



Fresh Properties and Compressive Strength of 3D Printing Concrete Containing GGBS as Partial Cement Replacement

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Abstract: 3D printing concrete is a particular mix of concrete that has been specially prepared to flow easily through the printing nozzle. The foundations of 3D printing concrete constructions are stacked, with each layer put on top of a preceding layer of pumped concrete. Despite its potential, the construction industry has been confronted with several material issues. The cement replacement in the concrete has also been intensively studied, but in 3D printing concrete, this matter has not been seen clearly. It still cannot be seen whether the cement replacement produces a good result for the 3D printed concrete. This research investigated the fresh characteristics and compressive strength of 3D printing concrete using GGBS as a partial cement replacement in the mixture. In addition, the optimal proportion of GGBS as a partial cement replacement in 3D printing concrete is also evaluated. In this study, the fresh properties of 3D printing concrete were examined by a flow table test, a buildability test, and an extrudability test, while compressive strength was assessed for the mechanical properties. The percentage of GGBS used varies from 20% to 50% with a 10% increment by weight of cement, and the water-cement ratio was fixed at 0.5. The cube specimen for the compression test was 50 mm x 50 mm x 50 mm and was cured for 7 and 28 days. The findings show that the flowability of this 3D printing concrete increased as the percentage of GGBS increased. All of the specimens also passed the buildability and extrudability tests. The compressive strength of this 3D printing also increased as the percentage increased, but it decreased back at 50% GGBS replacement. Overall, this experiment shows that 40% GGBS replacement is the optimum proportion as cement replacement in 3D printing concrete as it shows the highest compressive strength, which is 57.3 MPa.

Keywords: 3D printing, GGBS, fresh properties, compressive strength

1. Introduction

3D printing concrete is a specialised mix of concrete that has been specially prepared to flow easily through the printing nozzle. The 3D printed concrete buildings are formed utilising layering principles, with each layer put on top of a preceding layer of pumped concrete. This process is continued until the desired structure appears. 3D printing concrete is a cost-effective building approach since it eliminates the requirement for concrete to be cast into moulds or structure. The curing period for such concrete can be as little as three days, and full buildings can be built in just hours, giving it a faster and less expensive alternative to traditional construction processes.

For the past times construction techniques, formwork is commonly used for temporary support of cast-in-place concrete (Li et al. 2020). According to prior research, the construction industries generate about 80% of global trash

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which is formwork due to its reliance on conventional construction practices. When compared to traditional methods, 3D printing concrete uses fewer resources because no framework is required throughout the construction process. This procedure also eliminates the need for heavy labour. Li et al. (2020) also mentioned that the material must explicitly keep its form and support successive layers following extrusion. As a result, the quality of printed components is dependent on both the fresh and hardened qualities of the printing materials. The first thorough research of the characteristics of printable cementitious materials in fresh and hardened states was published in recent years.

The successful creation of a high-performance printable mortar for 3D printing provides a foundation for future study. Since then, a significant body of research has been reported on the characteristics of 3D-printed cementitious materials, with the goal of developing printable materials for freeform construction. This paper gives an experimental evaluation of the fresh characteristics of 3D printing concrete made using different materials instead of cement, with a focus on flowability, buildability, and compressive strength.

2. GGBS as Cement Replacement

Ground granulate blast furnace slag (GGBS) is a waste product of the iron industry and one of the cementitious materials that may be used to replace some of the cement in concrete (Turu'allo, 2015). Many studies have employed GGBS as a partial replacement for cement in various forms to generate high-strength and high-performance concrete. Studies have also employed alkali silicate activated slag cement at greater temperatures. Because there is no uniform production procedure, the physical characteristics of GGBS vary widely from source to source and area to region. As a result, its influence on the characteristics of fresh and hardened concrete differs dramatically. The characteristics of concrete formed from regular or mixed cement including GGBS are also affected by the curing process.

When the water-to-binder ratios of the mixes are considered, it can be inferred that as the GGBS content grows, the water-cement ratio lowers for the same workability, implying that the GGBS has a favourable influence on workability. The test also revealed that when the GGBS concentration is raised, the compressive strength of GGBS concrete increases until it reaches an optimal value, beyond which it declines. There is an ideal level of GGBS content for effective application that gives the best strength (Oner & Akyuz, 2007). Mineral admixtures, such as slag, are also a viable option for controlling the flowability of fresh paste. The influence of particle size, shape, pozzolanic nature, and mineral admixture concentration is based on this.

Many researchers used 30-40% of GGBS as it gives a goods result in all aspects (Li et al. (2020), Chandra Thakur & Kumar, (2016), Zhou et al., (2012), Talib Khalid et al., (2019) & ShreyasK, (2017)). Using GGBS as a cement substitute in concrete mostly affects the concrete's hardened qualities. Panda & Tan (2018) also found that adding ground granulated blast-furnace slag to a 3D-printable geopolymer improves its buildability. However, some researchers have shown that GGBS has an influence on the fresh qualities of concrete, such as flowability and buildability. GGBS has not been utilised as a cement substitute in many 3D printing projects, but it's worth looking into. In the future, the effect of GGBS as a partial cement substitute in new and hardened properties should be investigated further.

3. Materials and Method

3.1 Materials, Mixed Design and Methods

Cement, sand, water, superplasticizer, and GGBS are the materials that were utilised in this project to 3D print concrete.

3.1.1 Cement

The binding materials consist of Ordinary Portland Cement (OPC). OPC is a kind of cement that is commonly used in Malaysian concrete because it is appropriate for a wide range of concrete applications. Because it is accessible in the laboratory, this sort of cement was employed.

3.1.2 Sand

The sand was sieved to determine its size distribution, which in accordance with BS EN 993-1:2012. Sand must pass through a 2 mm sieve before being retained at a 0.075 mm sieve.

3.1.3 Water

Pipe water/tap water fits the BS EN 1008 standards and therefore it was used in the concrete mixing of this study.

3.1.4 Superplasticizer

This study uses 0.5% of plasticizer in order to increase the workability and flowability of the mix. The 0.5% was measured from the weight of cement.

3.1.5 GGBS

In this study, Ground Granulated Blast Furnace (GGBS) was used as cement replacement. Previous studies shows good result when GGBS used as partial replacement of cement. The percentage of GGBS used were 0%, 20%, 30%, 40% and 50%.

3.2 Mix Design

Water cement ratio in this study was fixed at 0.5 while different mix proportion of the material and specimen that used were are shown in Table 1. Zero percent (0%) of cement replacement represented control specimen with no GGBS added into the mix.

Table 1 - Ratio of GGBS replacement by weight of cement

Specimen	Ratio/Percentage GGBS (%)	Cement	GGBS	Sand	Water (Litre)	SP
SG0	0	1	0	2		
SG20	20	0.8	0.2	2	0.5 x 0.63	0.5 % of
SG30	30	0.7	0.3	2	= 0.315	weight
SG40	40	0.6	0.4	2		cement
SG50	50	0.5	0.5	2		

3.3 Methods

The concrete testing was divided into parts which are for the fresh properties and hardened properties of concrete. For the fresh properties, the testing included flowability test, extrudability test and buildability test. For the hardened properties, compressive strength test was conducted. All of the testing was conducted on all 5 mixture as shown in Table 1.

3.3.1 Flowability

Flow table testing was used to analyse the rheology of the paste qualities because it is a basic and uncomplicated approach. To guarantee that new concrete is capable of printing, it must have adequate flowability. The test was conducted based on BS EN 12350-5:2019. The data was taken by measuring the concrete spread in two directions. The flow value is given by:

$$f = \frac{d_1 - d_2}{2} \quad (1)$$

3.3.2 Extrudability

The purpose of the extrudability test was to find a suitable concrete mixture that could be extruded via a 38 mm x 11 mm diameter nozzle. The concrete mixtures were pumped into the nozzle and extruded. The procedure and outcome of extruding the concrete mixture were assessed by determining whether or not it could be extruded.

3.3.3 Buildability

The total layer that the concrete mixture can support was determined as part of the buildability test. A concrete pump with a 38 mm x 11 mm diameter nozzle was used to conduct the test. The maximum layering aim has been set at five layers, with a length of 150 mm, the height of the base layer measured for each layering deposition. To accept the mixture as printable, a researcher has developed a criterion for categorizing 3D concrete mixture as printable or not as in Table 2.

Table 2 - Criteria of printable concrete mixture (Papachristoforou et. Al, 2018)

Properties	Accepted	Not Accepted
Printability	1. Mixture extruded through nozzle 2. No voids, no dimensional variations of extruded material	If 1 or 2 not apply
Buildability	3. Achieved 5 layers of printing 4. Height of first layer versus fifth layer	If 3 or 4 not apply

3.3.4 Compressive Strength

The purpose of this test is to determine the compressive strength of hardened concrete. Cubic moulds of 50 mm x 50 mm x 50 mm were utilised and was cured at 7 and 28 days. The cubes were dried and tested based on BS EN 12390-2: 2009.

4. Result and Discussion

4.1 Flowability Test

The spread of the concrete on the flow table were recorded and the flow were calculated using Equation 1 as shown in Table 3 and Fig. 1. The flow ability graph as in Fig.2 demonstrates that when the GGBS percentage increases, the flowability increases. The 0% of GGBS had the lowest flowability, covering only 17.45 cm of the table test. 20% to 30% GGBS replacement gives nearly equal flowability results with a variation of only 0.1 cm. The 40 % GGBS replacement had a flowability of 20.9 cm, while the 50% GGBS replacement had a flowability of 21.35 cm. Overall, the result show that the increase of GGBS with addition of superplasticiser gives a good flowability to the fresh state of the concrete.

Table 3 - Flow ability test result

Specimen	30 - D (vertical), d ₁ , (cm)	30 - D (horizontal), d ₂ , (cm)	(d ₁ -d ₂)/2, (cm)
SG0	17.5	17.4	17.45
SG20	19.9	20.2	20.05
SG30	21.1	19.2	20.15
SG40	20.8	21	20.9
SG50	21.3	21.4	21.35



(i)SG0



(ii)SG20



(iii)SG30



Fig. 1 - Flow ability of each mixture

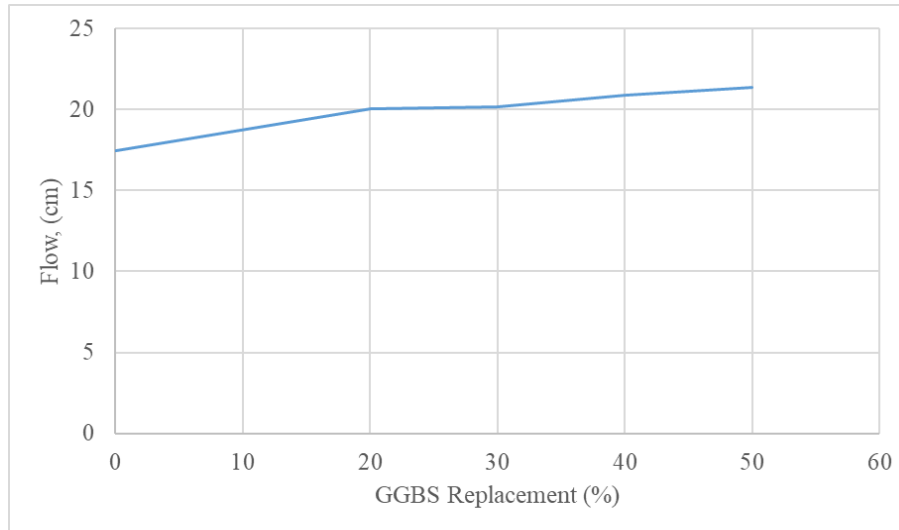


Fig. 2 - Flow ability graph

4.2 Extrudability

As shown in Table 4 and result in Fig.3, SG0 (0 percent GGBS replacement) can be extruded out of the pump, however there were several interruptions when it became stuck and then continued to extrude after the pump's force was increased. There is some disruption in the SG20 combination, but not as much as in SG0. The SG30, SG40, and SG50 may all be simply extruded from the pump without causing any problems. By virtue of the visual, all types of specimens can be extruded completely from the nozzle to the required length of 15 cm. As a result, all mixes have an acceptable extrudability outcome.

Table 4 - Extrudability test result

Specimen	Extrude	
	Yes	No
SG0	/	
SG20	/	
SG30	/	
SG40	/	
SG50	/	

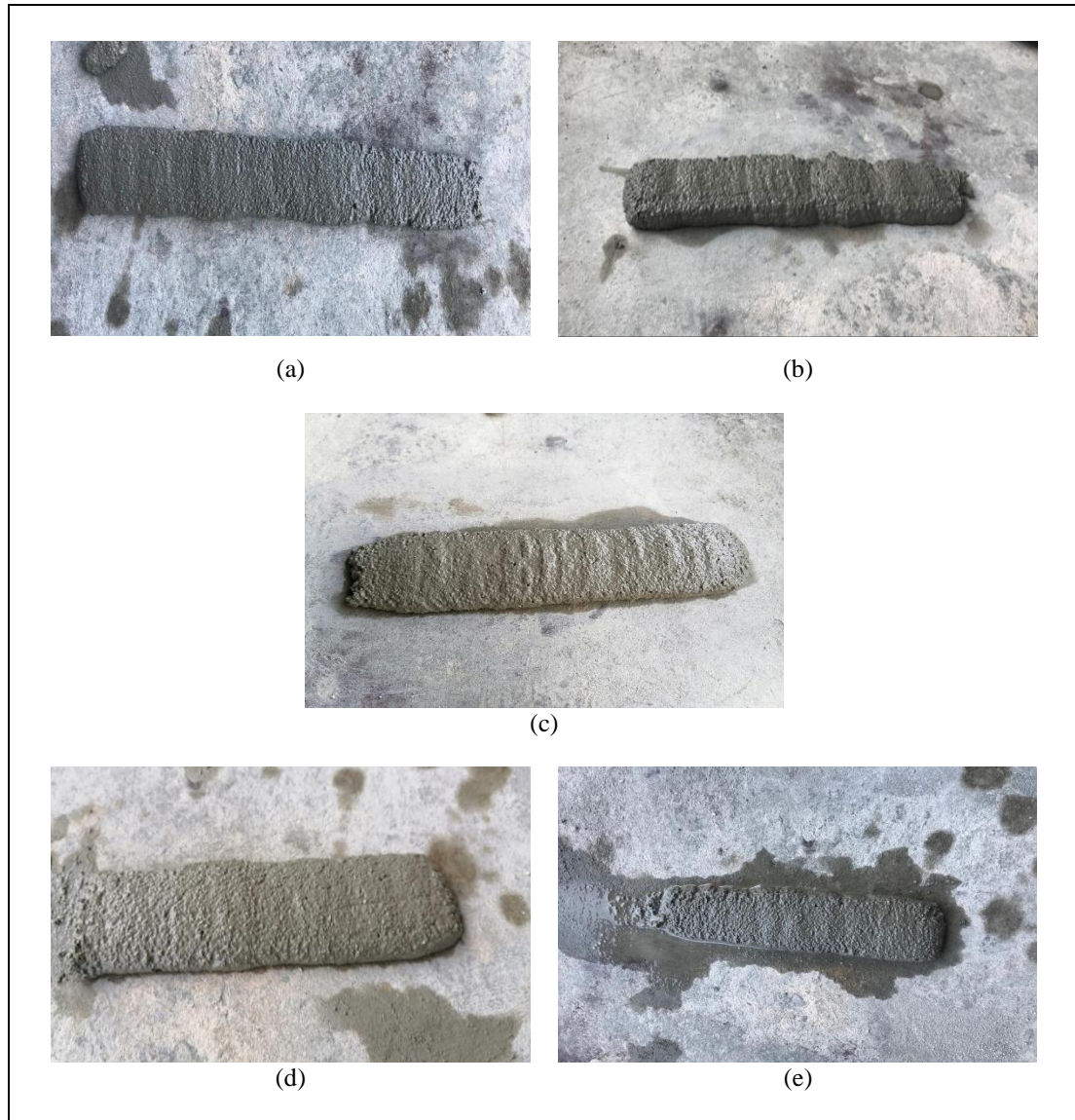


Fig. 3 - Extrudability test, (a) SG0; (b) SG20; (c) SG30; (d) SG40; (e) SG50

4.3 Buildability Test

All five types of mixtures with various GGBS percentages as replacements have effectively supported five-layer printing, as shown in Fig.4. All of the layers can be easily linked to one another, as shown in the diagram, however the bottom layer's thickness reduces as it bears the weight of the upper layer. As a result, slight deformation occurs in all types of mixtures. In comparison to SG0, S20, SG30, and SG50, SG40 causes the thickness layer to deform less. SG40 mixture shows slightly better performance in terms of deformation but not significant compare with the other mix. All mixture has a good buildability performance without different significant difference.

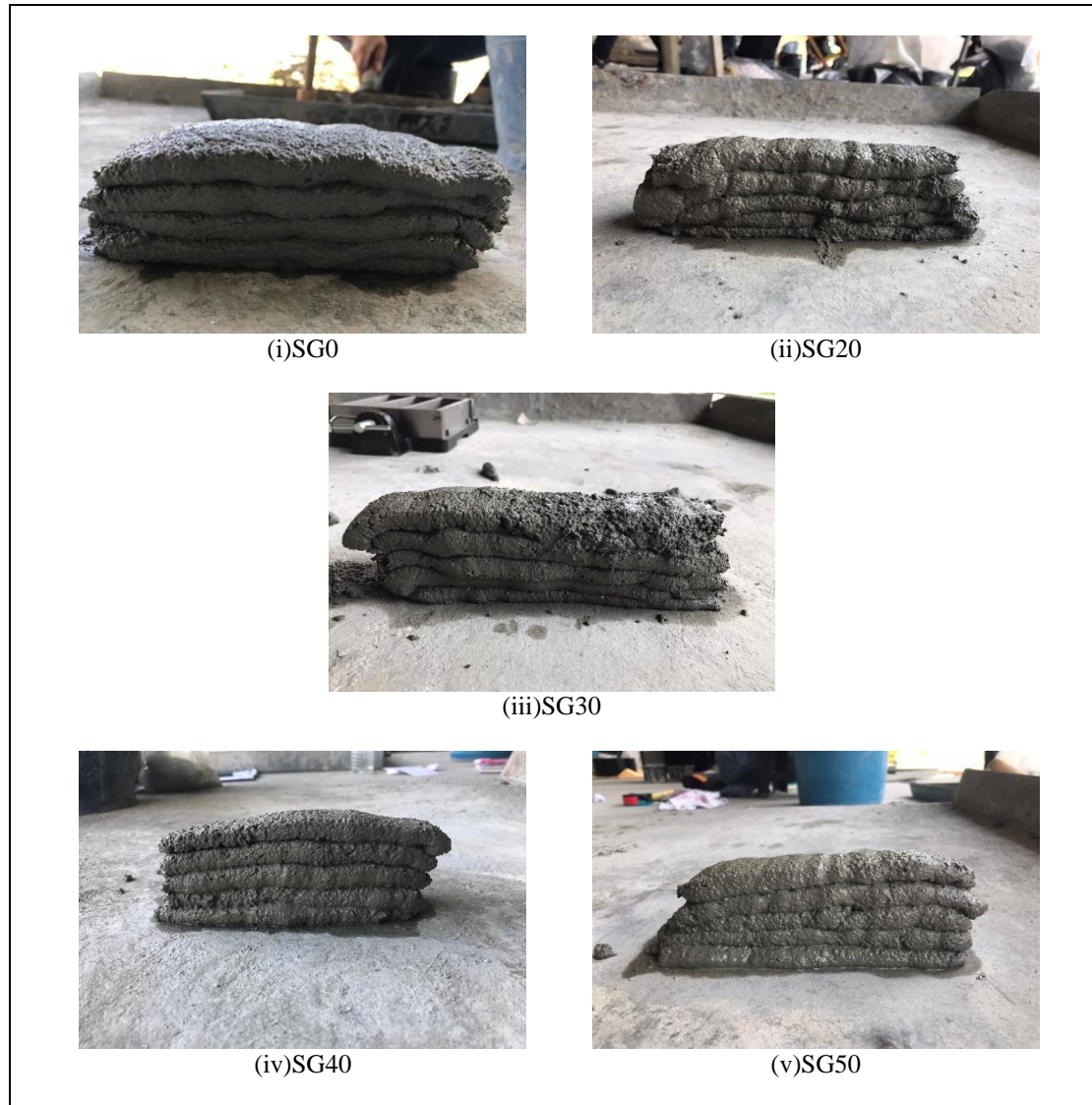


Fig. 4 - Buildability test result, (a) SG0; (b) SG20; (c) SG30; (d) SG40; (e) SG50

4.4 Compressive Strength Test

Based on Table 5 and Fig. 5, the compressive strength of the series of concrete mixtures increases until 40 percent GGBS replacement and then drops at 50 % GGBS replacement. After 7 days of curing, the 40% GGBS replacement had the highest compressive strength of 44.35 MPa, while the 0% replacement had the lowest compressive strength of 25 MPa. Although the compressive strength resulted in a greater value after 28 days of curing, the pattern of the increment was similar with the results of compressive strength for 7 days. The compressive strength of 40% GGBS replacement recorded the highest value at 57.3 MPa, whereas the compressive strength of 0 percent replacement was the lowest of the five. The results reveal that when the cement replacement increases, the compressive strength increases. The findings show that the compressive strength increases as the cement replacement increases until 40% of GGBS and then decreases back to 50%. The same result show by Chandra Thakur & Kumar, (2016) which show 40% is the optimum percentage of cement replacement on their compressive strength. The same trends also were obtained by Kumar Karri (2015). This show that the increase of GGBS until 40% gives with certain amount of superplasticizer and the good water-cement ratio gives higher compressive strength.

Table 5 - Compressive strength results

Specimen	Compressive Strength (MPa)	
	7 Days	28 Days
SG0	25.0	30.6
SG20	25.9	39.0
SG30	36.8	49.2
SG40	44.35	57.3
SG50	37.1	50.9

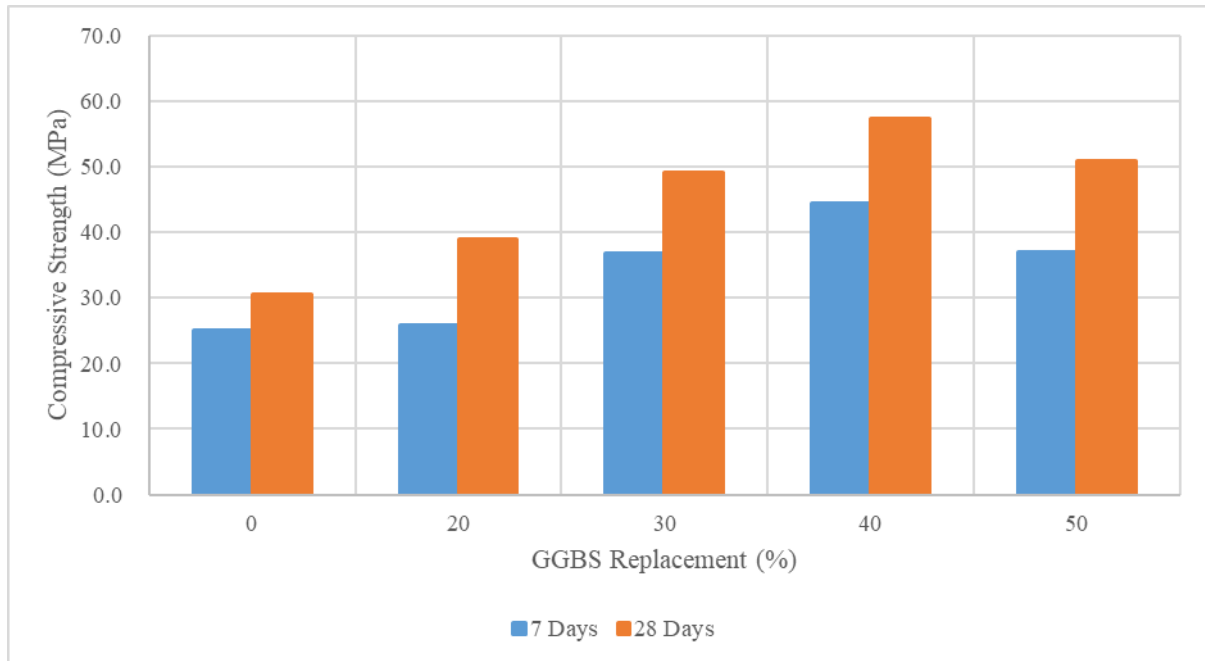


Fig. 5 - Compressive strength result

5. Conclusion

The mixture was tested for flowability, extrudability, and buildability of 3D printing concrete with GGBS as a partial cement replacement. Increased GGBS replacement enhances the flowability of fresh concrete, according to the findings. Extrudability and a smooth printing properties were found in a concrete mixture with a higher percentage of GGBS substitution. All of the mixture also passes the buildability test since they achieve the goal of 5 layers with varied deformations.

Overall, the results suggest that increasing GGBS replacement leads to improved flowability, extrudability, and buildability. In terms of compressive strength, all mixture recorded higher value compare with control specimen when GGBS replacement increases up to 40% for 7 and 28 days. However, the compressive strength decreased slightly at GGBS replacement of 50%. Although the 50% GGBS replacement recorded a decreased value of compressive strength, it still recorded a higher value compared with the control specimen of 0% GGBS replacement as well as the 20% and 30% of GGBS replacement. For all 7 and 28 days of curing times, the mixture with 40% GGBS substitution had the highest compressive strength. Because it performs well in fresh properties and compressive strength tests, the optimum percentage of GGBS replacement observed is 40%.

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References

British Standards Institution (2012). BS EN 993-1:2012. Tests for geometrical properties of aggregates - Determination of particle size distribution. Sieving method.

- British Standards Institution (2002). BS EN 1008:2002. Mixing water for concrete. Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete.
- British Standards Institution (2019). BS EN 12350-5:2019. Testing fresh concrete - Flow table test.
- British Standards Institution (2019). BS EN 12390-2:2019 Testing hardened concrete. Making and curing specimens for strength tests.
- Chandra Thakur, I., & Kumar, S. (2016). Assessment of the Properties of Cement & Mortar using GGBS. *International Journal of Innovative Research in Science, Engineering and Technology (An ISO)*, 5(8), 15224–15231. <https://doi.org/10.15680/IJRSET.2016.0508098>
- Kumar Karri, S., Rao, G. V. R., & Raju, P. M. (2015). Strength and Durability Studies on GGBS Concrete. *International Journal of Civil Engineering*, 2(10), 34–41. <https://doi.org/10.14445/23488352/ijce-v2i10p106>
- Li, Z., Hojati, M., Wu, Z., Piasente, J., Ashrafi, N., Duarte, J. P., Nazarian, S., Bilén, S. G., Memari, A. M., & Radlińska, A. (2020). Fresh and hardened properties of extrusion-based 3D-printed cementitious materials: A review. *Sustainability (Switzerland)*, 12(14), 1–33. <https://doi.org/10.3390/su12145628>
- Oner, A., & Akyuz, S. (2007). An experimental study on optimum usage of GGBS for the compressive strength of concrete. *Cement and Concrete Composites*, 29(6), 505–514. <https://doi.org/10.1016/j.cemconcomp.2007.01.001>
- Panda, B., & Tan, M. J. (2018). Experimental study on mix proportion and fresh properties of fly ash based geopolymer for 3D concrete printing. *Ceramics International*, 44(9), 10258–10265. <https://doi.org/10.1016/j.ceramint.2018.03.031>
- Papachristoforou, M., Mitsopoulos, V., & Stefanidou, M. (2018). Evaluation of workability parameters in 3D printing concrete. *Procedia Structural Integrity*, 10, 155–162. <https://doi.org/10.1016/j.prostr.2018.09.023>
- ShreyasK. (2017). *Characteristics of GGBS as an Alternate Material in Conventional Concrete*. 5(4), 3174. www.ijcrt.org
- Talib Khalid, W. T., Qazi, O., Abdirizak, A. M., & Rashid, R. S. M. (2019). Comparison of different waste materials used as cement replacement in concrete. *IOP Conference Series: Earth and Environmental Science*, 357(1). <https://doi.org/10.1088/1755-1315/357/1/012010>
- Turu'allo, G. (2015). Using ggbs for partial cement replacement in concrete: Effects of water-binder ratio and ggbs level on activation energy. *International Journal of Technology*, 6(5), 790–799. <https://doi.org/10.14716/ijtech.v6i5.1916>
- Zhou, X. M., Slater, J. R., Wavell, S. E., & Oladiran, O. (2012). Effects of PFA and GGBS on early-ages engineering properties of Portland cement systems. *Journal of Advanced Concrete Technology*, 10(2), 74–85. <https://doi.org/10.3151/jact.10.74>