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Investigation on micronized biomass silica as a sustainable material

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ABSTRACT

Micronized biomass silica (MBS) is an agricultural waste obtained from controlled burning of rice husk and grind in jar mill. This paper investigates the optimum percentage of MBS for the replacement of cement by conducting several experiments with the blended cement paste and mortar with MBS percentages varying from 0, 4, 8 and 12. In addition, hydration products were also investigated in the blended cement paste through X-ray diffraction. Due to the pozzolanic reaction of MBS with cement hydrates, secondary calcium silicate hydrates (CSH) were formed and also MBS which has a potential to reduce the intensity of $Ca(OH)_2$ exhibited improved properties. The experimental results showed that the optimum percentage of MBS for the replacement of cement was 8% for the materials used in this study. The mechanical and durability properties of recycled aggregate concrete by replacing cement with 8% MBS were also carried out and it was found that the concrete exhibited improved properties. There by, using MBS one can overcome the drawbacks of recycled aggregate concrete as it acts as a supplementary cementitious material. Thus, by combining recycled concrete aggregate with MBS will achieve sustainable development.

1. Introduction

The rapid increase in population and economic development has led to the increase in production of waste products, such as fly ash, GGBS, rice husk ash and silica fume whose disposal is becoming a challenging task. Presently, a number of research studies are being carried over towards the use of waste in the concrete [1–3].

Rice husk is an agricultural waste obtained during the processing of paddy. It constitutes 20% of the 590 million tons of paddy produced in the world [4]. In India the rice husk is considered as a waste and is used for cattle feeding, land filling, manufacturing partition boards etc. [5]. Rice husk ash (RHA) obtained by controlled burning contains high amount of amorphous silica which is used in concrete as mineral admixture [6–8]. This amorphous silica reacts with hydration products and forms more CSH gel. This enhances the mechanical and durability properties of concrete [9]. It is understood that the incorporation of RHA in concrete improves strength, reduces permeability, and gives resistance to corrosion [10]. Various studies also prove that recycled aggregate concrete (RAC) with rice husk exhibits better mechanical properties than those without RHA [11,12].

In the recent times, another common waste product that affects the environment is construction and demolition waste, which is increasing with the rapid growth in urbanization due to demolition of old buildings and constructing high rise buildings. The construction industry in India generates about 12–14.7 million tons of waste annually [13,14]. Of these 2.40–3.67 million tonnes are concrete wastes [15,16]. Since aggregate constitutes 60% to 75% of the concrete volume [17], the use of demolition concrete wastes as recycled concrete aggregate can conserve the environment. The carbon emission for the production and transportation of each ton of recycled aggregate is 0.0024 million tons which is less compared to virgin aggregates reported 0.0046 million tonnes [18]. The net carbon emission at the time of production of virgin aggregates can be reduced by the replacement of recycled aggregates which will give more environmental benefits [19]. Even though recycled aggregate is a good alternative to natural aggregate, there are some drawbacks for structural application.

The physical properties of the recycled aggregates depend on the presence of old mortar in the concrete and the strength of the parent concrete [20]. Higher water absorption is the significant difference between natural aggregate and recycled concrete aggregate concluded by Nixon [21]. Etxeberria et al. [22] reported that there was a strength reduction when natural aggregates are fully replaced by recycled aggregates in the concrete. Kou [23] reported that the recycled aggregate concrete is more permeable compared to the control concrete. Katz [24] observed from his study that the

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shrinkage of RAC at the age of 90 days could be about 0.55–0.8 mm/m, whereas for conventional concrete is only about 0.30 mm/m.

It was observed from various studies, that the major problem of recycled aggregate concrete was due to the adhered mortar. This can be improved through various methods like heating and rubbing method, and acid treatment method [25]. Post treatment, it was observed that the properties of the treated recycled aggregate was improved but still it was found to be lower when compared to the natural aggregate. Tangchirapat and Gonzalez-Fonteboa [11,26] suggested that the properties of the recycled aggregate concrete can be improved by the incorporation of supplementary cementitious materials in concrete mixes. Fly ash, silica fume, slag and rice husk ash are the industrial and agricultural by-product wastes which are more in the lime light these days because of pozzolanic activity, these products mainly improve the properties of the normal concrete as well as recycled aggregate concrete. Kou [23] observed that replacement of cement with fly ash leads to lower the strength. Silica fume can also be used as a replacement of cement in concrete, but the cost of silica fume is expensive when compared to cement.

Several studies have been conducted on the performance of normal concrete containing RHA, however, studies on concrete containing micronized biomass silica (MBS) are limited. The MBS is obtained by controlled burning of rice husk (500–600 °C) in rotary furnace and latter grinding in jar mill for few hours to reduce the particle size (i.e. micronized). Thus, the main difference in RHA and MBS is the higher silica content and finer particles. The RHA and silica fume has been used as replacement of cement in the production of high performance of concrete [27,28]. Hence, a study has been taken up to find the mechanical and durability properties of concrete having partial replacement of cement with MBS and replacement coarse aggregate with recycled concrete aggregate toward sustainability. For the present study commercially available MBS is procured from N.K. Enerprises, Orisa, India.

2. Experimental program

2.1. Materials

Ordinary Portland cement of grade 53, conforming to IS 12269-2004 [29] and micronized biomass silica from rice husk with an average particle size of 18 μm (procured from N.K. Enerprises, Orisa, India) was used in this investigation. Ennore sand as per IS 650:1991 [30] specifications were used for the mortar studies. The oxides present in the ordinary Portland cement (OPC) and MBS are reported in Table 1. It should be noted that the percentage of the major oxides (SiO_2, Al2O$_3$, and Fe2O$_3$) present in MBS is 95.03% which was more than 70%, hence it will act as a good pozzolanic material. The physical and mechanical properties of OPC and MBS are reported in Tables 2 and 3 respectively. Laser diffraction particle size analyzer was used to find the particle size distribution of both cement and micronized biomass silica (MBS) which is shown in Fig. 1. The nature of the material (MBS) was found through X-ray diffraction and the pattern is shown in Fig. 2. The diffraction pattern of micronized biomass silica shows a broad peak around $2\theta = 22°$ indicating the amorphous nature of the material, hence, it will be more reactive when it is used in concrete.

Recycled concrete aggregates with a size of 20 mm and 10 mm was prepared by a jaw crusher. These aggregates have the mortar adhered to natural aggregate, which leads to lower density and higher water absorption. Hence, these recycle concrete aggregates were subjected to heating for 3 h at 250 °C and quenched in water before rubbing in a pan mixture to remove mortars. These recycle concrete aggregates was named as treated recycled aggregate. Both untreated and treated recycled aggregates are used as coarse aggregates in this study. Grading of all type of aggregates used in this investigation is shown in Fig. 3. The physical properties of

Table 1
Chemical composition of PC and MBS.

Chemical composition	Portland cement (%)	Micronized biomass silica (%)
SiO_2	16.16	94.25
Al_2O_3	3.67	0.38
Fe_2O_3	4.77	0.40
CaO	70.46	0.91
MgO	0.73	0.42
SO_3	2.70	0.27
K_2O	0.67	2.08

Table 2
Physical and mechanical properties of Portland cement.

Property	Result
Standard consistency	31%
Setting time	
Initial setting time (min)	132
Final setting time (min)	330
Compressive strength (MPa)	
@ 3 days	28.15
@ 7 days	39.22
@ 28 days	54.02

Table 3
Physical properties of cement and MBS.

Sample	Average particle size D_{50} (μm)	Specific gravity	BET Surface area (m^2/g)
Cement	25	3.14	0.91
MBS	18.38	2.19	12.23

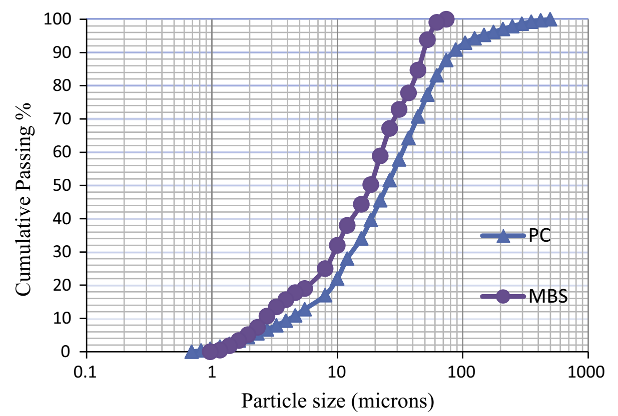

Fig. 1. Particle size distribution of PC and MBS (measured by laser diffraction particle size analyser).

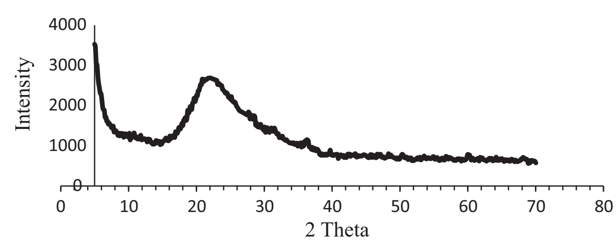

Fig. 2. X-ray diffraction pattern of MBS.