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THE PROPERTIES OF GROUND GRANULATED BLAST FURNACE SLAG LIGHTWEIGHT AGGREGATE (GLA) AT VARIOUS MOLAR RATIO AND ITS APPLICATION IN CONCRETE

The effects of supplementary cementitious materials (SCM) on the characteristics and internal structure of synthetic aggregate made from ground granulated blast furnace slag are investigated in this study (GGBS). Due to its high pozzolanic activity, GGBS was shown to be superior to other SCM materials, enhancing both the strength and durability of synthetic aggregate. Because sintering uses a lot of energy and generates a lot of pollutants, using a cold-bonded approach to make low density lightweight aggregates is particularly significant from an economic and environmental standpoint. Thus, the utilisation of ground granulated blast furnace slag (GGBS) as a substitute material in the production of green artificial lightweight aggregate (GLA) using the cold bonding method was discussed in this work. Admixtures of ADVA Cast 203 and Hydrogen Peroxide were utilised to improve the quality of GLA at various molar ratios. The freshly extracted GLA was then evaluated for specific gravity, water absorption, aggregate impact, and aggregate crushing in order to determine the optimal proportion blend. As a result, the overall findings offer great application potential in the development of concrete (GCLA). It has been determined that aggregates with a toughness of 14.6% and a hardness of 15.9% are robust. The compressive strength test found that the GCLA has a high strength lightweight concrete of 37.19 MPa and a density of 1845.74 kg/m^3. The porous features developed inside the internal structure of GLA have led to GCLA's less weight compared to conventional concrete.

Keywords: cold bonding; ground granulated blast furnace slag (GGBS); artificial lightweight aggregate; lightweight concrete

1. Introduction

Concrete is the second-largest materials demand after water [1], rapid development demand for concrete yet leads to depletion of natural resources such as aggregate. Since natural aggregates are recognized as a non-renewable resource, rehabilitation efforts to produce artificial aggregate are becoming more important as a means of preserving natural resources. Artificial lightweight aggregate made from pozzolanic material can efficiently substitute natural coarse aggregate in structural lightweight concrete by providing numerous technical, economic, and environmental advantages [2]. In addition, artificial or synthetic aggregates which are produced with addition admixtures can help to improve the properties [3].

GGBS is type of waste product obtained from steel industries and widely used for cement industries as a cement substitute pozzolanic material [4]. According to Suresh and Nagaraju (2015) [5], GGBS is known as slag cement and one of the 'greenest' materials towards the construction industry. It is a non-metallic hydraulic cement and made up of silicate and aluminosilicate calcium due to the formation of molten iron in a blast furnace slag. Since GGBS production accounting for just around 16% of CO_2 emissions from cement manufacture process, greenhouse gas emissions are reduced [6]. In comparison to the OPC production method, which requires mining and grinding raw materials such as limestone and clay, GGBS manufacturing does not involve the extraction of natural resources. Moreover, depletion of natural resources will eventually impact our geological system.

Previous study has shown that adding GGBS to concrete does not reduce its strength. According to Anathan et al., (2018) [7], the advantages of employing GGBS are a reduction in compression reinforcement, CO_2 reduction, high in resistance of sulphate and other chemicals, and better in workability. GGBS mixed with cement hydration takes time because it depends on the release of calcium hydroxide from PC hydration. Thus, the internal structure of GGBS paste seems to be more porous

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than that of PC paste in the early stages [8]. Since pores will produce a lower density, therefore, GGBS is suitable to be used to achieve a lightweight material. Based on the study of Gehlot et al. (2021) [9], it state that Ordinary Portland cement (OPC) has been substituted with ground granulated blast furnace slag (GGBS) in amounts of 0%, 5%, 10%, 15%, 20%, 25%, and 30%, respectively, whereas the addition of 15% and 20% of GGBS as partial substitutes of cement results in an increase in compression strength of concrete when compared to no replacement has been performed. When 10% GGBS and 5% sawdust powder are substituted in the mortar mix, the compressive strength is higher and the usage of sawdust powder and crushed GGBS improved thermal characteristics while also lowering CO_2 emissions [10]. Furthermore, when 30% of OPC is substituted with GGBS, higher compressive strength obtained at 81.6 MPa after 28 days of curing as compared to control mix with 76.75 MPa [11]. Based on the study of Cheah et al. (2019) [12], the compressive strength of ternary mixed concrete containing GGBS-fly ash at 50 and 60% of cement replacement showed higher at both early and later ages than the neat OPC control sample.

As mentioned above, GGBS applications were proven as a potential material that helped in the improvement of strength, durability, and workability of the concrete. However, there is a lack of data on the influence of GGBS on artificial aggregate. Therefore, this research is to identify the properties of GLA by using GGBS. In addition, the production of artificial lightweight aggregates required several methods such as sintering and cold-bonding processes [13]. Since the cold bonding process required lower energy consumption, it was chosen in this study to satisfy both economic and environmental problems caused by the sintering process [14]. The demand of lightweight aggregate has increased nowadays as have both low density and thermal insulating properties. Thus, this research was conducted as to obtain better in mechanical properties of green artificial lightweight aggregate (GLA) to be used in construction purposes.

2. Methodology

2.1. Raw Material

GGBS was collected from the macro dimension concrete (MDC), which located in Chuping, Perlis. The size of GGBS used in this research is 0.21 mm. Admixture also has been used in this study, consist of ADVA Cast 203 and Hydrogen Peroxide (H_2O_2). The ADVA Cast 203 has a dispersion of type HRWR type F with 40% of water reduction. The Hydrogen Peroxide has a density of 1.05 g/cm^3 and pH solution of 4.5.

2.2. Mix design and process

The ratio in GLA development was 3:1, 5g of ADVA Cast 203 was used for 1.8 kg of cementitious material while the concentration of H_2O_2 used was 3%. The mix designation of GLA development at various molar ratio is shown in TABLE 1. GLA paste was made by combining GGBS with OPC, and the mixing time was determined by how well the two ingredients mixed. Water and chemical admixtures such as ADVA cast 203 and H_2O_2 were gradually added to the mixture after it was homogenized, and the mixture was blended for about 5 minutes until it formed an OPC/GGBS paste. In order to make GLA, the paste must be pelleted into a circular shape. The GLA was then cured for 3 days at room temperature before going through a 4-day water curing process. The formation of the GLA is depicted in Fig. 1.

TABLE 1

Design mix proportion at various molar ratio of GLA

Components	0% (control)	10% GGBS	15% GGBS	20% GGBS	25% GGBS	30% GGBS
GGBS (kg)	0	0.18	0.27	0.36	0.45	0.54
OPC (kg)	1.8	1.62	1.53	1.44	1.35	1.26
Water (kg)	0.6	0.6	0.6	0.6	0.6	0.6
ADVA cast 203 (g)	5	5	5	5	5	5
H_2O_2 foam (g)	72	72	72	72	72	72

For green concrete lightweight aggregate (GCLA), the optimum percentage of 15% mixture of GLA were used as coarse aggregate replacement. The ratio in GCLA production is 1:1:2 and the method used is referred accordance to American concrete institute (ACI). The cubes of GCLA were cured in water for 7 and 28 days before subjected to compressive strength test.

2.3. Testing and analyzing

GLA samples were subjected to; Specific gravity and water absorption accordance to BS 812-2:1995; Aggregate impact value (AIV) accordance to BS 812-112:1990 [15]; Aggregate crushing value (ACV) accordance to BS 812-110:1990 [16]. GCLA samples were subjected to compressive strength accordance to BS EN 123903:2009.

3. Results and discussion

3.1. Performance of green artificial lightweight aggregate (GLA)

3.1.1. Specific gravity

The specific gravity of 2.0 was claimed as the maximum value for lightweight aggregate [17] which higher than the specific gravity of GLA of 1.649. Fig. 2 shows that when the GGBS content increased from 10% to 20%, the specific gravity decreased. However, after 20%, the specific gravity value increased to 25%, followed by a progressive decline from 25% to 30%. For all of these reasons, it is evident that adding pozzolanic material like GGBS to an aggregate can have a significant impact on the

Fig. 1. Procedure of producing GLA aggregate

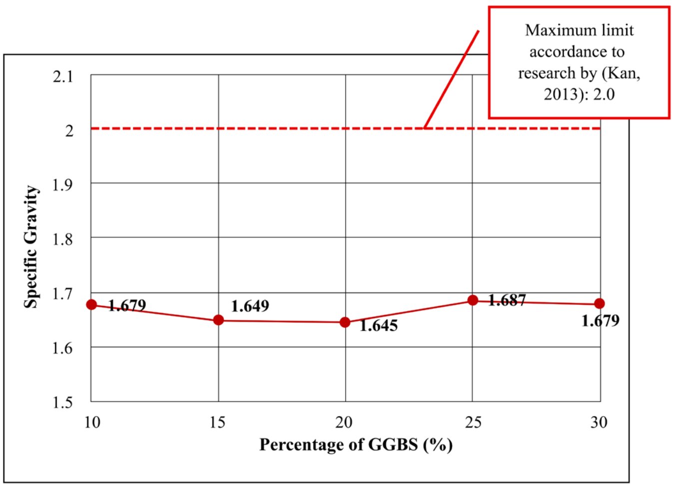

Fig. 2. Specific gravity of GLA at various percentages of GGBS at 7 days

aggregate's characteristics [18]. The presence of GGBS is found to influence the porosity [19]. Moreover, the porosity of GGBS reduce the specific gravity of GLA [20].

3.1.2. Water absorption

The percentage of water absorption upon varied levels of mixture was plotted to detect the contribution of GGBS in GLA production, as shown in Fig. 3. The lowest percentage of absorption can be detected at 15% of GGBS, which is 20.15%. The maximum percentage of absorption, 21.55%, was reported in a mixture of 20% GGBS. All of the mixes can be classified as acceptable materials absorption because the values obtained do not exceed the ASTM C127 [21] limitations.

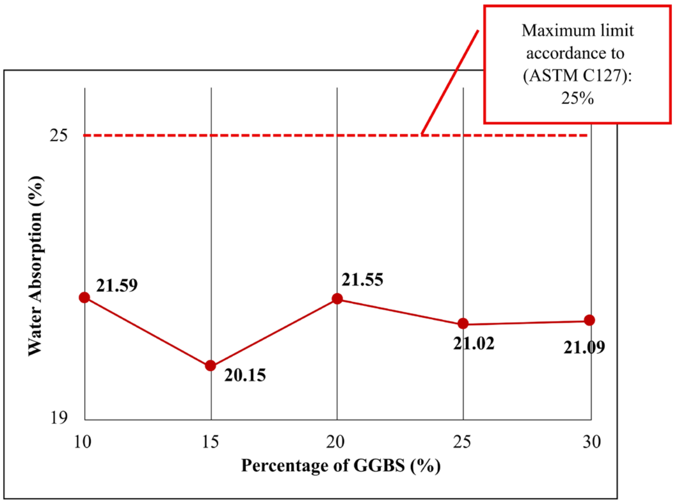

Fig. 3. Water absorption of GLA at various percentages of GGBS

Over the different degrees of combination, the trends for the influence of GGBS content on absorption parameter change were clearly different. It is because of the reactivity of the pozzolans material (GGBS) when combined with the usage of an admixture (H_2O_2) that the porosity index in the GLA internal structure was increased [22,23]. Fig. 4 depicted the internal structure of GLA and revealed the level of porosity, which increased the absorption value.

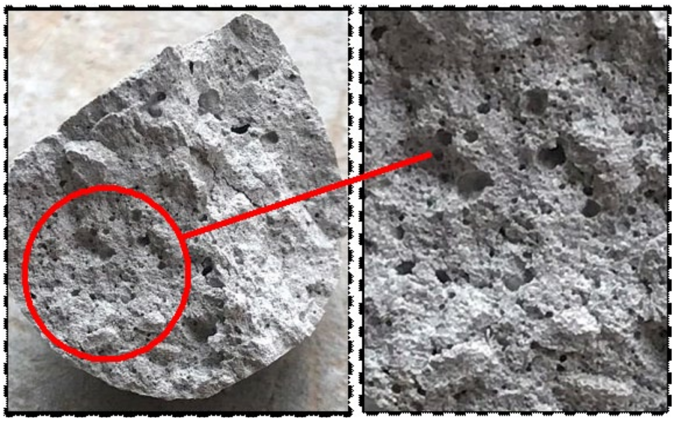

Fig. 4. Internal structure of GLA

3.1.3. Aggregate impact value (AIV)

As indicated in Fig. 5, the overall test result was successfully classified as lightweight aggregates because the value did not reach the BS 812-112:1990 [15] (30%) restrictions. The highest AIV results were recorded by combination 10%, with a hardness of 21.6%, compared to the lowest result, which was obtained by 15% mixture, with a toughness of 14.6%. The admixture ADVA Cast 203, which contains a 40% water reduction, was thought to be one of the causes for the improved strength. The cold bonded process has been shown to produce aggregate with a stable or even better impact value for use in construction. None of the GLA parameters have a significant value close to the limits, indicating that the newly developed GLA can be used as a coarse aggregate substitute in the construction industry.

The moisture movement within the mixture of GGBS, OPC and water, in which the dense matrix of the binder transition is believed to be more stable and properly filled in the voids or gaps that appear in the mixture, thus contributes to the high strength of GLA produced. The matrix bonding force that is associated with cement hydration and/or pozzolanic reaction plays crucial role that associated to the final product. Thus, optimization mixed design needs to be determined to aim the target of final product. This study found that replacement of GGBS of 15% showed the highest strength of GLA. However, GLA with substitution of GGBS at 20%, 25% and 30% also showed good strength of AIV, thus, it is still acceptable ranges of GGBS replacement for GLA production. The grain size contained in GGBS contribute better cementing properties of GGBS compared to OPC solely [24].

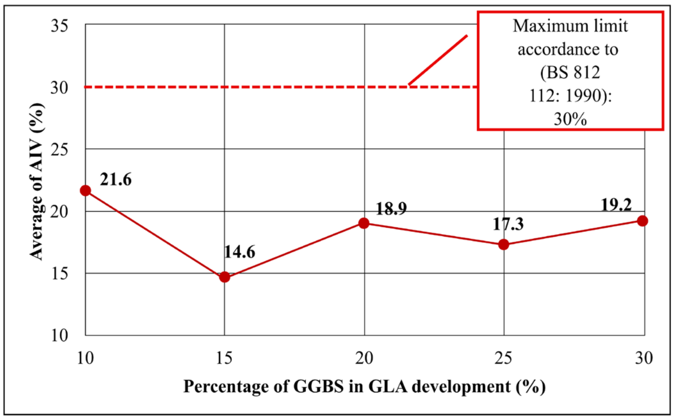

Fig. 5. Aggregate Impact Value (AIV) of GLA

3.1.4. Aggregate crushing value (ACV)

ACV also known as the hardness of the aggregate. Fig. 6 presents the ACV of GLA. Based on the results, all of the parameters appear to be better than the BS 812-110:1990 limits [16]. This assertion is supported by a recent study by Saberian et al. (2021) [25], who claimed that 35% of the ACV result indicated as the limit value for construction purposes.

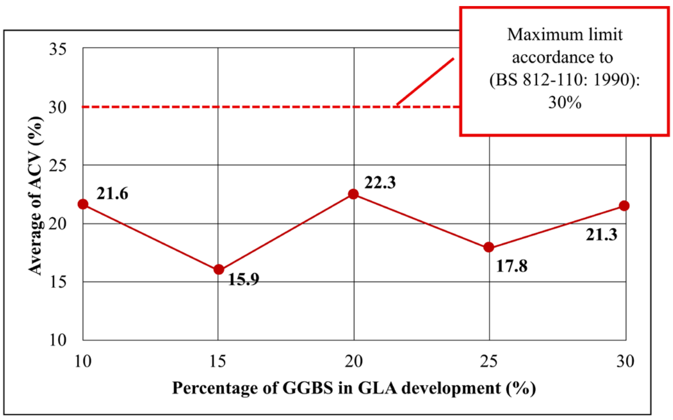

Fig. 6. Aggregate Crushing Value of GLA

The best results obtained for this study were 15.9%, which were less than the limits set (30% and 35%), indicating that the findings were successfully accepted because the value was less than the requirement. The findings of GLA's performance at various GGBS percentages are summarised in TABLE 2. The pattern of ACV results is the same as AIV results which shows 15% GGBS contributed to highest performance.

TABLE 2

Comparison of the properties for GLA and standard sample

Properties	GLA	Standard
Specific gravity	1.649	20
Water absorption (%)	20.15	25
AIV (%)	14.6	30
ACV (%)	15.9	30

3.2. Performance of green concrete lightweight aggregate (GCLA)

3.2.1. Density

The density of GCLA is 1845.74 kg/m^3, meanwhile the density of standard lightweight concrete is between 1680 kg/m^3 to 1920 kg/m^3 [26]. The percentage of difference is 0.23% only, however, both samples can be classified as lightweight concrete according to ASTM C330 [27] which stated as 1920 kg/m^3 is the maximum value of lightweight concrete identification.

3.2.2. Compressive strength

The compressive strength of GCLA at 7 and 28 days of testing were provided in TABLE 3. The 28 days result showed the compressive strength of GCLA is significantly higher from the standard strength of lightweight concrete accordance to ACI 213R-87 (Guide for Structural Lightweight Aggregate Concrete) [28], indicating that the inclusion of GLA towards coarse aggregate replacement plays significant effect to improve the strength of concrete. It is also believed that the compressive strength of GCLA is influenced by the kind of cement used. GGBS shows excellent substitute for cement which up to 30% replacement. Thus, this study has encourage more approach towards sustainable environment and green technology.

TABLE 3

Compressive strength of GCLA

Test age (days)	7	28
Compressive strength (MPa)	25.48	37.19

TABLE 4 shows the summary of properties for GCLA compared to requirements provided by ACI 213R87.

TABLE 4

Comparison between standard properties and GCLA properties

Properties	ACI 213R-87	GCLA	Percentage of difference (%), ACI 213R-87 – GCLA
Density (kg/m^3)	1850	1845.74	<0.23%
Strength (MPa)	17	37.19	>118.76%

4. Conclusion

In comparison to earlier study, the overall results for physical properties, specific gravity of 1.649, and water absorption of 20.15% of the GLA samples were significantly improved. The results revealed that GLA had a low specific gravity, indicating that it was a lightweight material, and a high absorption index, but not surpassing the standard set by BS 8122:1995. As a result, GGBS can be construed as being acceptable for use as a construction material replacement.

The overall mechanical characteristics of the GLA samples were considerably greater in mechanical resistance test, with toughness (aggregate impact value) of 14.6% and hardness (aggregate crushing value) of 15.9% above the standards set by BS 812-112:1990 and BS 812-110:1990. This shown that GLA can be utilized as a concrete substitute material for coarse aggregate.

Overall, the compressive strength test of 37.19 MPa for GCLA samples was high enough to withstand crushing resistance, making it suitable for use as a main structure component. In terms of physical condition, the density of GCLA (1845.74 kg/m^3) was superior to the normal density of lightweight concrete. The addition of GLA samples is thought to lower the density of the GCLA because the bonding creates voids in the internal structure of GLA instead of natural aggregate.

The newly developed GLA is a promising method for transforming construction materials from waste to value. Future study should focus on enhancing heat analysis tests and the production procedure including palletizing equipment.

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