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Evaluation of mechanical properties of Sugar Cane Bagasse Ash concrete

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HIGHLIGHTS

- Characterized Sugar Cane Bagasse Ash (SCBA) material.
- SCBA blended concretes exhibited higher Modulus of Rupture (MOR) than control.
- P-SCBA concrete has higher Modulus of Elasticity (MOE) than control concrete.
- Empirical equation is proposed to predict the MOR and MOE of SCBA blended concrete.
- Established a relationship between MOR and MOE.

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ABSTRACT

Sugar Cane Bagasse Ash (SCBA) is an advanced cementitious material contains significant amount of pozzolanic minerals like silica, alumina, etc. In view of this, in the present study it is proposed to partial replacement of Ordinary Portland Cement (OPC) by SCBA up-to 30%. OPC was replaced in two forms, namely, Original SCBA (O-SCBA) and Processed SCBA (P-SCBA). The mechanical properties such as cylinder compressive strength, Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) were evaluated for SCBA blended concrete and compared with conventional concrete. Further the relationships between cylinder compressive strength, MOR and MOE were established as per AS3600 (Australian Standards 3600), ACI318 (American Concrete Institute 318) and NZS3101 (New Zealand Standard 3101).

1. Introduction

Developing nation like India, solid waste management is currently most important domain in view of ecology and environmental aspects. About 960 million tonnes of solid wastes are being generated by India every year [1]. Solid waste generated from Indian agricultural sector contributes approximately to 13.64% overall solid waste generated in Asia every year [2]. With reference to overall production of SCBA across globe, India contributes to 45% which shows that bulk quantity is available in India and it has to be utilized for several purposes on urgent basis. In India, there are 500 operational sugar mills and is second largest sugar production across globe [3].

The fuel cost for electricity generation and demand, has increased drastically in the recent years. The dried sugar cane bagasse (heating value in order of 7.74 MJ/kg) can be employed as one of the major sources of fuel for boilers [4] for electricity generation of parent industries [5,6]. Every tonne of sugarcane crush, will yield 270 kg of wet bagasse [7–9]. The combustion of dried bagasse will not contribute to Carbon di Oxide (CO_2) emission into the environment as the amount of CO_2 liberated is neutralized by CO_2 consumed during sugarcane plant growth [10]. It is mentioned that an amount of 62 kg of SCBA is obtained by burning dried bagasse in boilers at temperature varying from 300 °C to 600 °C [9] per tonne of sugarcane crushed. Cement Industries are second largest industries in emission of CO_2. For production of one tonne of OPC, an equivalent amount of CO_2 is delivered into atmosphere [11], which accounts for 8% of overall production [12–14]. And also, for production of every tonne of OPC, 1.6 tonnes of natural resources are consumed [15].

In order to reduce CO_2 emission, one of the alternatives is to make use of blended Pozzolans like SCBA with OPC and produce Portland Pozzolana Cement (PPC). A Pozzolan is either natural or artificial which is finely divided siliceous or aluminous material, in presence of moisture it reacts with additional lime at ordinary

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Table 1
Physical properties of binders.

Properties	OPC	O-SCBA	P-SCBA
Specific gravity	3.158	1.856	2.218
Retained on sieve 75 μm	–	29.5%	7.25%
Density (kg/m^3)	3144	2235	2454
Mean particle size (μm)	28	105	30

Table 2
Chemical properties of binders in mass (%).

Properties	OPC	O-SCBA	P-SCBA
SiO_2	21.15	55.05	66.50
Al_2O_3	5.10	3.87	4.82
Fe_2O_3	2.62	0.42	4.67
CaO	65.52	5.09	3.83
Na_2O	–	0.94	0.59
K_2O	0.35	4.00	4.07
MgO	3.04	4.82	2.87

temperature and form secondary calcium silicate hydrate (CSH) gel [16]. ASTM C618 (1992) classified SCBA as N Pozzolan, many studies were reported in the literature and it was used in blended cements [6,9]. The specific surface area is increased due to reduction in size uniformly. The increased specific surface area is directly useful for the kinetics of their pozzolanic reactions. By the addition of fine pozzolan, packing density of mix will improve significantly due to micro-filler effect [17]. The other physical effect is that with the decrease in particle size results in heterogeneous nucleation due to increase in specific area surface for reaction. In this situation, pozzolan fine constituent part settles in between the clinker minerals, allowing nucleation of hydrates on fine particles of silica from SCBA and decreasing the energy obstruction [18]. Original SCBA (O-SCBA) contains higher carbon content and higher quantities of crystalline silica which acts in adverse manner if it is used as pozzolan. Other possibilities to improve the reactivity of crystalline silica in SCBA are burning or grinding, etc. On other hand, SCBA consumes higher energy to grind or burn into finer parts. This limits the usage of SCBA in cement. Although some studies were reported in improvement of SCBA properties, but the procedures are not clear in terms of burning temperatures, controlled conditions/operatable conditions, optimum conditions. In view of this, a study has been undertaken to optimize the conditions.

In this paper, a simple and effective method has been proposed to process SCBA for use in cement industries. Hence in this study, combination of grinding for 45 min initially and burning at low temperature for 4-h is proposed to reduce the energy consumption, reduction in time for SCBA process to obtain the so called processed-SCBA (P-SCBA). P-SCBA has been used for further studies.

2. Experimental program

2.1. Materials

O-SCBA sample was collected at Bannari Sugars Private Limited, Sathyamangalam, Tamil Nadu, India which produces sugar, alcohol and electricity. Samples were collected during the cleaning process of the boilers from the factory. The sugar cane bagasse is burnt in boiler for the temperatures ranging from 300 °C to 600 °C, reliant on the moisture content and feedstuff of the bagasse. Table 1 shows a summary of the physical characteristics and Table 2 shows the summary of the chemical composition of both SCBA and OPC. In the present study, sieved raw SCBA is denoted as O-SCBA. The sieving is done for selection of appropriate size of SCBA in view of binder materials. P-SCBA used in this investigation is obtained by grinding O-SCBA in laboratory ball mill for 45 min, with three balls of 8 mm, 18 mm and 25 mm diameter in the ratio of 1:5 (volume of ash: ball), 1:10 ratio (volume of ball and ash: volume of mill container) at 300 rpm.

After grinding SCBA, it is kept in muffle furnace for four hours at a temperature of 400 °C, hence forth, it is called P-SCBA. This process results in energy consumption reduction, decrease of SCBA wastage, less CO_2 emission, natural resources protection, avoiding negative environmental effects, etc., may lead to achieving the sustainability of SCBA based concrete. Other school of thought reported that high grinding time and high burning temperature as processing techniques for making SCBA as reactive Pozzolan [6,19]. In order to increase the packing density of concrete mixture, the combination of 20 mm aggregate and 12.5 mm aggregate in proportions of 70% and 30% respectively is used as coarse aggregate. Fig. 1 shows the particle size distribution of aggregates and SCBAs used in this investigation. The physical properties of fine and coarse aggregate are presented in Table 3. In the present study, processed SCBA has been utilized concrete by partial replacement of cement aiming at compressive strength is about 20 MPa. To demonstrate the efficacy of SCBA initially, the studies were carried out for compressive strength of 20 MPa.

2.2. Mixture proportions

Six mix proportions of O-SCBA and P-SCBA blended concrete and one control mix proportion are proposed to study and the details are shown in Table 4. Mixture proportions 'O1, O2, … O6' for O-SCBA, blending varying from 5% to 30% of OPC replacement. Another series of mixture proportions 'P1, P2, … P6' denotes for P-SCBA with varying proportion in 5%, 10%, … 30% for OPC replacement. Table 4 also presents the various quantities for several combinations. The mix design for control mix and blended mixes are carried out as per IS 10262:2009 [20].

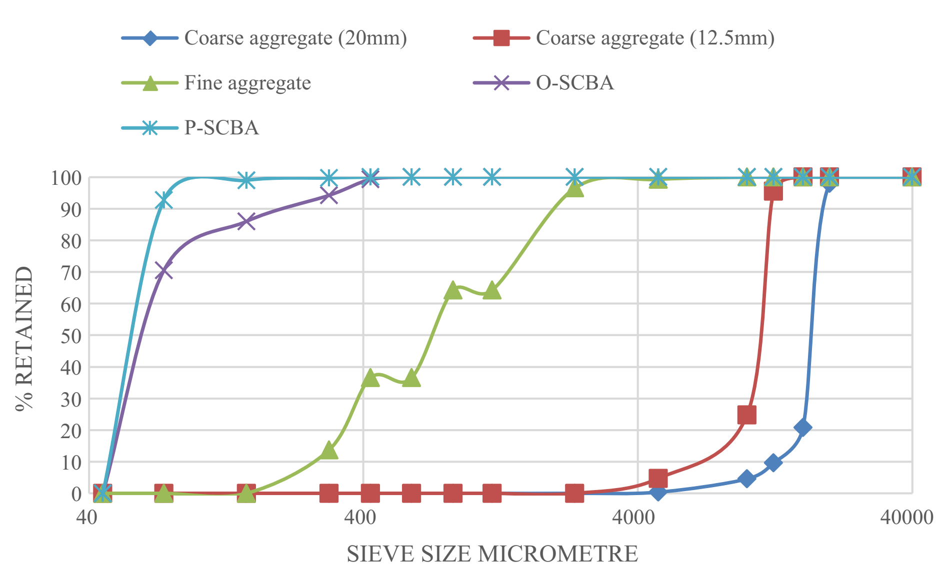

Fig. 1. Particle Size Distribution of Aggregates and SCBAs.