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Development of sugarcane bagasse ash based Portland pozzolana cement and evaluation of compatibility with superplasticizers

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HIGHLIGHTS

- Development of sugarcane bagasse ash based Portland pozzolana cement is reported.
- Interaction of superplasticizers with bagasse ash based Portland pozzolana cement was studied.
- Influence of irregular structure of silica particles on loss of fluidity is discussed.

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ABSTRACT

Sugarcane bagasse ash is a by-product from sugar industries and can be used as supplementary cementitious material in concrete. The development of new cementitious blends with processed sample of sugarcane bagasse ash is described in this paper. Utilization of various supplementary cementitious materials significantly influences fresh and hardened properties of concrete. Interaction of pozzolanic material with cement and chemical admixtures produces diverse effects in the fresh properties of blended cement concrete. This paper aims to ascertain the effect of different bagasse ash replacements of cement on the compatibility with superplasticizers in cement paste. Sugarcane bagasse ash based Portland pozzolana cements were produced with three different levels of replacement – 10%, 15%, and 20%. Marsh cone and mini-slump test were used to determine the effect of superplasticizer type and water binder ratio on the saturation dosage. From this study, it was observed that polycarboxylic ether based superplasticizer was more compatible with bagasse ash blended cement than sulphonated naphthalene based superplasticizer.

1. Introduction

The manufacturing process of cement results in the depletion of limited natural resources, consumption of excess energy and also leads to significant levels of carbon dioxide emission to the atmosphere. It is thus very important to effectively utilize alternative supplementary cementitious materials in concrete. Sugarcane bagasse is used as fuel in the cogeneration process to produce steam and electricity in sugar industries. When bagasse is burnt in combustion boiler under controlled burning, reactive amorphous silica is formed in the residual ashes [1]. After burning, bagasse ash is collected as a by-product from cogeneration boiler and directly dumped to nearest disposal area. Sugarcane bagasse ash (SCBA) is generated in large quantities (67,000 tonnes/day) in India, because of the extensively developed sugar industry [2]. Disposal of bagasse ash is a critical issue for sugar industries because of environmental constraints and land requirement. Rapid implementation of new cogeneration plants and expansion of cogeneration capacity of existing plants in sugar industries are further expected to increase bagasse ash generation significantly in the major sugar producing countries. Because of its good pozzolanic performance, bagasse ash has been suggested as an excellent alternative cementitious material in several previous research studies [2–7].

Chemical and mineral admixtures are widely used in concrete to attain high performance and durability. The partial replacement of cement with industrial by-products such as fly ash and slag in the cement manufacturing process leads to the production of durable, sustainable and less energy expended blended cement. Several other additives such as silica fume, rice husk ash and metakaolin are used as mineral admixtures in concrete.

Chemical composition of cement, fineness, presence of soluble alkali, C_3A content, types of gypsum and addition of supplementary cementitious materials used during cement manufacturing process

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are important factors which significantly govern the compatibility between superplasticizer and cement [8–10]. Compatibility of superplasticizer with blended cement paste has been studied by several researchers. Alteration of the rheological parameters for control and fly ash blended cement paste was observed for different dosages of polycarboxylic ether (PCE) based superplasticizers [11,12]. Effect of addition of fly ash and limestone powder on flow properties was studied by Sahmaran et al. [13], who found that flow properties were enhanced for the same dosage of PCE based superplasticizer compared to control paste, up to 30% of replacement. Higher fluidity of fly ash blended cement paste is attributed to the spherical shape of fly ash particles [14]. Lesser saturation dosage was observed for slag blended cement paste than control paste [15]. Another study reported that yield stress and plastic viscosity decreased for samples containing slag than fly ash blended paste [16]. Addition of metakaolin as pozzolanic material significantly increased saturation dosage and caused reduction in fluidity [17]. Incorporation of silica fume as mineral admixture increased dosage of admixture and water demand compared to control paste [18].

The addition of water reducing chemical admixtures in concrete enhances its fresh and hardened properties [7]. Characteristics of superplasticizer including type of structure, presence of functional groups, and its dosage significantly influence the flow properties of cement paste [19,20]. Different chemical families of superplasticizers are used in modern high performance concretes to achieve required fluidity. Since most high performance concretes have binary or ternary combinations of cementitious materials, or use blended cements, proper understanding of the interaction between different superplasticizers and blended cement is essential. Improper selection or incompatibility of superplasticizer with cement and pozzolanic materials leads to adverse effects on the fresh and hardened properties [8]. Segregation, delayed setting, loss of workability, less workability retention are the common problems observed in incompatible superplasticized concrete [17]. This primarily happens because the incorporation of supplementary cementitious materials in modern high strength concrete leads to greater consumption of superplasticizer when compared to conventional concrete [18,19]. Influence of sugarcane bagasse ash and fly ash on the rheological behavior of cement pastes was studied by Quero et al. [21] and loss on fluidity was observed with SCBA replacement. Increase in viscosity and yield stress was observed with increase in bagasse ash replacement, but the interaction of different superplasticizers with bagasse ash was not addressed.

Concerning all the discussions mentioned above, it is evident that types of superplasticizer, types of pozzolanic material and water binder ratio significantly affect compatibility of superplasticizer with blended cement. There is still a need to evaluate the effect of the interaction of superplasticizer with cementitious systems containing pozzolanic materials, in order to achieve desirable fresh and hardened properties. A comprehensive investigation of compatibility concerns between sugarcane bagasse ash based Portland pozzolana cement (PPC) and superplasticizer is not available in the existing literature. In previous research studies, bagasse ash was only used as mineral admixture without proper characterization of its pozzolanic performance. This study aims to develop SCBA based Portland pozzolana cement and also investigate the interaction of superplasticizer with SCBA blended cement by using simple methods such as Marsh cone and mini-slump tests.

2. Materials and methods

2.1. Sugarcane bagasse ash

Sugarcane bagasse ash is collected by using bag-house filter from cogeneration boiler and disposed to the nearest area. The sample of raw bagasse ash consists of different types of particles. Most of the particles of raw bagasse ash are completely burnt fine particles. The presence of fibrous unburnt particles was visually observed in the raw bagasse ash. Structure and size of these fibrous particles are entirely different from the burnt fine particles. Plants consume orthosilicic acid from ground water, which is later polymerized as amorphous silica in the plant cells [22]. Due to controlled burning of sugarcane bagasse in the cogeneration process, reactive amorphous silica is formed and exists as main component in the residual ashes [2]. Similar behavior was observed in rice husk ash [23–26]. Generally bagasse is burnt around 550 °C to utilize maximum fuel value in the cogeneration boiler. Incomplete burning of plant cellular structured fibers leads to presence of more amount of fibrous particles in the raw bagasse ash. Two different types of fibrous unburnt particles were observed in the raw bagasse ash, namely coarse fibrous unburnt particles (CFU) and fine fibrous unburnt particles (FFU). The appearance of raw bagasse ash is shown in Fig. 1.

Raw bagasse ash has high moisture content because water is mixed during disposal. Raw bagasse ash was dried at 105–110 °C for 24 h to remove evaporable moisture content, and the dried sample was directly used for material testing without grinding. Oxide composition of raw bagasse ash was determined using an X-ray fluorescence spectrometer and the results are presented in Table 1. In addition, oxide composition of raw bagasse ash was corrected with respect to loss on ignition. Raw bagasse ash had more than 55% SiO_2, 7% K_2O and 6% CaO, along with significantly high SO_3 content. Mineralogical characterization by X-ray diffraction revealed the presence of Quartz and Crystobalite, apart from the amorphous hump that is associated with reactive silica [2,7]. This is explored further in a later section.

2.2. Superplasticizers

Different types of superplasticizers are used to achieve good workability with minimum water content. Sulphonated naphthalene formaldehyde (SNF) and sulphonated melamine formaldehyde (SMF) based superplasticizers and polycarboxylate ether (PCE) based superplasticizers are generally used in modern concrete applications because of their superior performance compared to lignosulphate based admixtures, which have problems of excessive retardation and inconsistent performance. To understand the interaction between different superplasticizers and the SCBA based PPC, two different superplasticizers were used in this study – an SNF based admixture (denoted as DC), and a PCE based admixture (denoted as GL). SMF superplasticizers are not commonly used in India because of poor high temperature performance as well as high costs, and were thus not used for the current study. Water content in the superplasticizer was adjusted in the water used for mixing process. Characteristics of superplasticizers, as reported by the manufacturers, are given in Table 2.

2.3. Methods

The method of preparation of paste, type of mixer, time of addition of superplasticizer etc. are governing factors in affecting cement superplasticizer interaction [17]. To avoid a negative influence of these parameters, similar methods of mixing and preparation of paste were adopted for all the combinations of cement and superplasticizers. Various methods are available to evaluate rheological parameters and relative fluidity. However, most of the methods including rheometry need specialized equipment, controlled environment and skilled operators. Simple methods such as Marsh cone test and mini-slump test were selected in this study. Three different replacements of bagasse ash (10%, 15%, and 20%), two different water to cementitious materials ratios (0.40 and 0.45) and two different superplasticizers (GL and DC) were used in this study.

Fig. 1. Raw sugarcane bagasse ash.