: 3.86, with water to cement ratio as 0.45 and super plasticizer (SP) dosage of 1%. RAC mixes are prepared by replacing NCA by RCA at 20%, 30% & 40%.The performance of three RAC mixes are evaluated and the optimum replacement level of RCA is determined. SBA is partially replaced by cement at 10%, 15% & 20% for the RAC mix containing optimum level of RCA. The coarse aggregates are used in saturated surface dry (SSD) condition, the water and SP content is maintained constant throughout the study. The details of mix constituents are given in Table 5.

Table 5: Mix Constituents in kg/m^3

Mix Designation	Cement	SBA	M Sand	NCA	RCA	Water	SP
CM	320	-	700	1238	-	144	3.2
20RCA	320	-	700	990.4	219.03	144	3.2
30RCA	320	-	700	866.6	328.54	144	3.2
40RCA	320	-	700	742.8	437.5	144	3.2
10SBA+30RCA	288	22.7	700	866.6	328.54	139.8	3.2
15SBA+30RCA	272	34.06	700	866.6	328.54	137.8	3.2
20SBA+30RCA	256	44.8	700	866.6	328.54	135.4	3.2

The modified two-stage mixing approach (TSMA) was used to mix concrete in this study in which the pan mixer was been loaded with all the materials except natural coarse aggregate in I- stage of mixing itself. And then, the natural coarse aggregate, which actually did not require any surface treatment, was added in the II stage of mixing to complete the entire process. was added because; the RCA only needed surface treatment[17]

F. Fresh properties of concrete

The workability of the concrete mixes is assessed by conducting slump test as per IS: 1199- 1959[18].

G. Hardened properties of concrete

The cubes were removed from curing tank then dried and tested. Three cubes are tested at 7 and 28 days, for each mix variants, three cylindrical specimens are assesed as per IS: 5816-1999[19] at 7 and 28 days, for each of the mix variants, three beams are tested as per IS: 516-1959[20] at 28 days, for each of the mix variants and three cylinders, are tested at 28 days, for modulus of elasticity of concrete.

H. Microstructural properties of concrete

The microstructural properties are carried out for three types of mixes i.e., controlled mix, optimum RCA content in concrete and optimized RCA content and SBA content in concrete which are assessed by scanning electron microscopic test at 28 days. The test is carried out in material science department, university of Mysore, Mysuru Karnataka.

IV. RESULTS AND DISCUSSIONS

A. Fresh properties of concrete

The slump of the designated concrete mixes is depicted in Fig.4. The workability of a concrete mix containing only RCA tend to decrease, with an increase in replacement level. This is attributed to greater water absorption characteristics of RCA, as well as its rough texture [4, 24 & 25].With partial replacement of cement by SBA, the workability of the RAC mix tends to increase with increase in SBA content. This is due to lubricating effect of SBA as the particle exhibits spherical in its shape.

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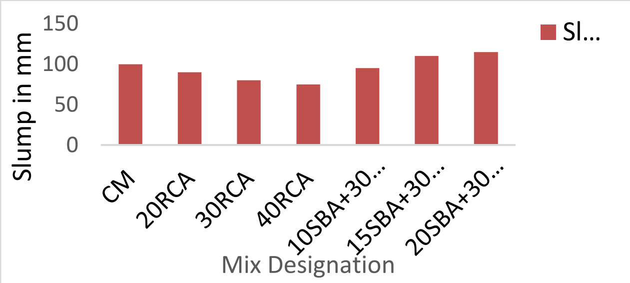

Fig.3. Slump values of mixes

B. Hardened properties of concrete

The hardened properties such as the compressive, tensile and flexural strength of the concrete mixes are given in Table 6.

Table 6: Hardened properties of various concrete mix.

Mix Designation	Compressive Strength in Mpa				Split tensile strength		Flexural strength in Mpa	
	at 7 days		at 28 days		at 28 days		at 28 days	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CM	42.6	1.6	47.3	0.7	3.5	0.2	4.8	0.0
20RCA	31.0	1.6	38.0	1.1	2.5	0.1	3.6	0.3
30RCA	32.9	0.4	41.8	3.4	2.9	0.1	4.2	0.1
40RCA	30.2	0.7	41.6	3.1	2.8	0.1	3.4	0.5
10SBA+30RCA	33.5	1.2	43.9	2.8	2.9	0.0	4.6	0.3
15SBA+30RCA	22.7	1.3	31.5	2.0	2.4	0.2	4.4	0.6
20SBA+30RCA	21.0	2.9	28.4	1.5	2.3	0.0	3.5	0.2

1. Compressive Strength of Concrete

It is observed that all the concrete mixes attain the target compressive strength of 31 MPa at the age of 28 days. The variation in compressive strength among the designated concrete mixes is highlighted in Fig.4.

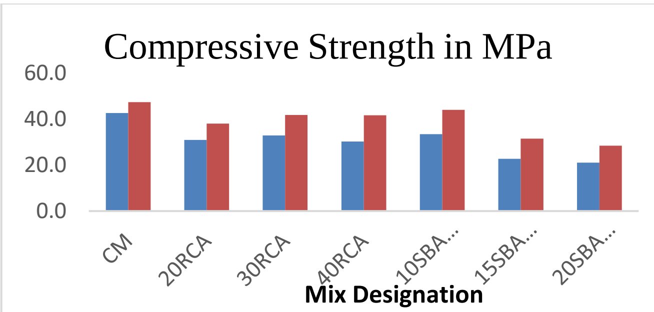

Fig.4: Compressive strength of mixes

The compressive strength of RAC mixes decreases with the increase in RCA content; this is due to the formation of the weak interfacial transition zone. The reduction with respect to control mix is found to be 19.69, 11.56 & 11.97% for 20%, 30% and 40% respectively. These observations are consistent with some of the studies available in the literature [21, 23, 24, and 25]. The compressive strength of the mixes 30RCA and 40RCA behaves more or less in the same way. However, by considering the workability of the mixes, it can be inferred that 30% replacement of RCA is an optimum one. The 10% replacement of cement with SBA, marginally increases the compressive strength as compared to the mix 30RCA.Further, with an increase in SBA content for the mix containing 30%RCA decreases the strength. The reduction in strength is about 25% and 33% for the mix 15SBA+30RCA and 20SBA+30RCA respectively. Hence it can be inferred that 10% replacement of cement by SBA is a feasible replacement for the mix 30RCA.

2. Split tensile Strength of concrete

The splitting tensile strength of the concrete mixes is shown in Table 6. The reduction in tensile strength is observed with the replacement of RCA. These observations are in line with other studies available in the literature [22, 26&27]. The reduction in splitting tensile strength of RAC mixes attributed to physical properties of RCA and interfacial transition zone(ITZ) between RAC and hydrated cement paste, exhibits few mechanical bonds[26]. The strength of RAC mix with 10% of SBA is comparable with that of 30RCA.Further increase in SBA beyond 10% decreases the splitting tensile strength.

3. Flexural Strength of concrete

The flexural strength of the concrete mixes is given in Table 6.The flexural strength decreases with increase in replacement of RCA. The reduction is about 26.33, 14.44 & 29.62% for mix comprising 20%, 30% and 40% RCA respectively. Further with the incorporation of 10%SBA, a slight improvement in the strength is observed, however at 15 and 20% replacement of RAC mixes, the flexural strength decreases.

4. Modulus of Elasticity of concrete

The static modulus of elasticity of three mixes is given in Table 7.The modulus of elasticity (MOE) is higher for concrete mix prepared with NCA. The RAC mix without SBA recorded the lowest MOE (4.32% lower than CM).With the inclusion of 10% of SBA, MOE increases by 2.18% as compared to mix with only RCA, however, it is still lesser than the CM.

Table 7: Modulus of Elasticity in GPa

Mix Designation	Mean
CM	48.36
30RCA	46.27
10SBA30RCA	47.28

C. Microstructural analysis of concrete

Microstructural analysis of three concrete mixes at 28 days of curing is carried out by Scanning Electron Microscope (SEM) technique for observing transition zone cracks formation in concrete and are shown in Fig 6. The microstructure of CM and 30RCA exhibits the formation of the interfacial transition zone, which is defined as the gap length between the aggregate and cement paste. Small micro cracks were also observed in 30RCA mix.

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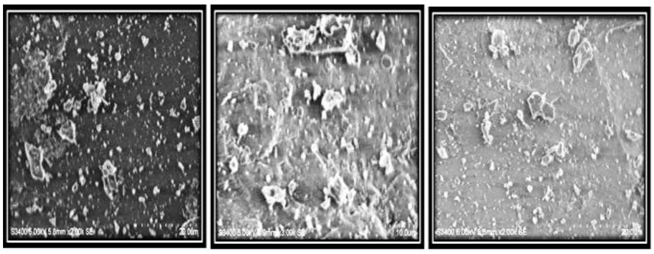
The inclusion of 10% SBA in the RAC mix, enhances the interfacial transition (minimizes the gap between the aggregate and cement paste).The microstructure is more homogenous as compared to other two mixes. It can be observed that SBA fills the microcracks developed in RAC mixes and leads to densification of the interfacial transition zone.



(a) CM (b) 30RCA (c) 10SBA+30RCA

Fig.5. SEM analysis of CM, 30RCA, and 10SBA+30RCA mixes

V. CONCLUSIONS

The following conclusion were drawn

1. The workability of the RAC mixes decreases, with an increase in RCA replacement level. However, with the replacement of cement by SBA, it is possible to improve the fresh properties of RAC mixes.
2. The reduction in compressive, split tensile and flexural strength of concrete mixes is observed with increase in RCA content in RAC mixes. RAC mix with 10% SBA content in the mix exhibits better performance as compared to the mix without SBA content (30RCA).The increase in SBA content beyond 10% causes a reduction in the strength of the RAC mixes. Thus it can be concluded that 10% replacement of cement by SBA has a beneficial effect on strength of concrete mix.
3. The modulus of elasticity of the mix 30RCA and 10SBA+30RCA are comparable to that of Control Mix.
4. The microstructural analysis reveals that RAC mix with 10% SBA content exhibits better pore structure than the mix without SBA content, this is attributed fineness of the SBA.

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