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Cement & Concrete Composites 28 (2006) 33–38
Cement & Concrete Composites
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Influence of binders on properties of sintered fly ash aggregate

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Received 18 June 2004; accepted 14 June 2005
Available online 16 September 2005

Abstract

Sustained research and development work on the utilization of fly ash for various productive uses have been carried out in the past. In the construction industry, major attention has been devoted to the use of fly ash in concrete as a cement replacement. The production of artificial lightweight coarse aggregate using fly ash has potential for its large-scale utilization in the construction industry and this is an area that merits attention in many parts of the world, bearing in mind the rapid dwindling of sources of natural aggregates. As only limited details on manufacture and parameters influencing properties of sintered fly ash aggregates have been reported in the literature, a systematic study was undertaken. In this paper, the relative performance of three binders, viz., cement, lime and bentonite, on the properties of sintered fly ash aggregate is reported. The salient observations are (i) the characterization studies on sintered fly ash aggregates show that the properties of aggregates depend on the type of binder and its dosage, (ii) the significant improvement in strength and reduction in water absorption of sintered fly ash aggregate is observed when bentonite is added with fly ash, (iii) the binders used did not alter the chemical composition, while they influence the microstructure of the aggregate, which results in enhancement in the properties of aggregates.

Keywords: Fly ash; Pelletization; Aggregate; Sintering; XRD; SEM; Bentonite

1. Introduction

The production of artificial lightweight coarse aggregate using fly ash allows its large-scale utilization in the construction industry and this is an area that would merit attention in many parts of the world, bearing in mind the rapid dwindling of sources of natural aggregates. Most of the research work on the performance of lightweight aggregate concrete used sintered fly ash aggregate. Factory-made sintered fly ash aggregate is available in many countries and has been used in practice [1–8]. Since the technology is not freely available, such factory-made sintered fly ash aggregates are not available in several developing countries. In such cases, attempts have been made to use laboratory-produced aggregates [9,10]. Sintering, cold bonding or autoclaving are the three methods generally used for the hardening of fly ash pellets. Sintering process hardens the pellets by fusing the fly ash particles together at the points of mutual contact. Cold bonding is a type of bonding which accounts for the ability of fly ash to react with calcium hydroxide at ordinary temperatures to form a water-resistant bonding material, which accounts for the pozzolanic reactivity of fly ash. Autoclaving uses pressurized saturated steam curing for hardening of fly ash pellets [11]. The pore structure of aggregates made from sintered pulverized fuel ash, their absorption characteristics and relative density have been reported [1,3]. Yang and Haung [12] reported that the saturated surface-dry unit weight of aggregates from fly ash using varying percentages of cement as binder ranged from

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doi:10.1016/j.cemconcomp.2005.06.005

1.62 to 1.73 g/cm^3 and 30-min water absorption varied from 21.05% to 33.39%.

As only limited details on manufacture and parameters influencing properties of sintered fly ash aggregates have been reported in literature, a systematic study was undertaken by the authors. As a first step, a detailed study was carried out on the process of pelletization with different parameters such as the influence of angle of pelletizer disc, moisture content, effect of fineness of fly ash, and sintering temperature and its duration [13]. The salient observations are (i) for a chosen diameter of the pelletizer disc and the speed of revolution, the optimal angle of pelletizer has to be determined to maximize the pelletization efficiency, (ii) adjustment of moisture content results in production of pellets of different size, (iii) for a given temperature and duration of sintering, pellets made with finer fly ash yield relatively higher strength, and (iv) strength and water absorption of pellets are influenced mainly by the speed of pelletizer and strength is influenced by the interaction effect between angle of pelletizer and moisture content. The properties of the sintered fly ash aggregate mentioned in Table 1 indicate that (i) the 10% fines values of these aggregates were very low and the water absorption is high, and (ii) as the fineness of fly ash increases, the 10% fines value also increases.

From the above, it appears that further increase in fineness of fly ash can increase the strength of pellets. The use of finer fly ash has limited scope, as one should aim to utilize the available fly ash without further processing. In order to increase the strength of pellets and reduce its water absorption, the next option is to use binders, which are often used in metallurgical applications. Binders play an important role in pelletizing. Binders help to (i) improve the ballability of the material, (ii) affect the green and dried strength of balls and fired strength of pellets, and (iii) adjust the chemical and mineralogical consistency and quality of fired pellets. Conventional binders used in metallurgical process are bentonite, lime, cement, and some organic substances like dextrin, sulfate waste liquor, tars and alkali compounds [14]. In the present study, the relative performance of three binders, viz., cement, lime and bentonite, on the properties of sintered fly ash aggregate is studied.

2. Materials and methods

The physical and chemical characteristics of fly ash used, which are listed in Table 2, indicate that it conforms to Class-F as per ASTM C 618. Ordinary Portland cement, Na–bentonite and powdered limestone were used as binders in 10%, 20%, and 30% by weight of fly ash for pelletization. A disc type pelletizer of diameter 0.57 m and having a depth of 0.25 m was used. The speed of the pelletizing disc was controlled using a gear arrangement and also by attaching motors with different speed of revolutions per minute. The angle of the pelletizer with reference to the normal was varied using a shaft arrangement. Based on first stage of studies [13,15] (i) the optimal speed and angle were fixed at 40 rpm and 55°, respectively, and (ii) after pelletization, the aggregates were dried before sintering at a temperature of 1100 °C for 1-h duration in a muffle furnace. The physical properties (microstructure and water absorption), chemical characteristics (using X-ray diffraction) and mechanical property (10% fines value) of sintered fly ash aggregates realized with different types of binders were determined and the results are presented and discussed below.

3. Influence of binders on properties of aggregate

3.1. Specific gravity

The essential characteristics of lightweight aggregate are its high internal porosity, which results in a low

Table 2
Physical and chemical properties of fly ash

Properties	Properties of fly ash used and specifications	
	Fly ash used	ASTM C 618 (Class-F)
Specific gravity	2.00	–
Fineness (m^2/kg)	428	–
Retention on 45 μm sieve (%)	33	–
$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	91.01	70 (min)
MgO (%)	0.60	5 (max)
SO_3 (%)	0.46	–
CaO (%)	6.93%	<10

Table 1
Variation in properties of sintered fly ash aggregate with fineness of fly ash [13]

Property	Test method adopted	Class-F fineness		Class-C fineness	Limiting value
		428 m^2/kg	452 m^2/kg	340 m^2/kg	
Dry loose bulk density (kg/m^3)	ASTM C 330	807	820	773	880 (max)
Specific gravity	ASTM C 128	1.75	1.76	1.6	–
24-h water absorption (%)	IS 2386	21.3	23.2	35	–
10% fines (tonne)	BS 882	1.76	1.78	1.1	5 (min)

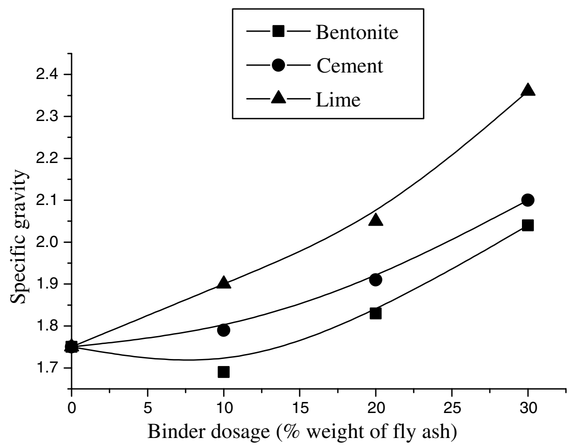

Fig. 1. Variation of specific gravity of sintered fly ash aggregate with binder dosage.

apparent specific gravity. Fig. 1 shows that in general the specific gravity increases when binders are used. Among the binders, aggregate with bentonite has a lower specific gravity compared to lime and cement. The addition of bentonite, which contains a higher amount of very fine organic matters, increases the quantity of gases evolved during sintering thereby reducing the density of the aggregates [14].

3.2. 10% fines value of the aggregate

For lightweight aggregate, as crushing value test is not appropriate (aggregate will get compacted before the full load of 40 t is applied and hence the amount of crushing during later stages of the test is reduced), a 10% fine value is used to compare the strength of aggregates. Fig. 2 shows the influence of these three binders at different dosages on the 10% fines value of aggregate. Addition of lime does not improve the 10% fines value but it has been found that it helps in appreciable improvement of the ballability of the material. Addition of cement resulted in marginal improvement in 10% fines value. It is also found that this increase is pronounced at higher dosage. Bentonite was observed to enhance the 10% fines value of aggregates significantly and the maximum value was obtained with 20% dosage. Beyond this dosage, there is no further enhancement in the 10% fines value of sintered aggregate. Bentonite is a clayey material consisting mainly of montmorillonite. Montomorillonite has one exceptional property, viz. it can take up water into the interlayer space. This is connected with the typical swelling ability of bentonite, which is important for balling because it enhances the cohesion of particles in the ball and the ball strength depends on cohesion of particles [4].

3.3. Water absorption

It can be seen from Fig. 3 that the 24 h water absorption of sintered fly ash aggregate without binders is in the range of 21–22%. Addition of lime reduces the water absorption marginally. Cement performs relatively better than lime as a binder in reducing water absorption. With the addition of 20% bentonite as binder, water absorption reduced significantly to 15–16%. Beyond 20% dosage, the binders did not exhibit further reduction in water absorption.

To identify the possible reason for variation in the properties of sintered fly ash aggregate with different binders, scanning electron micrograph and XRD studies were undertaken.

3.4. XRD studies

X-ray diffraction spectra were recorded by a powder diffractometer using Cu Kα radiation. Powdered samples were used for the study of XRD. Fig. 4 shows the XRD results of raw fly ash sample. The main chemical compositions of the fly ash identified through XRD

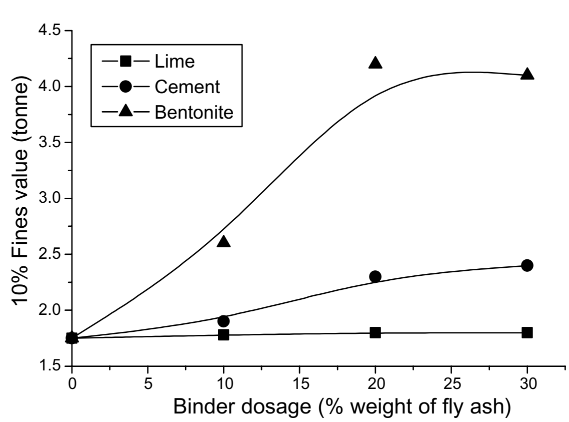

Fig. 2. Variation of 10% fines value of sintered fly ash aggregate with binder dosage.

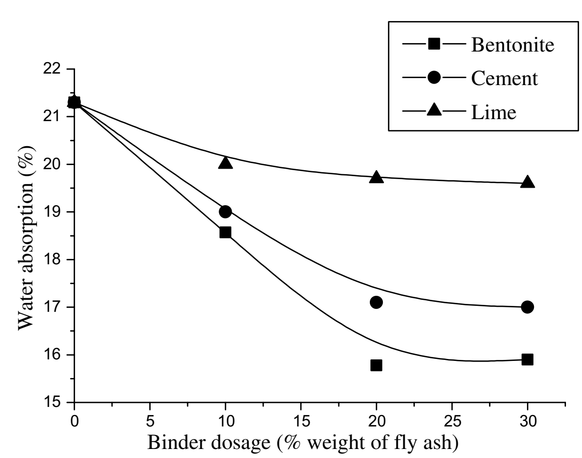

Fig. 3. Variation of 24-h water absorption of aggregate with binder dosage.

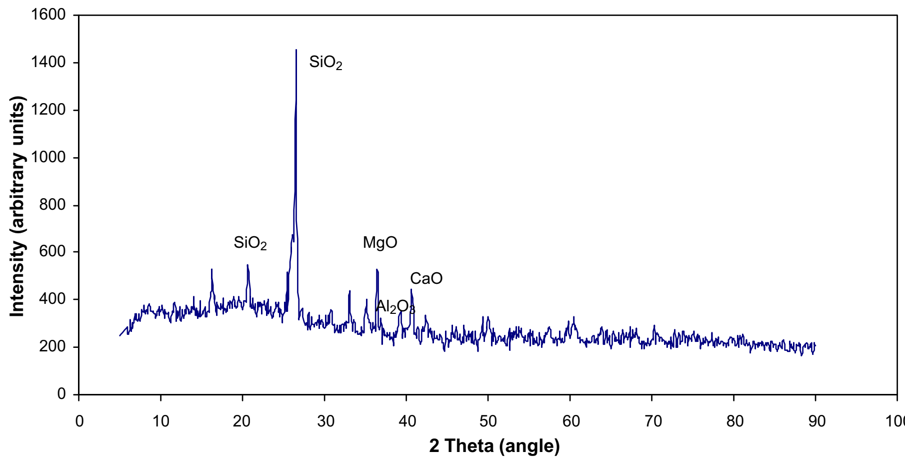

Fig. 4. XRD of raw fly ash sample.

and chemical analysis are SiO_2, Al_2O_3, MgO, and CaO. Representative XRD patterns of sintered fly ash aggregate samples with bentonite and lime (20% by weight of fly ash) are shown in Figs. 5 and 6, respectively. It is seen that the XRD peak is characterized by the presence of SiO_2 along with trace amounts of MgO and CaO. Irrespective of the binders used, the overall XRD pattern remain unaltered, indicating that there are no major variation, in the chemical composition of the product and no new compounds are formed. Hence, it may be concluded that the enhancement in properties of aggregates may be attributed to the binding ability of

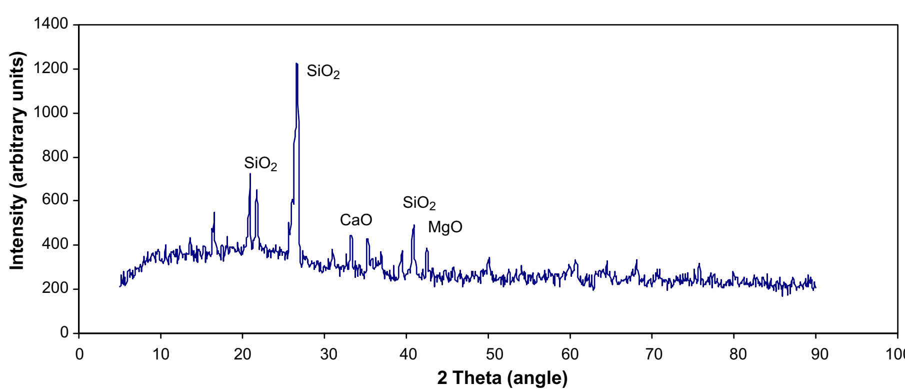

Fig. 5. XRD of fly ash and bentonite (20% by weight of fly ash) pellet sample.

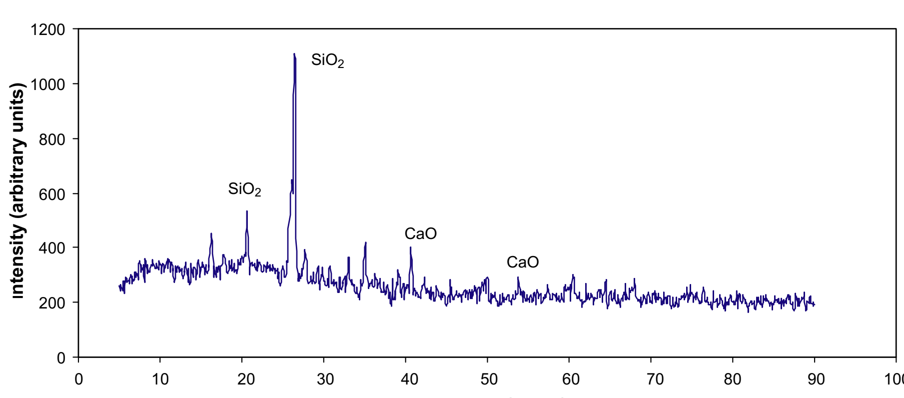

Fig. 6. XRD of fly ash and lime (20% by weight of fly ash) pellet sample.

binders and all properties, including density, water absorption, and strength of a porous material, are influenced by the internal pore structure of the material. Further, Zhang and Gjorv [16] have analyzed "Lytag" lightweight aggregate chemically and reported that major compounds were SiO_2, Al_2O_3, and CaO. Swamy and Lambert [1] reported that after sintering process, the main chemical constituents of aggregates were silica (about 30–60%) and alumina (about 15–30%). And thus the XRD studies reported in this paper corroborate with previous studies.

3.5. Scanning electron microscope studies

Regular pieces of 10 mm size were kept in an oven for 24 h at 105 ± 5 °C to remove evaporable water and mounted on metal stubs and sputter coated before subjecting to the electron beam from a JEOL 5300 scanning electron microscope. For micrographs, a magnification of 750 was used. The structure of sintered fly ash aggregate without binders in Fig. 7 indicates that the shapes of pores in general are irregular, spherical, and discrete, while others are elongated and interconnected. There are a few relatively large voids. Lack of binding among the grains may hence be the reason for the lower strength of fly ash aggregate. Fig. 8 shows the micrograph of fly ash aggregate with lime. Relatively smaller pores distributed uniformly in these aggregates indicate that cement and lime improve the binding ability. But still the presence of some large voids results in higher water absorption and lower strength of these aggregates. The dosage of bentonite affects the microstructure. With 10% bentonite, the presences of large voids are reduced. The use of 20% bentonite results in minute pores distributed uniformly as compared to all other cases (Fig. 9). This corroborates well with strength and water absorption

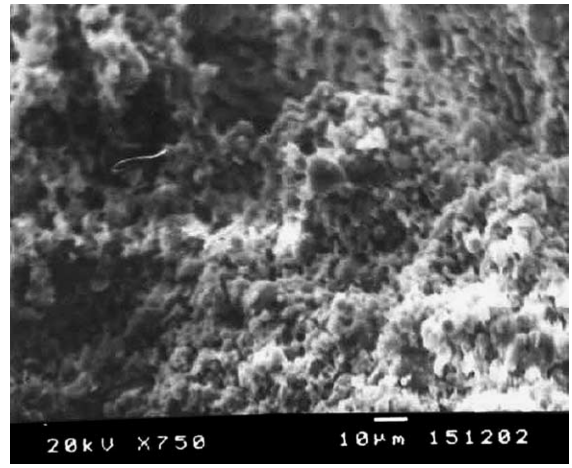

Fig. 8. Fly ash aggregate with lime as binder (20% by weight of fly ash).

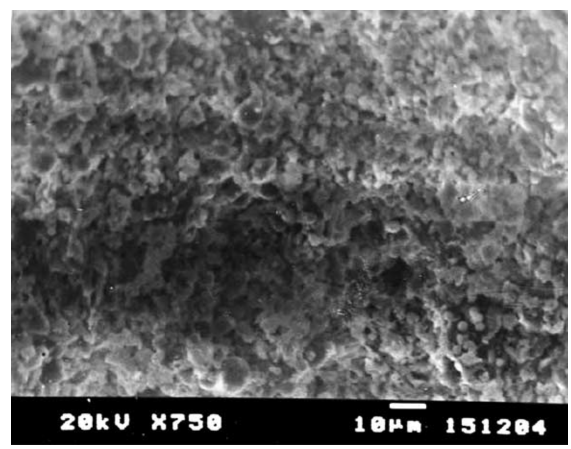

Fig. 9. Fly ash aggregate with bentonite as binder (20% by weight of fly ash).

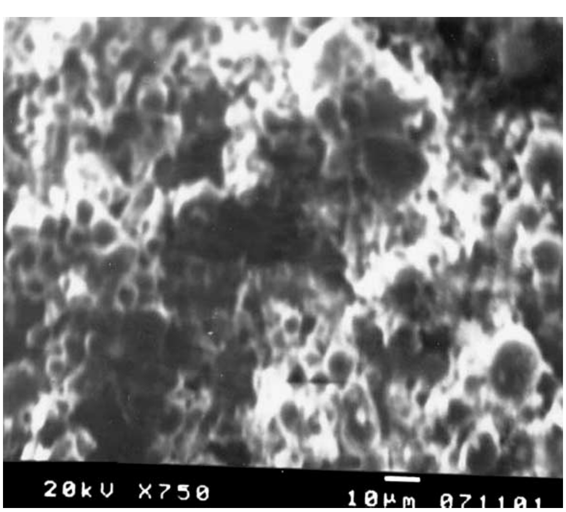

Fig. 7. Fly ash aggregate without binders.

characteristics of aggregates. Further increase in bentonite content to 30% was observed to affect the pore size and its distribution. Bentonite helps in pore refinement of the aggregates and finer distribution of closed pores on entire body and thus reduces the specific gravity.

3.6. Comparison of properties with specification

Table 3 summarizes the properties of sintered fly ash aggregate with 20% bentonite as binder. The high water absorption value indicates that pre-soaking of aggregate is essential before concrete mixing. The dry loose bulk density is below the limiting value of ASTM C 330, indicating that it is classified as lightweight aggregate. The test for organic impurities of these aggregates showed light color. Hence, it is concluded that sintered fly ash aggregates do not have objectionable organic impurities. Clay lumps and friable particles are very low and were less compared to the limiting value of ASTM C 330.

Table 3
Properties of sintered fly ash aggregate with bentonite as binder

Property	Test method adopted	Properties of aggregate with fly ash + 20% bentonite	Limiting value
Dry loose bulk density (kg/m^3)	ASTM C 330	850	880 (max)
Specific gravity	ASTM C 128	1.83	–
24-h water absorption (%)	IS 2386	15.8	–
10% fines (tonne)	BS 882	4.2	5 (min)
Clay lumps and friable particles (%)	ASTM C 330	0.2	2 (max)
Organic impurities	ASTM C 40	Light colour	Light colour
Stain	ASTM C 641	Light	Light colour

4. Conclusions

The following conclusions are made from the above study, which is applicable to the materials used and range of parameters studied.

1. The characterization studies on sintered fly ash aggregates show that the properties of aggregates depend on the type of binder and its dosage.
2. The significant improvement in the 10% fines value and reduction in water absorption of sintered fly ash aggregate is observed when bentonite is added with fly ash.
3. The addition of 20% sodium bentonite resulted in optimal strength (represented through 10% fines value) and minimum water absorption characteristics.
4. The binders used did not alter the chemical composition, while they influenced the microstructure of the aggregate, which results in enhancement in the properties of aggregates.

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