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Durability characteristics of Ultra High Strength Concrete with treated sugarcane bagasse ash

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HIGHLIGHTS

- Ordinary Portland cement was replaced with 5–20% by weight of sugarcane bagasse ash.
- Compressive strength, chloride penetration resistance and sorptivity tests were carried out.
- 15% substitution of treated sugarcane bagasse ash (TBA) exhibited a better durability property.
- Treated sugarcane bagasse ash could be used in making the ultrahigh strength concrete (UHSC).

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ABSTRACT

This paper discusses the feasibility of utilizing sugarcane bagasse ash as a pozzolanic material in the production of Ultra High Strength Concrete (UHSC). Ordinary Portland Cement was replaced with Treated Bagasse Ash (TBA) in this investigation. The replacement dosage varied from 5% to 20% by weight of cement. The effect of bagasse ash on workability, compressive strength, chloride penetration resistance and sorptivity was examined. In addition to this, the effect of different curing regimens on hardened properties of UHSC was carried out. The results proved that it is possible to produce UHSC with cylinder compressive strength more than 160 MPa by incorporating bagasse ash. Optimum replacement ratio of 15% yielded better performance in all the tests, without having any adverse effects on hardened concrete. Convincingly, 20% substitution of sugarcane bagasse ash is good enough for producing UHSC.

1. Introduction

In the recent period, the use of pozzolanic materials in concrete has become essential to improve its inherent characteristics. Often industrial and agro residual wastes are used as a partial replacement for cement and the concrete so produced is referred as blended cement concrete. The most common type of agro wastes used as pozzolans are rice husk ash, palm oil fuel ash, and sugarcane bagasse ash. Addition of these has a positive influence on mechanical and durability properties of concrete, due to the pozzolanic reaction with calcium hydroxide produced from primary hydration of cement [1]. An enormous amount of research has been carried out in utilizing pozzolans in concrete.

Sugarcane bagasse is a by-product of sugar industries, obtained after extraction of juice from sugarcane. This fibrous material is used as fuel in sugar industries for power generation, and the residue of this process is called as sugarcane bagasse ash. As like most of the secondary cementitious materials, bagasse ash cannot be used directly in concrete. It requires certain prior treatment, in particular, heat treatment under the controlled condition to remove the unnecessary components [2]. The hydration characteristics of bagasse ash blended Portland cement was investigated by Singh et al. [3], and it was concluded that 10% replacement of cement was optimum for better performance. The influence of bagasse ash as cement replacement on the physical and mechanical behaviour of concrete was evaluated by Ganesan et al. [4] and it was found that bagasse ash can be used as pozzolanic admixture with 20% optimal replacement. Impact of incineration temperature, residence period for incineration and duration for ultrafine grinding on the physical-chemical characterization of bagasse ash was examined by Cordeiro et al. [5], along with its use in High-Performance Concrete (HPC). It was reported that bagasse ash burnt less than 600° C and subjected to 120 min of vibratory grinding when used in HPC improved the rheological characteristics,

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compressive strength, and chloride ion penetration resistance. The possibility of utilizing bagasse ash in High Strength Concrete (HSC) as a partial substitute for cement was investigated by Sumrerng Ruzkon et al. [1], varying the replacement from 10% to 30%. They recommended the optimum replacement percentage as 10% and up to 30% replacement is acceptable for producing High Strength Concrete.

Several studies have been reported by investigators from various parts of the world on the use of sugarcane bagasse ash in ordinary cement concrete [1,2,6–9]. However, only few research data are available on the incorporation of bagasse ash in High Strength Concrete and almost nil in Ultra High Strength Concrete.

All through from the day of the invention of hydraulic cement, continuous research is in progress with an aim to produce cementitious composites with high mechanical performance. Based on this continuous research, concrete with high resilience characteristics was invented called as Reactive Powder Concrete (RPC) [10–16]. RPC also labeled as Ultra High Strength Concrete (UHSC) with ultra-high compressive strength and excellent flexural behaviour, addresses the strength and durability performance deficiencies associated with Normal Strength Concrete (NSC) and High Strength Concrete (HSC). Several studies reported the production of UHSC with different materials, its mechanical and durability characteristics and its applications [2,4,12,15,17–20]. UHSC has been used in various structures such as foot over bridges, bridge deck overlays and as repair material. But in India, the application of UHSC in structures is almost nil because of its high cost. The best-suited cost reducing approach is to adhere to the concept of sustainable material development, in which non-conventional and innovative techniques are used. These methods compensate for the lack of natural resources and add positive value to environmental conservation. Hence this study was made to evaluate the possible use of sugarcane bagasse ash as cement replacement material in the production of UHSC, which make UHSC, more affordable for large-scale practical applications. For the above, the knowledge of physical and mechanical behaviours like workability, compressive strength, sorptivity, and chloride ion penetration resistance is essential and investigated in the present study. Also, this study investigated the effect of different curing regimens on the above-stated properties.

2. Experimental

2.1. UHSC constituents

The materials used in the production of UHSC vary from that used in Normal Strength Concrete and High Strength Concrete. Essential components of UHSC consist of Ordinary Portland Cement (53 grade conforming to IS 12269:1987), silica fume, quartz powder, quartz sand, steel fibre, superplasticizer, and water. Densified silica fume conforming to ASTM C1240-97 was used as the strength enhancement component. Quartz powder with maximum particle size of 25 μm was used to act as filler material. Quartz sand used had particle size varying from 150 μm to 600 μm and this provides structure to the mixing matrix as in UHSC no coarse aggregates were introduced. The fibre used in this study was straight brass coated steel fibres of 10 mm length and 0.12 mm diameter. Polycarboxylate ether based high range water reducing admixture was used to achieve the required workability.

2.2. Sugarcane bagasse ash

Sugarcane bagasse ash used in the study was collected from Shakthi Sugars (P) Ltd, Madurai, Tamil Nadu, India. Raw bagasse ash collected from the industry was dried at 110° C for 24 h to remove the moisture present in it. After the removal of moisture, bagasse ash was incinerated under controlled condition in the furnace for different temperatures between 450° C and 650° C with 50° C variation; heat rating of 13° C per minute. The time of residence in furnace varied from 1 h to 3 h. After incineration, samples were subjected to dry grinding in vibratory ball mill of 5 L capacity for 120 min as detailed by Cordeiro et al. [5]. Samples after heat treatment and grinding process were labeled as Treated Bagasse Ash (TBA). To ascertain the reactivity of BA, the samples which were burnt at different temperatures in a furnace were characterized by X-ray diffraction pattern (XRD) and Energy-dispersive X-ray spectroscopy (EDX) tests. From X-ray diffraction patterns, it was observed that ashes burnt between 450° C and 600° C were amorphous in nature with a poor crystal growth of SiO_2 in hexagonal crystal system with primitive structure in difference space groups (ICDD-89-3433 and 89-1961) and above 600 °C, they exhibit the crystallization of silica in the same hexagonal phase with primitive lattice structure of cristobalite. The EDX spectrum shows the presence of Silicon as the only primary compound along with other metal ions like Al, Ca, Fe, Mg, and K as minor compound elements. Table 1 presents the chemical composition of the cement and TBA obtained from EDX analysis. In addition to the XRD analysis, the reactivity of the TBA produced at various incineration temperatures and residence time in the furnace was evaluated by conducting the lime reactivity test in accordance with IS1727: 1967. Also, the grinding time of the bagasse ash was taken into consideration in assessing the reactivity. In this test for each mix, the water content was fixed on a trial basis by conducting the flow test on the freshly mixed samples, the water content required to produce 70 ± 5 percent flow was fixed as the required water content. The reactivity of the bagasse ash is represented as the compressive strength of standard mortar test. Cubes of size 50 mm, prepared by mixing the standard hydrated lime, bagasse ash, sand and water at a ratio of 1:2M:9, where M is the ratio of the specific gravity of pozzolana and specific gravity of hydrated lime. The loading rate was 35 kg/cm^2/minute. The load at failure was noted, and the compressive strength was calculated for an average of three specimens. The test results are presented in Table 2. It is clear from the results shown in Table 2 and based on XRD and EDX comparative analysis, TBA produced with controlled combustion at 550 °C and residence period of one hour was found to perform superior, and the same was selected for the study. XRD pattern and EDX spectrum of bagasse ash incinerated at 550° C for one hour are shown in Figs. 1 and 2.

2.3. Mix composition and specimen preparation

Ordinary Portland Cement was replaced with 5%, 10%, 15% and 20% of TBA, in the production of Ultra High Strength Concrete. The concrete used in this study was prepared as per the mix composition given in Table 3. Mixtures used were given a unique identification with a combination of letters and numbers. The first letter

Table 1
Chemical composition of Treated Bagasse Ash and cement.

Oxides	TBA	OPC
SiO_2 (%)	86.79	25
Al_2O_3 (%)	2.45	4
Fe_2O_3 (%)	1.75	0.60
CaO (%)	3.42	63
K_2O (%)	3.83	1.3
MgO (%)	1.46	4
SO_3 (%)	0.30	2.1
LOI (%)	7.0	2.5