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The use of Ground Granulated Blast Furnace Slag (GGBS) as Partial Cement Replacement in Brick

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Abstract: The production of Ordinary Portland Cement (OPC) has contributed to excessive emission of carbon dioxide to the atmosphere. The replacement of OPC with certain percentage of supplementary cementing material (SCM) can reduce the usage of OPC. Thus, the purpose of this study is to use Ground Granulated Blast Furnace Slag (GGBS) as partial cement replacement in sand cement brick. Since GGBS is a waste product, by using it as cement replacement significantly can reduce our environmental pollution. The experimental work was carried out to determine the physical and mechanical properties of sand cement brick containing high amount of GGBS as partial cement replacement and to obtain the optimum percentage of GGBS in brick. The percentage of GGBS for partial cement replacement are 30%, 40% and 50 %. A 215 mm x 103 mm x 65 mm (length x depth x height) size of brick is used to produce 48 samples of brick. The brick samples were tested after curing days of 7 and 28 days. The physical and mechanical test were carried out to achieve the objectives of the project such as density test, water absorption test, shape and size test and compressive test. From experimental results it can be concluded by using 30% of GGBS can increased the compressive strength of cement brick compared using fully OPC. The samples that use 40% and 50% of GGBS was lower than the strength that used 30% of GGBS. Therefore, 30% of GGBS replacement in cement brick was the optimum percentage and exceed the minimum requirement in standard of compressive strength cement bricks.

Keywords: Ordinary Portland Cement (OPC), Ground Granulated Blast Furnace Slag (GGBS), Physical Properties

1. Introduction

Ordinary Portland Cement (OPC) is one of the most important building materials, particularly for reinforced concrete structures. There are a few risks in the cement manufacturing process, including contamination, high temperatures, and contact with corrosive chemicals[1]. Furthermore, quarrying for OPC contributes to the direct discharge of cement via a synthetic process known as calcination. The

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calcination occurs when calcium carbonate (limestone) is heated and separated into calcium oxide and CO_2. This procedure represents half of all discharges from cement creation. Alternative materials should be highlighted in concrete work to reduce the use of OPC. Ground Granulated Blast Furnace Slag (GGBS) is industrial waste materials which contain similar properties as cement hence suitable to be used as cement replacement. The use of GGBS will provide lower impact on the environment because of slag that produced in a furnace is not exposed to the environment during the process. Also, the usage of waste materials of GGBS can reduce the cost brick then lead to sustainable concrete for masonry products.

The aim of this study is to determine density, water absorption, shape and size of sand cement brick containing high amount of GGBS as partial cement replacement and investigate the optimum percentage of GGBS as partial cement replacement in brick. The use of GGBS as cement replacement are 30, 40 and 50 percent. All bricks were cured for 7 and 28 days. An experimental lab work was carried out for physical and mechanical test to find out the results. From previous study, Arivalagan [2] state that GGBS generated various results depending on the percentage of mixture used and revealed that using 30% GGBS in concrete can enhance tensile strength. Hence, the GGBS exhibit limited performance because of it slow harden which causes longer curing period thus affect the structure that must be put into service quickly.

2. Literature Review

In this chapter, the performance of using Ground Granulated Blast Furnace Slag (GGBS) as cement replacement in brick is reviewed. Since GGBS is a waste product, by using it as cement replacement is a best way to protect our environment from contamination. It can also reduce the issues of waste dumping around the world, especially in Malaysia. According to Agnihotri et al. [3] The estimated global cement supply in 1995 was just 1.39 billion tonnes, demonstrating how much the building industry has progressed since then. It was discovered that one tonne of Portland cement required approximately 1.5 tonnes of mineral extraction together with 5000 MJ of energy and generate 0.95 tonnes of carbon dioxide (CO_2) equivalent, while GGBS just generate 0.07 tonne of carbon dioxide (CO_2) equivalent and only consume 1300 MJ of energy.

GGBS is a substance made by blasting pig iron in a furnace so that the iron extracted can be used as slag. Slag produces silica, alumina, and lime in its formulation. Silica is a cementitious substance that can be used in construction [1]. According to Sudharsan & Palanisamy [4], GGBS is utilised to create long-lasting concrete buildings. For its higher concrete durability, GGBS has been widely employed in Europe, and increasingly in the United States and Asia (especially in Japan and Singapore), extending the lifespan of structures from fifty to a hundred years. The use of GGBS would result in an additional substance that can be used as a cement replacement in concrete work. It can also create synthetic objects in solid, force, probability, and consistency over time. As a result, it is strongly suggested that GGBS is the best complement for bonding. Thus, GGBS is definitely the "global eco-wise" product [5]. Previous research Oner&Akyuz [6] has found the possibility of cement replacement with GGBS. When compared to conventional concrete, GGBS concrete has a reduced strength at an early age. It was happened because pozzolanic process is slow, and calcium hydroxide production takes a lot of time. However, during the curing process, the concrete's strength increased after 28 days. The typical compressive strength between concrete with and without GGBS can be seen in Figure 1.

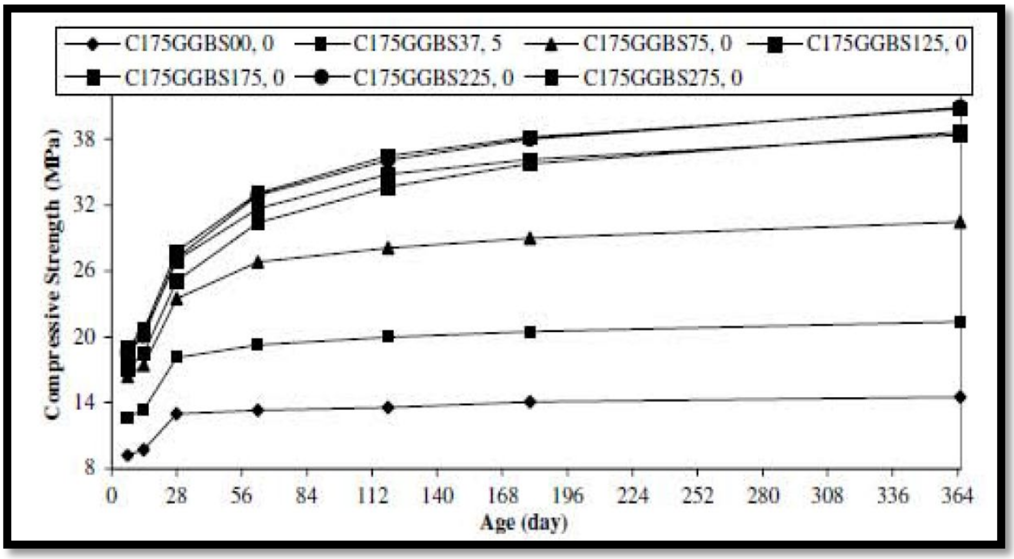

Figure 1: Increased of Compressive Strength in Time[6]

3. Materials and Methods

The methodology of experimental work is presented to achieve the objectives of this study. The study involves the preparation of materials and brick samples, curing, testing, results and data analysis.

3.1 Materials

The Ordinary Portland Cement (OPC) is one of the basic ingredients for all concrete work under construction. The material was kept in dry place and prevent from air moisture to keep the quality of cement. Air moisture is potential to hydrate the cement particles and effect the formation of calcium silicate hydrate gel [7]. Figure 2 shows OPC that was used in this experimental work.

Figure 2: Ordinary Portland Cement

Ground Granulated Blast Furnace Slag (GGBS) is a waste product that produce during iron manufacturing. The percentage of partial cement replacement used in the mixture are 30, 40 and 50 percent. Figure 3 shows the GGBS that have been used to replace the cement partially. It is shown that the colour of GGBS was white and has fine texture compared to OPC.

Figure 3: GGBS used during experimental work

The aggregate was used is fine aggregate which is sand. During experimental work, the weather at UTHM was rainy season and the sand need to keep dried before mixing it. To remove the moisture in the sand, the sand was exposed to sunlight for certain period until it dried. Then, it was sieved using 5mm sieve and kept at the dry place. Figure 4 shows the sand were dried under the sunlight until dry.

Figure 4: Sand

In concrete mix, water must free from other impurities and maintain with a neutral pH. The conventional tap water was used to cast cement brick. For this study, the water cement ratio was 0.6. The detail calculation of usage water needs to determine before mixing.

3.2 Methods

The standard size of bricks not including 10 mm mortar joints is 215 mm x 103 mm x 65 mm (length x depth x height). As total, 48 bricks samples were prepared for testing. There are two types of bricks samples that were prepared which is brick using Ground Granulated Blast Furnace Slag (GGBS) as partial cement replacement (M1, M2 and M3) and conventional sand cement brick (C) as control brick that produced without any GGBS.

Table 1: Mix design table

Type of Sample	Percentage of GGBS Replacement (%)	W/C Ratio	Sand (kg)	Water (kg)	Cement (kg)	GGBS (kg)
Control	-	0.6	69.95	14.04	23.33	-
GGBS-30	30	0.6	69.95	14.04	16.33	7.00
GGBS-40	40	0.6	69.95	14.04	15.40	10.26
GGBS-50	50	0.6	69.95	14.04	11.66	11.67

The weight for all material was calculated and table the data that shown in Table 1. The material was extra 10% to ensure the batching is enough for whole sample because during the concrete mixture the mixture will spill out from the mould and sticky at the concrete mixture machine.

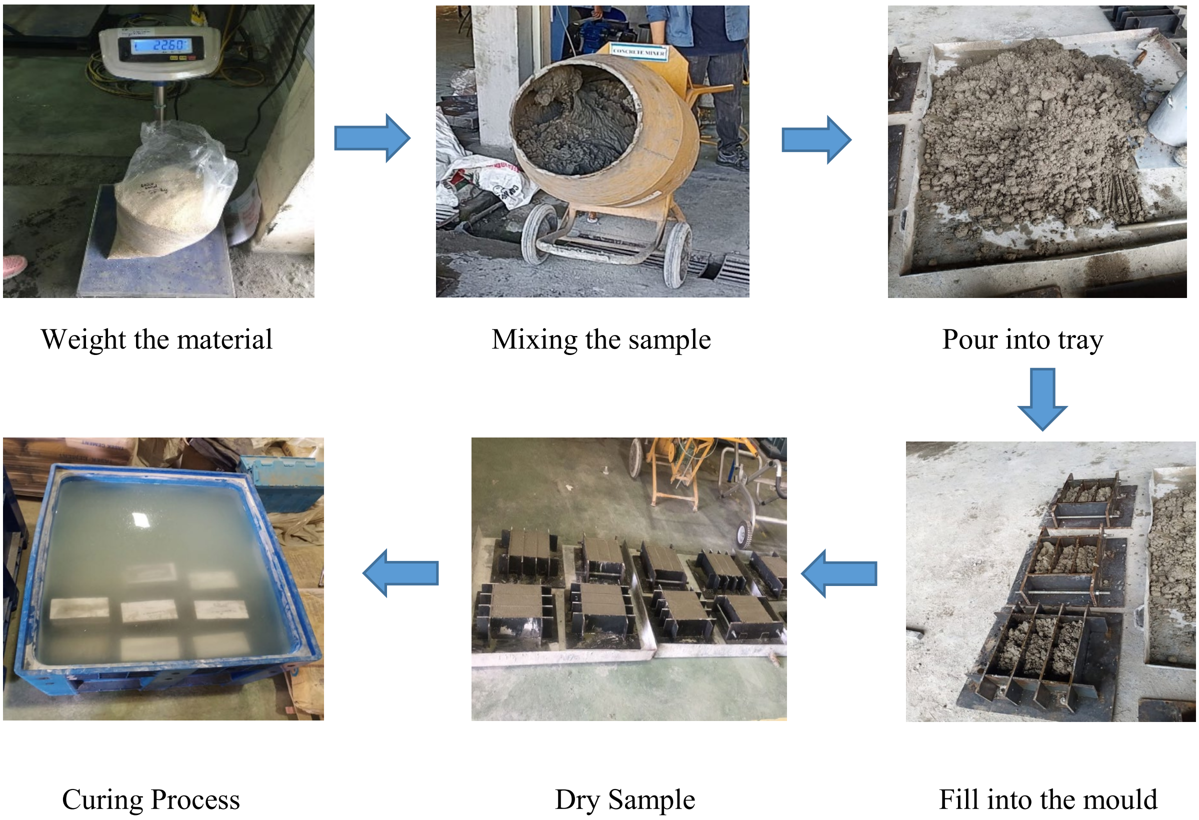

Figure 5: Flow chart of cement brick process

Figure 5 shows the process of making cement brick in the laboratory. The laboratory tests have been conducted on the sample once the brick samples had passed 7 and 28 days of curing process. Density is an important parameter because it indicates the weight of the brickwork. The mass and volume of brick was measured using vernier caliper, steel ruler and balance. The next test was Water absorption tests on bricks. It used to measure the bricks' durability properties, such as degree of burning, quality, and weathering behavior. A brick with a water absorption rate of less than 7% is more resistant to freezing damage. Vitrified bricks are those that have a water absorption rate of less than 3% [8]. The average water absorption shall not be more than 20% by weight up to class 12.5 and 15% by weight for higher class. The other test was shape and size test. The shape of brick was in rectangular with sharp edges. The standard size of bricks not including 10 mm mortar joints is 215 mm x 103 mm x 65 mm (length x depth x height). Thus, when all the sample are same shape and size, it will be eligible to use for building construction. The final test performed was Compressive strength test. This was carried out to determine the compressive strength of the sand cement brick containing OPC and GGBS. The compressive strength average will obtain from the results of three bricks samples.

4. Results and Discussion

The results from physical and mechanical test have been recorded for all the brick samples. The results were analysed to obtain the optimum percentage of GGBS as partial cement replacement in brick.

4.1 Density Test

Density was measured after the brick samples was removed from the mould and the tests was important because it indicates the weight of brickwork. Table 1 shows the density of brick samples for brick without GGBS (control) and brick containing GGBS from 30 to 50 percent. The volume of the sample was calculated by multiplying area with the length of the cement brick. All the sample have the same measurement of 1.439 x $10^{-3} m^3$. From the table, the highest density was obtained by control sample about 2048.78 kg/m³. The lowest density was found in brick GGBS-30 that contain 30% GGBS. In average, the density of brick containing GGBS in range 2.95 to 2.98 which this difference occurred because of manual procedure during the design mixture. Generally, the sample did not compact in same pressure hence some samples might be getting low pressure and the others with high pressure which may lead to difference density. From the results it is shows that brick with GGBS is obtained lower density than control brick.

Table 2: Density of the samples

Type of Sample	Sample 1 (kg)	Sample 2 (kg)	Sample 3 (kg)	Average (kg)	Volume (m^3)	Density (kg/m³)
Control	3.03	2.97	3.03	3.00	1.439 x 10^{-3}	2084.78
GGBS-30	2.97	2.95	2.93	2.95		2050.03
GGBS–40	2.99	2.97	2.98	2.98		2070.88
GGBS–50	2.97	2.95	2.96	2.96		2056.98

4.2 Water Absorption Test

The dry mass result was obtained from the samples that took out from the oven after cooling down at room temperature. While the wet mass was the weight of the sample that had immersed in tap water for 7 and 28 days. Based on Figure 6, the average water absorption with different percentage of GGBS on 7 and 28 days. From the graph, it shown that water absorption of control sample decrease at age of 28 days. The sample contains GGBS of 40% and 50% also had same performance which reduction of water absorption on 28 days. However, brick sample that contain 30% of GGBS has increased the water absorption on 28 days.

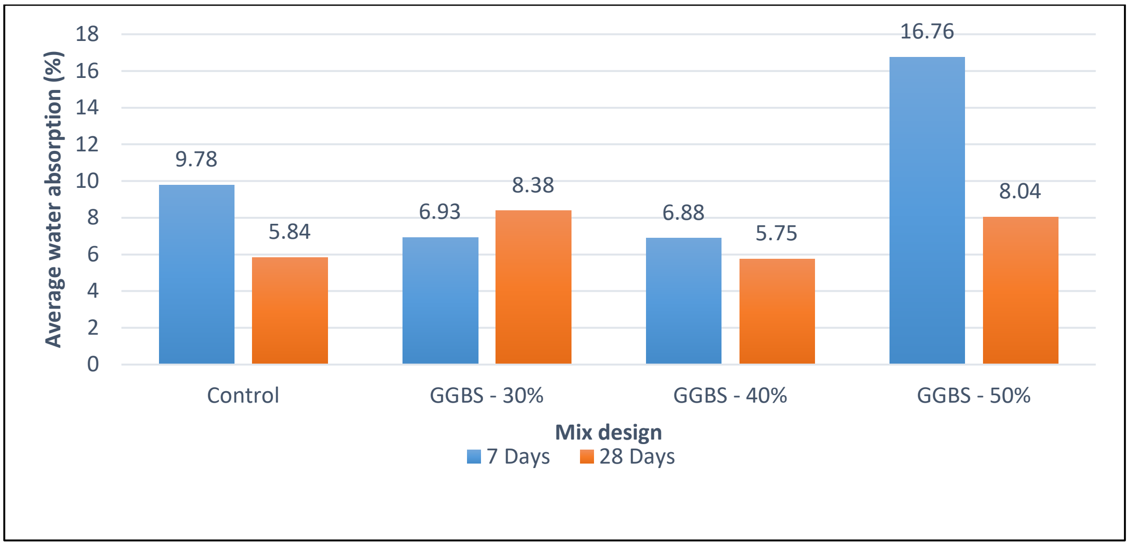

Figure 6: Average water absorption versus mix design

4.3 Compressive Strength Test

The compressive strength of all brick samples is shown in Table 2. From the table, it shows that the average strength of all brick containing GGBS increased at 28 days compared to control brick except GGBS-50. In addition, the differences compressive strength slightly increases when using GGBS 30% and 40% and 50%. The used of more GGBS up to 50% slightly decreased, the strength of brick by 4.58%. Thus, the cement replacement by using GGBS tend to affect the compressive strength of brick. Therefore, in term of compressive strength, the optimum percentage of GGBS as partial cement replacement is 30% which provide high strength for brick.

Table 2: Compressive Strength of Brick Samples

Type of Sample	7 Days (MPa)	28 Days (MPa)	Differences (%)
Control	36.4	43.7	-
GGBS – 30	36.2	47.6	8.92
GGBS – 40	33.4	45.6	4.35
GGBS – 50	30.3	41.7	- 4.58

Figure 7 shows the graph of comparison compressive strength for all brick samples. The graph shows all compressive strength samples were increasing. GGBS-30 was the highest meanwhile GGBS-50 was lowest among other samples. The graph for GGBS-40 increasing rapidly at 28 days compared to other samples.

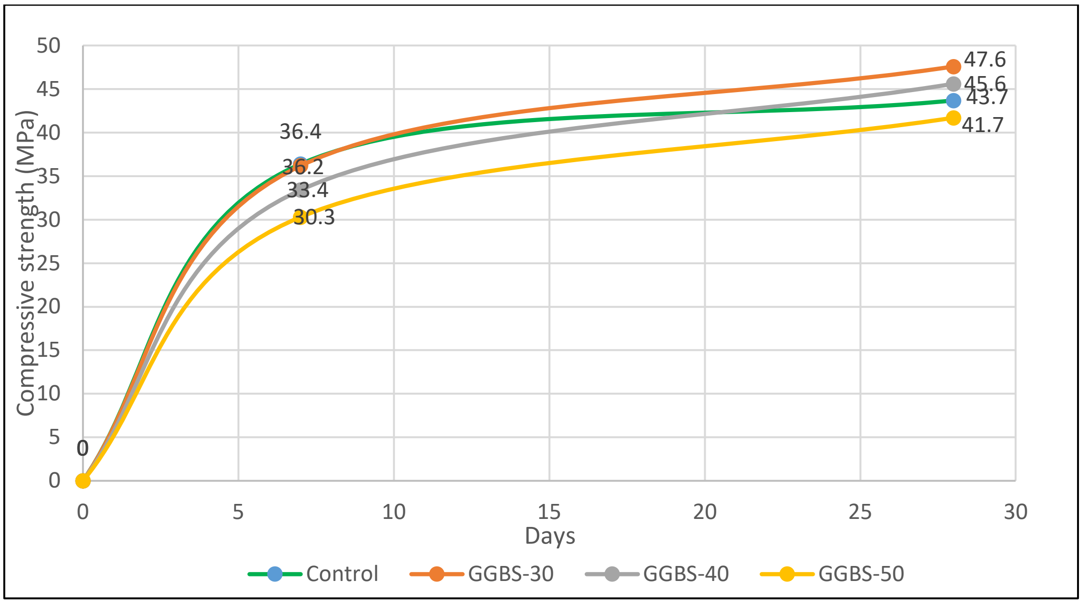

Figure 7: The plot comparison strength for all brick samples

5. Conclusion

In conclusion, the mixture of mix design plays important role in development of building as it will give great physical and high quality of strength to withstand the pressure or loading. Moreover, the production of cement brick with Ordinary Portland Cement is too costly and become high demand production for construction industries. From the experimental result, the objective of the study has been achieved. Thus, a few conclusions can be made from this study. The first objective of this study is to determine density, water absorption, shape and size of sand cement brick containing high amount of

GGBS as partial cement replacement have been achieved. From result obtained, the control brick had achieved high compared with brick containing GGBS for density test. The sample that contains GGBS decreased the water absorption on 28 days but only the sample that contain 30% of GGBS has been increased. For the compressive strength test, the result was show that the increasing of the average strength of the samples. From the results also show that highest strength of the sample is archive by 30% of GGBS and followed by 40% and 30% of GGBS. The second objective is to investigate the optimum percentage of GGBS used as partial cement replacement in brick. From the results, the optimum percentage of GGBS as partial replacement is 30% of GGBS regarding the compressive strength of brick. This sample that consists 30% of GGBS also has lower water absorption than control sample at 7 days. Thus, the lower water absorption, the higher the performance of the cement brick. Therefore, 30% of GGBS was suitable to be optimum percentage as partial cement replacement in brick

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