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Research Article

Physical and Mechanical Properties of an Artificial Aggregate Made up of Ground Granulated Blast-Furnace Slag

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ABSTRACT

Manufacturing artificial aggregate by utilizing waste materials has gained great importance as the aggregate occupies a high volume in concrete (60–70%). In this paper, ground-granulated blast-furnace slag (GGBFS) is utilized in aggregate manufacturing. Cold bonding and sintering methods were used as production processes. The pellets were put through a series of tests such as dry density, specific gravity, water absorption, and crushing strength. The results indicated that the density of pellets increased by increasing the GGBFS dosage while the water absorption capacity was reduced. Furthermore, the highest crushed strength was recorded at 50% addition of GGBFS.

Keywords: Artificial aggregate, cold bonded, ground-granulated blast-furnace slag, pelletization, waste materials

INTRODUCTION

The enormous expansion of industry in recent years makes it all the more important to manage trash effectively and lessen its impact on the natural world and on people's health. The annual production of ground-granulated blast-furnace slag (GGBFS) as a solid waste material from the iron melting process is very high. Reusing trash to make new building supplies or synthetic exaggerate (like fly ash, a byproduct of thermal power plants) is supported by research,[1,2] sewage sludge,[3,4] quartz powder,[5] and different types of ashes[6] which were studied.

Cold bonding (cement-based pelletization) and sintering processes[7] are the most common methods in aggregate production. Although the properties of sintered aggregate are better than those of cold-bonded aggregate in terms of strength, it is a costly and energy-consuming method when compared to the cold-bonded process. The disadvantage of the cold bonding process is the time that the pellets need to gain the required strength,[8] in contrast to the sintering method, in which the pellets gain strength and are ready to use immediately after the sintering is completed.[9]

Utilizing cold-bonded and sintered artificial aggregates in concrete production has been investigated in the literature. Some studies have shown that 30% replacement of artificial aggregate with natural aggregate could result in comparable properties to normal concrete.[10,11] Sintered fly ash artificial aggregate as a replacement for fine aggregate improved the mechanical properties and fracture strength of concrete.[12] A compressive strength of concrete between 20 MPa and 80 MPa could be achieved using artificial aggregate. The axial strength of the concrete increased with the use of 10% of fly ash artificial aggregate as a replacement for natural coarse aggregate.[13] In addition to the mechanical properties, the workability can also be improved when using artificial aggregate due to its spherical shape.[14] Although some studies resulted in the lower mechanical properties of artificial aggregate concrete compared to normal concrete, artificial aggregate concrete has advantages such as being low-cost, eco-friendly, and lower in dead load.[15-17] The cost of concrete produced with artificial aggregate reduces by 13–15% compared to the cost of normal concrete.[18]

There are few studies on the use of GGBFS in the production of lightweight aggregate. Therefore, the aim of this study is to propose a new idea of utilizing the large amount of such waste materials in the production of the frequently and in

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large quantities used material, which is aggregate. Thus, this investigation concentrated on the possibility of manufacturing artificial aggregate using GGBFS and optimizing the amount of GGBFS that would result in physical and mechanical properties of aggregate that can be compared with those of natural aggregate.

MATERIALS AND METHODOLOGY

In this experimental study, ordinary Portland cement (OPC) of grades CEMI 42.5 R and GGBFS from the local markets was used to manufacture the cold-bonded and sintered aggregates. The GGBFS was oven-dried for 24 h at 105°C before being used followed by grinding into powder. The major components of GGBFS are CaO, SiO_2, and Al_2O_3. Table 1 shows the physical and chemical compositions of OPC and GGBFS.

Manufacturing of Aggregate

To produce the cold-bonded aggregate, GGBFS was mixed with cement in proportions of 20, 30, and 50%, as shown in Table 2. The proportions were selected after trials to get the appropriate pellets in terms of shape and size. The ratio of GGBFS above 50% showed difficulty in forming rounded pellets, and the loss of materials started to increase. The combinations have been labeled by considering the ratio of cement and GGBFS; for example, 80C20G refers to pellets made with 80% of cement and 20% of GGBFS. The dry materials were fed into the pelletization disk with a diameter of 800 mm and a depth of 300 mm, as shown in Figure 1. The first stage of the cold bonding process is to mix the dry materials for 3–5 min to get a homogenous mixture followed by adding the water by way of spraying onto the materials while the rotating of the pelletization disk is continued. After 15–20 min, the pellets started to be formed in the size range of 8–16 mm. Figure 2 shows the cold bonding process, and Figure 3 shows the produced pellets. The pellets were then collected and kept in plastic bags to be cured at room temperature and humidity of 20°C and 95 %, respectively, for 28 days before being used as cold-bonded aggregates. On the other hand, a quantity of the produced pellets was taken once the pelletization process had been completed and exposed to a high temperature of 900°C for 2 h, as shown in Figure 4, to produce the sintered aggregates. The difference in appearance and color between cold-bonded and sintered aggregate is shown in Figure 5.

Table 1: Physical and chemical composition of the materials used in this study

Composition (%)	OPC	GGBFS
CaO	62.58	34.12
SiO_2	20.25	36.41
Al_2O_3	5.31	10.39
Fe_2O_3	4.04	0.67
MgO	2.82	10.26
SO_3	2.73	-
K_2O	0.92	0.97
Na_2O	0.22	0.35
Loss on ignition	3.02	1.64
Specific gravity	3.15	2.79
Blaine fineness (m^2/kg)	326	418

OPC: Ordinary Portland cement, GGBFS: Ground-granulated blast-furnace slag

Table 2: Mix proportions

Mix ID	OPC (%)	GGBFS (%)
80C20G	80	20
70C30G	70	30
50C50G	50	50

OPC: Ordinary Portland cement, GGBFS: Ground-granulated blast-furnace slag

Test Procedures

To investigate the physical and mechanical properties of the produced pellets, tests of bulk density, specific gravity, and water absorption were carried out in accordance with ASTM 127,[19] and particle size distribution by sieve analysis procedures. Furthermore, the crushing strength value was measured as per BS 812 Part 110.[20]

Figure 1: The pelletization disk

Figure 2: During the cold-bonding process

By measuring the pellets' oven-dry weight (W1), pellets' weight (W2) while submerged in water, and pellets' saturated weight (W3) after 24 h in water, we were able to determine the pellets' oven-dry (OD) relative density and water absorption. To do the math, we used these relationships:[19]

$$\text{Relative Density } (\text{OD}) = \frac{W1}{W3 - W2} \tag{1}$$

$$\text{Water absorption} = \frac{W3 - W1}{W1} \times 100 \tag{2}$$

The pellets were tested individually for crushing strength by applying the aggregate particle between two parallel plates and applying a load of 28 KN until failure, as shown in Figure 6. The following equation[20] was used to determine the crushing strength after taking the average of ten pellets for each mix.

$$\text{Crushing strength} = \frac{2.8\ F}{\pi d^2} \tag{3}$$

Where F is the maximum load at failure (N), and d is the diameter or the distance between the loading points (mm).

Figure 3: The produced pellets

Figure 4: Sintering the pellets at 900°C

RESULTS AND DISCUSSION

The results of density, specific gravity, water absorption, and crushing strength values for the cold-bonded artificial aggregate are listed in Table 3 and graphically shown in Figures 7–9. It can be seen from the results that the addition of GGBFS improves the aggregate properties by increasing the specific gravity and density and reducing the water absorption capacity. The cold-bonded artificial aggregate can be considered lightweight aggregate as the densities are less than 2000 kg/m^3.[21] The high porosity of artificial aggregate resulted in a higher water absorption capacity, which is not a desirable property when used in concrete because the aggregate will affect the water-cement ratio that affects the hydration process. However, in this type of artificial aggregate, the voids were reduced by

Figure 5: Difference in appearance between (left) cold bonded and (right) sintered pellets

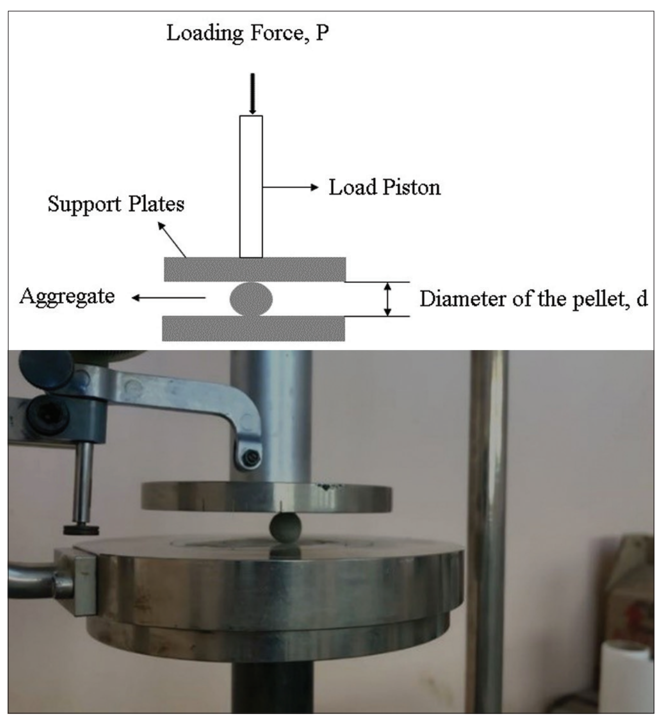

Figure 6: Test of crushing strength

Table 3: Physical and mechanical properties of cold-bonded artificial aggregate.

Mix ID	Specific gravity	Density (kg/m^3)	Water absorption (%)	Crushing strength (N)
80C20G	1.84	652.18	18.05	453.29
70C30G	1.80	750.00	17.20	541.78
50C50G	1.74	1114.42	16.27	1038.98

Table 4: Physical and mechanical properties of sintered artificial aggregate at 900°C

Mix ID	Density (kg/m^3)	Water absorption (%)	Crushing strength (N)
80C20G	1299	15.85	690.8
70C30G	1324	14	858.5
50C50G	1337	11.15	1059.87

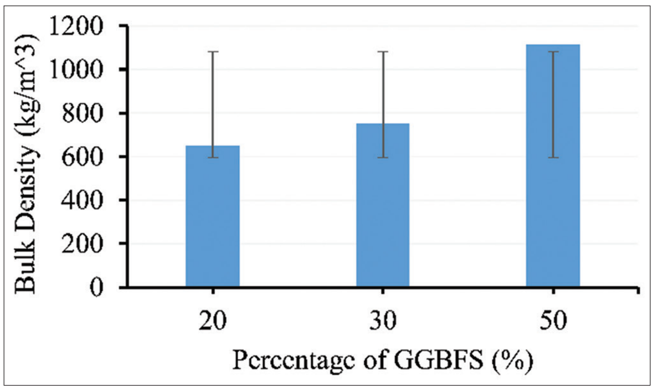

Figure 7: Bulk density of artificial aggregate

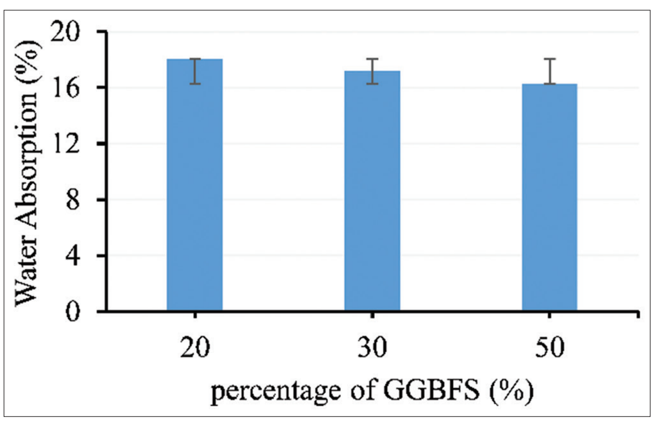

Figure 8: Water absorption of artificial aggregate

increasing the GGBFS dosage to 50%, and as a result, the minimum water absorption of 16.27 was achieved.

In addition, the particle size distribution is shown in Figure 10 for the cold-bonded artificial aggregate at different ratios of GGBFS.

Furthermore, the crushing strength results agree with the density and water absorption results, with the maximum crushing strength of 1038.98 N recorded at the mix with a maximum density of 1114.42 kg/m^3. This means that increasing the ratio of GGBFS could improve the physical and mechanical properties of artificial aggregate.

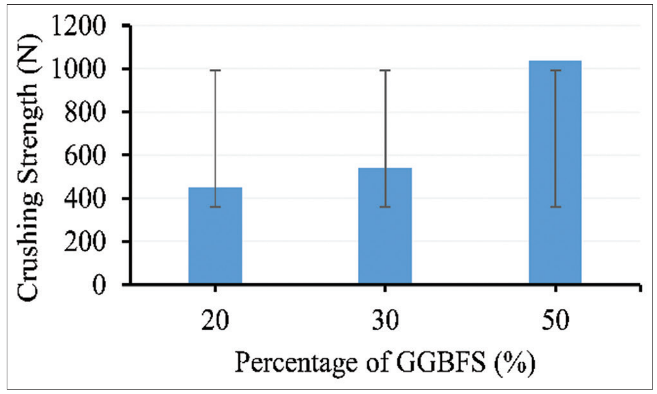

Figure 9: Crushing strength of artificial aggregate

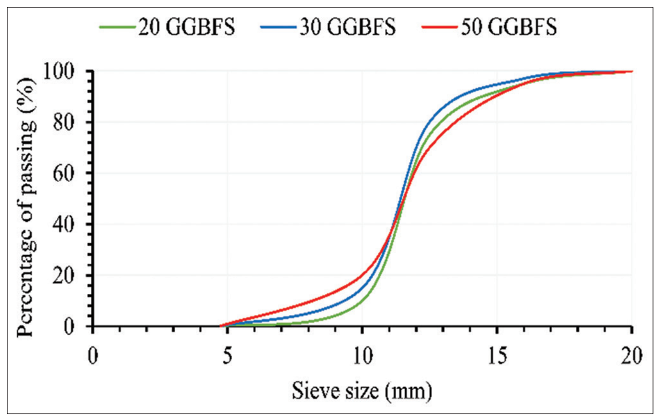

Figure 10: Particle size distribution of artificial aggregate

The results of the sintered aggregate properties are shown in Table 4. The results indicated better performance when exposed to high temperatures by increasing the density and reducing the water absorption. The high temperature leads to a glassy texture inside the pellets, which, in turn, reduces water absorption.

From the show results, the mixture of 50% of GGBFS can be considered the optimized mixture for producing the artificial lightweight aggregate, as it resulted in the best physical and strength properties. In the study of Kumar *et al.*, 2016, the physical properties of an artificial aggregate made up with GGBFS were found to be similar to the results in this study, where the water absorption was found to be 18% and the specific gravity was 2.76.[22]

CONCLUSION

In this experimental study, GGBFS was selected to be utilized in the production of cold-bonded and sintered artificial aggregates. Due to the obtained results, the following conclusions are drawn:

1. All of the produced aggregate can be considered lightweight aggregate since the densities are less than 2000 kg/m^3 in accordance with BS EN 13055-1 (2002). The highest density recorded at the artificial aggregate contains 50% of GGBFS in both cold-bonded and sintered aggregates, while the minimum is at 20% of GGBFS mixture.
2. The capacity of pellets to absorb water was found to be reduced by increasing the amount of GGBFS. The minimum water absorption obtained at 50% of GGBFS mixture.
3. It was found that the sintering temperature affects the water absorption and can reduce it to about 31% at a mix of 50% of GGBFS. This is due to the glassy texture that is obtained during the sintering process.
4. The artificial aggregate's crushing strength increases as the percentage of GGBFS increases. Crushing strength increased by 56% when GGBFS was increased from 20% to 50%. The sintered artificial aggregate yielded similar results. Due to the properties obtained from the artificial aggregate, further studies are planned to be carried out to investigate the influence of the produced aggregate on the mechanical and durability aspects of concrete.

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