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Feasibility Study of Using Ground Granulated Blast Furnace Slag as Modified Cement Composites In 3D Printing Mortar

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Abstract: There's the layer bonding, which is a weakness in the manufactured printing part. It's worth mentioning that as the time between layers increases, the bonding strength diminishes and the wastes that had been produced by Malaysians had been estimated to continue to increase as the population grows and more worryingly it will demand saturation on landfills across the country. Having GGBS as waste material can help contribute to waste reduction and strength layer bonding. The objective of this study is to define the chemical composition of Ground Granulated Blast Furnace Slag (GGBS) and to determine the compressive strength of mortar containing GGBS as partial cement replacement. There are four samples using different proportions of materials which is the mixture with 0%, 30%, 40% and 50% of GGBS by fixing 0.5w/c ratio and water-binder ratio. Those tests had been performed to achieve the objective which are compressive test, flow test and collapse test. Those testing has been complied with ASTM standard procedures to conduct the study. From the observation, there are increments for the strength in 7days but decrease when at 50% on 28days. The workability for 0.5water-binder ratio toward this study increased within percentage GGBS replacement increase. The buildability for them has increased at 0%, 30%, 40% and decreased at 50% GGBS replacement. Those studies found that using a rectangular shape nozzle with a bigger opening which is 20mm can gain the best result of buildability during collapse tests. Past research also mentioned the same outcome. The percentage of GGBS replacement must increase in the future.

Keywords: 3D Printing, GGBS, Cement Replacement, Compressive Strength

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1. Introduction

3D printing is digital fabrication technology that delivers by automation with the interlayer bonding strength of the mortar with the advanced technology that can be done undergoing modification continuously to upgrade it day by day where it can assist in digital technologies. For example, building information modeling and being more eco-friendly materials than traditional construction. 3D printing technology has been used in a wide range of industries. For construction, it is constructed layer by layer for the wall to the building. It was stated that due to the size of 3D printers, medium or large-scale models or structures would not be able to be manufactured utilizing 3D printing technology. However, in recent years, there has been a substantial advance in the development of large-scale 3D printers to fulfill the need for industrial-scale 3D printing. There have been three notable advancements in the use of 3-D printing to produce full construction projects [1].

From Muzammir (2020), the wastes that had been produced by Malaysian about 37tans0 tan per day with 1.17kilogram per person and had been estimated to continue to increase as the population grows and more worryingly it will demand saturation on landfills across the country. The factor is early age failure and limited-service life can be caused by an inappropriate in the characteristics of either old or new concrete. Because 3D printing creates the entire item layer by layer and bond strength is one of the important factors to assure structural integrity [2]. So, by overcoming these issues by using GGBS as a material replacement for cement and improving the strength of 3D printing mortar by defining the properties of GGBS in 3D mortar.

The objective of this study was to determine the physical and mechanical properties of mortar containing GGBS as partial cement replacement. Using mineral admixture Ground Granulated Blast Furnace (GGBS) as a replacement of the cement. Four samples' mixes were produced with different cement content and with or without GGBS. Four mixes were divided into two groups according to their cement content. The first group contains GGBS and the second one does not contain any additive materials. Those groups had two types of nozzles that had been used. The first is using a circular nozzle and the second uses a rectangular nozzle with the water/cement ratios of groups being constant at 0.5 respectively. Moreover, each group had four sub-mixes with 30%, 40%, and 50% of GGBS powder as a replacement of cement and without GGBS power as the control sample. All mixes had 0.5 of binder by weight of water. An experimental study was carried out to examine four mixtures made with GGBS to produce mortar for 3D printing. There are many studies that show the optimum mix composition for printing concrete. However, none of these reports discusses the use of aggregate for the same material. The fresh state material behavior of printed concrete influences its various properties, such as its extrudability, buildability, stiffness, and strength [3].

The strength of concrete is assessed and not measured through an experimental relation between the property and value of compressive strength. Hence, the strength of the mortar itself can be known from those properties. The optimum of GGBS as partial replacement materials in mortar for 3D printing application will be identified by comparison with the control sample. So, this study of 3D printing applications can be as references improved in terms of strength, properties, structure, and the application itself to wider use. The result of the mortar with fine sand, fixed water-cement ratio having the highest compressive strength, average workability with optimum GGBS will be defined. So that, it can be used as an improvement material in mortar 3D print application besides improving the environment and applying sustainability in construction by reducing the waste.

2. 3D Printing

The process of transforming items modeled in a digital environment into real items in layers utilizing the appropriate raw materials is known as three-dimensional (3D) printing. The 3D printer was formerly thought to be a complicated and costly technology. Over the years, however, it has become one of the most crucial truths in the sector [4]. In an appropriate manner, it engages a layering process, at which point a part exists created tier by tier just before it exists. In this sense, 3D printed matter allows the United States of America to move outside limits to bulk production and toward unique customization [5]. Making a virtual model of the product you wish to make is the first step in 3D printing. The virtual design is utilized to produce a template for the real thing. This virtual design may be created from scratch using a 3D modeling application like CAD (Computer-Aided Design). A 3D scanner of 3D may also be used to scan an existing object. This scanner creates a three-dimensional digital replica of an object then makes an input into its modeling program [5]. Existing structures and artifacts can be measured in space using three-dimensional (3D) scanning imaging systems and photogrammetric shape measurement tools.

Mass customization has been likened to and contrasted with 3D printing. 3d Printing proponents believe that, like mass customization, this technology allows businesses to produce personalized items in small quantities at a low cost. While both technologies can successfully produce limited quantity lot sizes and share other advantages, their production technology is vastly different. 3D printing involves fusing a range of materials with a laser utilizing CAD software and additive manufacturing-based technology [6].

2.1 3D Printing Requirement

There are many studies that show the optimum mix composition for printing concrete. However, none of these reports discusses the use of aggregate for the same material. The fresh state material behavior of printed concrete influences its various properties, such as its extrudability, buildability, stiffness, and strength [3]. Has been stated in research that the shape of the nozzle is also a critical element that affects the properties of the concrete. Its flowability is proportional to the diameter of the concrete mix [7]. The development of compressive strength demonstrates that concrete with GGBS has a slower compressive strength growth at an early age. However, as compared with the control mix, the strength growth after 91 days reveals a larger strength improvement [7].

2.2 Mix Design with polymer

The classification of powder combination in 3D printing where polymer design, additives, and processing parameters are discussed in relation to increasing build speed and accuracy, functionality, surface quality, stability, mechanical characteristics, and porosity. For 3D printing manufacturing with metallic and ceramic powder particles, binder-containing printing inks are frequently utilized. These binder solutions are composed of aqueous or non-aqueous dispersions of inorganic materials such as silica, aluminum nitrate, silver nitrate, or polymer solutions and dispersions, which dry to form films that securely adhere to the particles, essentially gluing them together. There are also a lot of acidic binder solutions. The printing ink's lack of binders and reactive resins is helpful in this situation since it lowers the possibility of blockages in the printing head. Powders based on water-soluble polymers such as polyurethane can be solidified by inkjet printing of aqueous inks vinyl alcohol [8]. The compressive and flexural strength of geopolymer and cement mortar specimens diminishes as the mix ratio is changed from 1:1 to 1:2 owing to the decrease in binder concentration. Geopolymer specimens have compressive and flexural strengths that are around 90% and 70% of those of cement mortar specimens, respectively [6].

3. Materials and Methods

Research technique is a critical component that must be emphasized for research to be well-structured, methodical, and effective. The process is also based on data from earlier infants who were included in a literature study. The methodology is a process for performing a study for a project in a structured and planned manner. The study focuses on a method for identifying properties of GGBS as cement replacement in 3D cement mortar with a constant w/c ratio and water-binder ratio that produces high strength.

3.1 Materials

3.1.1 Water

In the production of concrete, water is a vital ingredient. It helps to combine cement and the mixture is brought together to form a cement slurry. It can hydrate the cement and make concrete feasible. To prevent possible harmful reactions to degrade concrete, the water used in the concrete must be clean and free of chemical impurities. The role of water is crucial because the ratio of water to cement is the most critical factor in concrete production. On the other hand, water quality is a key consideration in controlling water quality. Specific performance. In the current analysis, ordinary water derived from the laboratory faucet comes directly from the water supply used. Domestic water usually meets the standard and is suitable for construction and construction. However, the water-cement ratio in this design mix is 0.50 respectively.

3.1.2 Portland Cement

OPC is a commonly used building material. Made in Malaysia is a type of cement. The choice of cement is based on the specific application and environmental conditions. The OPC used in this study can be Materials Engineering Laboratory, UTHM. The classification of this OPC is to comply with Portland Cement Class I and pass SIRIM certification complies with MS 197-1:2007. But the cement used should be sealed and stored in a container, to avoid contact with moisture.

3.1.3 Fine Aggregate

In this study, the fine aggregate used can be obtained in Advanced Materials Engineering laboratory, UTHM. From COBOD 3D printing company in the Europe also stated that prefer small than 10mm particles to make sure the nozzle print smoothly [9] and it was found that the FKAAB laboratory has a size of 6mm. Besides the surface quality become smoother and nicer which is good quality for 3D printing. The natural sand passed selected to pass through a 6 mm sieve as the fine aggregate in the concrete mixture used to prepare concrete specimens. In addition, this fine aggregate the obtained classification complies with ASTM C136. In concrete production, sand will react to fill small spaces or voids between. This is also to minimize the honeycomb, which can significantly reduce the strength of concrete. By drying at a temperature of 105 °C ± for at least 24 hours. This is important to ensure that the sand is dry because they affect the water-cement ratio in the mixing process of concrete production.

3.1.4 Sika Latex

Sika Latex SP is a synthetic rubber emulsion used to add to cement mortars that require good adhesion and water resistance. It is suitable for tropical conditions. Sika Latex SP is usually added to clean mixed water in a ratio of 1:1–1:2.5. It is suitable for all applications. In addition to spraying dust, a bonding slurry should be used. The subsequent mortar construction must be carried out while the adhesive layer is still wet. In this study 0.5 was used for the water-binder ratio that represents the Sika Latex with the water mixture.

3.1.5 GGBS

The granulated slag exists next dry and ground to a very fine powder, popular as GGBS, fashionable as an upright swell mill or whirling sphere mill. The substance is glassy in appearance and is ground to a fineness of less than 45 microns. Blaine's surface area is between 350 and 450 m^2/kg. Ground slag reacts chemically with GGBS in the presence of water and an activator, which is typically sulfates and/or alkali given by Ordinary Portland Cement, and hydrates and sets in a similar way to Portland cement [10]. In an appropriate, further comment this waste material into factual can help to maintain established actual parts like cement, fine aggregate, and rude aggregate and differing studies bear in addition to put on display that contain the GGBS act not lower the substance of the actual. GGBS exist as a side product of blast furnaces fashionable iron creating of goods plants [9].

3.2 Methods

3.2.1 Flow Test

This test is intended to evaluate the workability of a mortar mix by determining the flow of cement mortars. Based on ASTM C1437-15 specifications, the quantity of mortar flow is estimated by averaging four diameter measurements of new mortar placed on the flow table while flow isn't usually included in hydraulic cement specifications, it is commonly included in standard tests that require the mortar to have a specified quantity of water content to allow for flow [11]. Workability is a complex characteristic of concrete. It directly affects the strength, quality, and appearance of concrete. It also determines the difficulty of mixing, pouring, compacting, and finishing fresh concrete, and at the same time reduces the loss of uniformity. To the lowest or no loss. The flow table test of concrete also determines the quality of concrete, including its consistency, cohesion, and segregation tendency.

3.2.2 Collapse Test

Collapse test is to know the mortar buildability. Buildability refers to a concrete layer's ability to sustain layers above it without collapsing. The concrete must also have sufficient compressive strength to gain good buildability. Based on this experiment conducted to simulate 3D printing application for the buildability for every sample that has a different percentage of GGBS as cement replacement. The experiment had been conducted with different types of nozzle which are the circular diameter and rectangular nozzle. The experiment had been extruded for 25mm length on the plywood that had a flat surface so that the sample would be more stable.

3.2.3 Curing

Water curing is an important method for cement concrete to gain strength. In this experimental study, the hardened concrete specimens were cured in a water tank until the compressive strength evaluation age was 7 to 28 days. The water temperature is usually in the range of 25-30°C. However, it is important to thoroughly immerse all concrete specimens in water. Based on Figure 2 is the process of concrete water curing specimens.

Figure 2: Curing process on every sample for 7 and 28 days

3.2.4 Compressive Strength

The ASTM C109-16 (2016) standard covers the determination of the compressive strength of hydraulic mortar. The compressive strength of the mortar is obtained by testing a 50 mm cubic sample. The water content of other cement is sufficient to reach a flow rate of 110 ± 5 in a 25-drip platform. Two-layer compaction can compact a 50 mm test cube. In the mold, the cube cures for one day. For each test time or test age, two or three samples are made from a batch of mortar. The air temperature around the mixing plate, dry ingredients, mold, bottom plate, and mixing bowl must be maintained between 73.5 ±5.5°F and [23.0 ±3.0°C]. The water temperature of the room and storage tank must be set at 73.5±3.5°F or [23±2°C]. The minimum relative humidity in the laboratory must be 50% [12]. A compression test is performed to determine the internal resistance of the material to the load acting on it. The size of the cast cube is 50mm x 50mm x 50mm, and it is allowed to solidify in water. The samples are tested for 7 days and 28 days. This study was carried out using a computer program connected with the machine that had been operated by the lab technician. The results were computed and projected through a program. The strength of concrete is determined by the failure load divided by the cross-sectional area of the resisting load. The reaction between cement and water is known as hydration. Hydration is carried out in the presence of evaporable water. During the curing process, water is constantly replenished, and the hydration process is continued. However, this ensures an increase in the compressive strength value.

4. Results and Discussion

From Table 1 the result for the samples shows that mortar that adds GGBS as the replacement has incremented when the percentage of GGBS as replacement increases. The control sample has the highest flow spread than another sample which is for 0.5 water binder ratio is 215mm. This shows the workability of A1 for control samples is higher due to the mixture of water and binder that make the flow spread bigger. From past research, the authors recommended that the mix 3D printing have a slump value of 2 mm to 12 mm and a slump flow value of 130 mm–210 mm for printability [13]. Based on Table 1 all mixtures contain GGBS as cement replacement for mortar in the range 190mm to 205mm which is in the range recommended by the author.

Table 1: Flow test result according to material replacement and water-binder ratio

Sample	GGBS replacement	Water binder ratio	Diameter flow (mm)	Flow
A1	0%	0.5	215	1.15
		0.4	200	1.00
		0.35	195	0.95
A2	30%	0.5	190	0.90
		0.4	180	0.80
		0.35	170	0.70
A3	40%	0.5	200	1.00
		0.4	180	0.80
		0.35	170	0.70
A4	50%	0.5	205	1.05
		0.4	180	0.80
		0.35	178	0.78

Based on Table 2 shows that the sample A4 that contains 50% GGBS replacement has the highest value of height maximum and layer collapsed for nozzle rectangular shape than using circular shape. From Table 2 sample A4 gained 10cm height maximum with 12th layer at 15mm nozzle and 12cm height with 13th layer at 20mm nozzle size. This showed that using a rectangular with a large opening gained higher height and the layer collapsed. This is because by using the nozzle those mortars become more stable due to the area, width, and thickness of each layer from the nozzle size and shape. Past research stated that, because the contact area between the extruded beads is bigger in the former circumstances, it is recommended to utilize a rectangle or square nozzle orifice instead of a circular one for better interlocking [13].

Table 2: Sample that had been tested with the rectangular and circular nozzle

Sample	GGBS replacement	Size Nozzle	Rectangular		Circular	
			Height maximum (cm)	Layer failed	Height maximum (cm)	Layer failed
A1	0%	15mm	7.5	9th	-	-
		20mm	10.5	9th	3.6	9th
A2	30%	15mm	6.5	7th	-	-
		20mm	11.0	10th	4.0	11th
A3	40%	15mm	9.0	10th	-	-
		20mm	12.0	13th	5.8	13th
A4	50%	15mm	10.0	12th	-	-
		20mm	12.0	13th	6.4	16th

The average compressive strength for 7days and 28 days of each mix design is illustrated in Table 2 and 3. Overall, the compression strength in every mix design trend indicates that their strength increases with the rise in the curing age of the concrete. In this study, the target means strength design for mortar has incremented at 28 days for higher GGBS replacement. Any material's compressive strength is defined as its resistance to failure when subjected to compressive pressures. Compressive strength, for concrete, is a key criterion in determining the material's performance under service circumstances. The technical and durability attributes required by the design engineer can be obtained by designing or proportioning the concrete mix.

Figure 3 shows the 7days result which is the sample A4 with 50% GGBS replacement having the highest reading, 17.17kN. Next as shown in Figure 3, the normal mix design of OPC mortar without adding GGBS is known as the control sample for A1. The result for A1 as the control sample is 16.77kN which is the second highest. The strength for A2 and A3 having just a small increment with 0.44kN which are A2 and A3 reading got 13.33kN and 13.77kN which are lower than the control sample. From 7days of age, it can be made an early assumption that by adding GGBS can increase the strength and amount of GGBS at this stage is not satisfied with the control sample due to samples A2 and A3 gaining lower value than the control sample. This is because past research also stated that, the development of compressive strength demonstrates that concrete with GGBS has a slower compressive strength growth at an early age. However, as compared with the control mix, the strength growth after 91 days reveals a larger strength improvement [7].

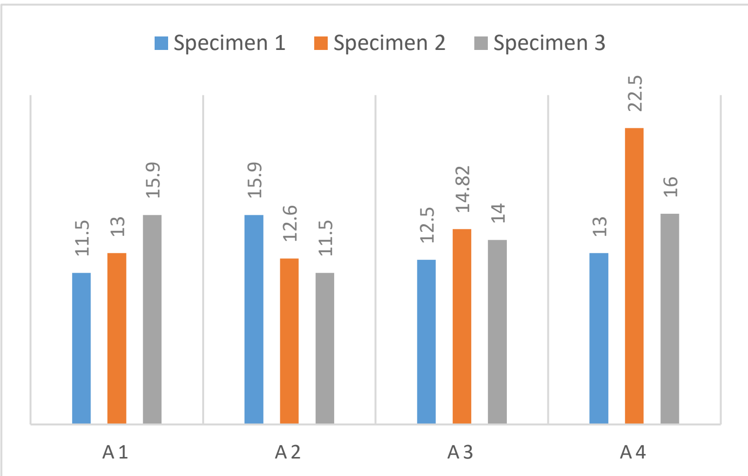

Figure 3: Figure example of compressive strength at 7 days

From the result shown in Figure 4., sample A1 had the highest compressive strength of 26.83kN or 10.73MPa which are known as the control sample with 0% GGBS. However, the strength of sample A4 GGBS as a replacement for mortar used is 50% achieved was 23.67kN at 28 days which is the second highest but lower than sample control. Besides, the design mix of sample A3 for 40% GGBS as the replacement also achieves the compressive strength with approximately 21.67kN at 28 days which is lower than control sample. On the other hand, concrete containing 30% GGBS as a replacement which is for sample A2 had the lowest compressive strength of 18.5kN. This showed that by adding more GGBS as replacement cement can gain more strength but for the study the amount of GGBS not satisfied with the control sample.

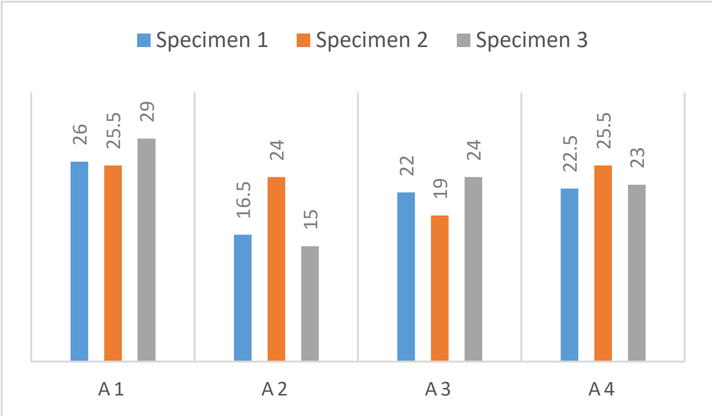

Figure 4: Figure example of compressive strength at 28 days

This can be seen from the trend from the graph that contained GGBS. The more percentage of GGBS as replacement cement the higher strength will be gained where the least percentage of GGBS, sample A2 gained the least strength from all the samples. Besides, the higher percentage of GGBS contained as cement replacement gained the highest strength than all samples containing GGBS which are samples A2, A3, and A4. So, future study needs to increase the amount of GGBS as partial cement replacement to obtain the optimum percentage as cement replacement. From the past study in 2015 said by Sun-Woo Kim et. al., in research at the influence of GGBS on the workability of concrete means higher workability decreases the strength. The findings were compared to a control concrete made of Ordinary Portland Cement without GGBS where the results for compressive development demonstrate that GGBS has a lower compressive development at an early age. However, as compared to the control mix, the strength growth after 91 days reveals a larger strength development [14].

This study also can be sync with the buildability whereby adding more percentage of GGBS as cement replacement can increased the good bonding between layer by layer and increase the strength for the mortar which can be the best materials for 3D printing where the study was able to precisely forecast the failure-deformation mode and advised that printed concrete be assessed early on. Using strength-based failure models, Jayathilakage et al. constructed buildability requirements based on concrete's green strength [14].

5. Conclusion

The physical properties of mortar that contain GGBS as partial cement replacement in 3D printing mortar can be identified. Recent studies have shown that GGBS have an increment on their flow spread and buildability. For workability the sample that contained GGBS having smaller diameter spread than sample without GGBS as replacement. If the cement replacement with GGBS increases, the flow spread increases which means the workability for the mixture also increases. The spread flow will increase when the percent of GGBS increase. So that the binder ratio must add less than 0.5 water binder ratio. The compressive strength of mortar containing GGBS as partial cement replacement can be determined. The sample A4 which has 50% GGBS as partial cement replacement gains higher strength for early age, 7days while the control sample provides second highest strength of hardened mortar at age 28 days.

The study shows that there is an increment in the strength of hardened mortar when GGBS is used as cement replacement. The buildability for the samples can be seen from layer failure which A4 with 50% GGBS as replacement cement provides a higher value for height maximum and layer failure which is 16th with 6.4cm height for the circular nozzle and collapse at 13th layer with 12cm height for the rectangular nozzle size 20mm while it collapsed at 10th layer with 10cm height for nozzle size 10mm. It means that the size and shape of the nozzle play an important role in the buildability of mortar. So, a large opening with larger width can gain a higher thickness of each layer and become more stable than a smaller opening nozzle. The physical properties for buildability can be synchronized with strength value where are from the result can obtain the sample A4 with 50% GGBS as good replacement cement for strength bonding but need to increase more percentage of GGBS in the future study. This study also can be in sync with the buildability whereby adding more percentage of GGBS as cement replacement can increase the good bonding between layer by layer and increase the strength for the mortar.

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