OPTIMIZING CONCRETE PERFORMANCE: INVESTIGATING COMPRESSIVE STRENGTH IN BLENDED FLY ASH-SLAG MIXTURES WITH DIFFERENT WATER-TO-BINDER RATIOS

Muhammad Mustafa*[1] and Md. Moinul Islam[2]

[1] *Lecturer, Bangladesh University of Business and Technology, Bangladesh, e-mail:* mustafa@bubt.edu.bd
[2] *Professor, Chittagong University of Engineering and Technology, Bangladesh, e-mail:* mislam@cuet.ac.bd

***Corresponding Author**

ABSTRACT

The use of concrete in the construction industry is extensive due to its durability and cost-effectiveness. It is challenging to identify an alternative construction material that matches concrete's combination of strength and affordability. Ordinary Portland cement (OPC) is the primary ingredient in the production of conventional concrete. However, the production of CO_2 during the production of OPC has prompted environmental concerns. This CO_2 emission has been reduced by replacing OPC with the most common industrial wastes, fly ash and slag. The use of fly ash and slag enhances the strength and durability of concrete. Additionally, since fly ash and slag are industrial by-products, their utilization is economical. This research investigates the impact of blended fly ash-slag concrete on compressive strength, employing three different water-to-binder (w/b) ratios: 0.3, 0.35, and 0.40. Fly-ash and slag were used in three different combinations: 10%, 25%; 15%, 30%; and 20%, 35% by weight, respectively, as the replacement of OPC. A total of 144 Nos. 4 in. x 4 in. x 4 in. cubical concrete specimens were casted and which were cured for 7, 28, 56, and 90 days. Subsequently, a compressive strength test was conducted following each specific curing period. According to test results, Fly ash and Slag blended concrete of mix proportion 10% and 25% gives the highest compressive strength. This value is around 7% higher than the OPC concrete.

Keywords: *Compressive Strength, Fly Ash-Slag blended Concrete, Ordinary Portland Cement, Granulated blast furnace slag, Super-plasticizer.*

1. INTRODUCTION

Cement-based concrete is currently and will continue to be the dominant construction material (Shaikh, 2016). The manufacturing of Portland clinker, a primary component of cement, is characterized by high emission levels as well as significant energy and material usage. The current ecological conditions have driven the quest for solutions that aim to increase the usage of cement and concrete components with decreased amounts of Portland clinker (decrease of emissions of greenhouse gases such as carbon dioxide, protection of deposits of nonrenewable resources, and utilization of waste from industrial processes). The most recent production processes involve significant consumption of raw materials and contribute to substantial carbon dioxide emissions, approximately 846 kg per ton of clinker (Giergiczny, 2019) (Wardhono et al., 2015). Huge efforts have been made to lower the carbon footprint connected to cement production in order to minimize environmental effects (Zareei et al., 2019). The two most practical and effective methods to reduce the environmental impact associated with cement production are increasing the use of cement components other than Portland cement clinker and using the clinker in composite types of cement more effectively. Fly ash, which is mostly composed of siliceous materials, and slag are the Portland clinker additives that are the most well-known and often utilize (Giergiczny, 2019). Ground granulated blast furnace slag (GGBFS), a type of slag, can be substituted for concrete with a high cement concentration (Y. H. M. Amran et al., 2020), although it may exhibit reduced mechanical strength (Siddique & Bennacer, 2012). Furthermore, the larger particle size of GGBFS has fewer cementing qualities, which may make it harder for GGBFS particles to bond to calcium silicate hydrate gels (M. Amran et al., 2021). For GGBS, replacement rates range from 30% to up to 80 % (Siddique & Bennacer, 2012). Fly ash use dates back to the early 20th century, whereas the use of GGBFS dates back to 1865 in Germany (Y. H. M. Amran et al., 2020). About 900 – 1000 million tons of fly ash and 140 –330 million tons of blast furnace slag are produced globally each year as industrial byproducts (Giergiczny, 2019). In comparison to fly ash, which makes up around 30% of cement and concrete, ground granulated blast-furnace slag is utilized at a rate of over 90% (Giergiczny, 2019). The troposphere of the planet becomes warmer as a result of greenhouse gases in the atmosphere. According to the international panel on climate change, the average increase in global temperature over the next 100 years should range from 1.9°C to 5.3°C. Unfortunately, producing cement requires a lot of energy and emits a lot of CO_2 into the sky (Singh et al., 2015). According to studies, the demand for OPC has increased by 115 – 180 percent since the 1990s and is expected to reach 400 percent by 2050 (Benhelal et al., 2013). However, the production of OPC uses around 1.5 tons of raw materials and emits about 0.9 tons of CO_2, or about 7% of all CO_2 emissions into the atmosphere worldwide (Hosan & Shaikh, 2021). Therefore, a large reduction in CO_2 emissions can be achieved by partially substituting mineral materials such as slag, fly ash, silica fume, etc. for Portland cement in mortar and concrete. Strength is the most crucial aspect of the structural concrete and cement mortar's demand for durability. Undoubtedly, cement's chemical makeup has a significant impact on its strength and other characteristics. The inclusion of fly ash or slag as a partial replacement when creating mortars and concrete results in decreased heat of hydration, increased soundness, decreased permeability, enhanced concrete strength as it ages, and increases workability. Thus, depending on the cement's composition, the different qualities of cement might change, which naturally affects structural durability. The objective of this study is to assess the strength and applicability of fly ash and slag as partial replacements for cement in the production of traditional concrete alternatives.

2. METHODOLOGY

2.1 Materials

For this experiment, Ordinary Portland Cement (OPC), Type-I, was sourced from the local market in Chittagong. The fine aggregate used, with a fineness modulus (FM) of 2.36, was obtained from Sylhet. Additionally, crushed stone of 20 mm size was employed as coarse aggregate. Both fine and coarse aggregates were conditioned to a saturated surface-dry state. This study also incorporated class F fly ash and granulated blast furnace slag (GGBS). Table 1 and Figure 1 detail the material characteristics and gradation curves of the coarse (CA) and fine aggregates (FA) used in this investigation, respectively. The physical properties of the fly ash and GGBS are presented in Table 2. To enhance the workability of the concrete mixture in compliance with ASTM specifications, a superplasticizer was used, the characteristics of which are listed in Table 3.

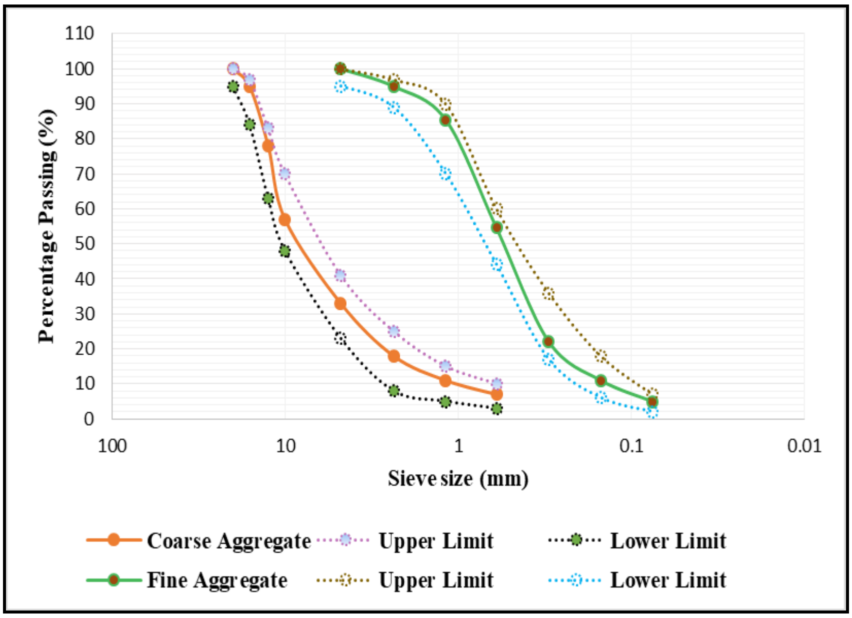


Figure 1: Gradation Curves of Aggregates

Table 1: Specification of Coarse Aggregate and Fine Aggregate

Specifications	**CA**	**FA**
Specific Gravity	2.71	2.62
Unit Weight	1600 kg/m^3	1630 kg/m^3
Absorption Capacity	0.76 %	1.62 %
Maximum Aggregate Size	20 mm	2.36 mm
Fineness Modulus	6.82	2.36

Table 2 : Physical properties of GGBS and Fly Ash

Property	GGBS	Fly Ash
Color	Light-gray	Dark-gray
Specific gravity	2.8	2.4
Bulk density	1225 kg/m^3	1460 kg/m^3
Fineness	370 m^2 /kg	235 m^2 /kg

Table 3 : Characteristics of Superplasticizer

Color	Reddish Brown
Specific gravity	1.08 ± 0.02 at 25^o C
p^H	≥ 6.5
Chloride ion Content	< 0.3%

2.2 Methodology

A total of 144 concrete cubes are produced employing three different water-to-binder ratios of 0.30, 0.35, and 0.40. The proportions of blended cementitious material were used as C100 (Cement 100% + Fly ash 0% + Slag 0%); C65 (Cement 65% + Fly ash 10% + Slag 25%); C55 (Cement 55%+ Fly ash 15% + Slag 30%) and C45 (Cement 45% + Fly ash 20% + Slag 35%). ACI Mix Method was used in this experimental work to develop the mix percentage of concrete with a 28-day compressive strength of 40 MPa. All necessary ingredients for the needed mix were first batched on a weight basis. Then, for the control mix, one-half of the water was added to the mixture and manual mixing continued for an additional 8 to 10 minutes before the final addition of the remaining water was made, and mixing continued until a homogeneous nature appeared. After the aforementioned mixing was complete for each layer mix, fourteen 4 in x 4 in x 4 in cube steel molds were periodically cast with the mixture in three layers. An appropriate amount of compaction was manually applied using a temping rod for each layer. The upper surface finishing of the third layer was completed with the aid of a planer after which the casted mold was left in this state for 24 hours to allow for the final set. The concrete samples were removed from the mold 24 hours following casting kept at room temperature immersed in a curing water tank. The specimens were submerged for 7 days, 28 days, 56 days, and 90 days respectively. Following the curing process, the specimens were taken out of the curing tank & left outside in the sun for at least an hour before being brought inside to be tested for compressive strength. The top surfaces of the specimens were prepared through grinding to ensure horizontal alignment. Then strength measurement of the cube specimens was carried out on a Compressive Strength Testing Machine, under a load control regime with a loading rate of 0.2 MPa/s, according to BS-EN-12390. For each data point, three concrete cubes were tested. Here, Figure 2 illustrates the flow chart of the complete methodology. Also, Figure 3 & 4 illustrates the process of mixing, casting, curing, preparation of specimens, and testing of the specimen.

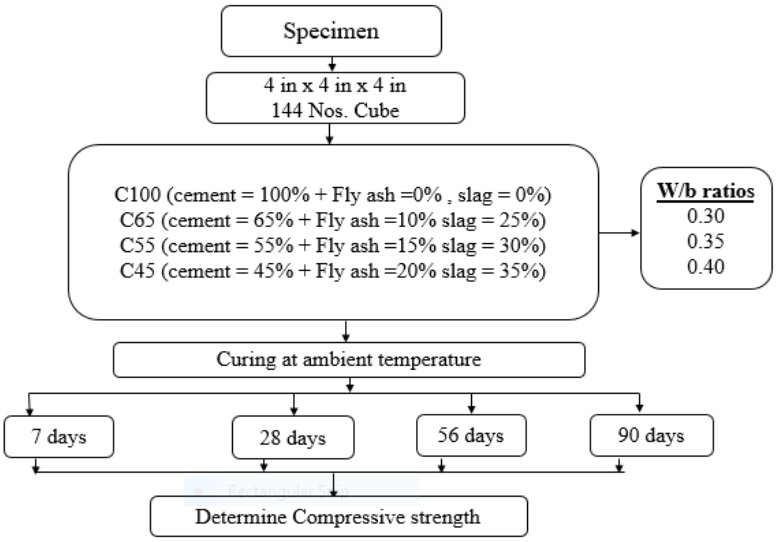


Figure 2 : Flow Chart of the Methodology

Figure 3: Mixing, Molding, Curing, and Preparation of Specimens for test

Figure 4: Preparation of Specimens and Testing

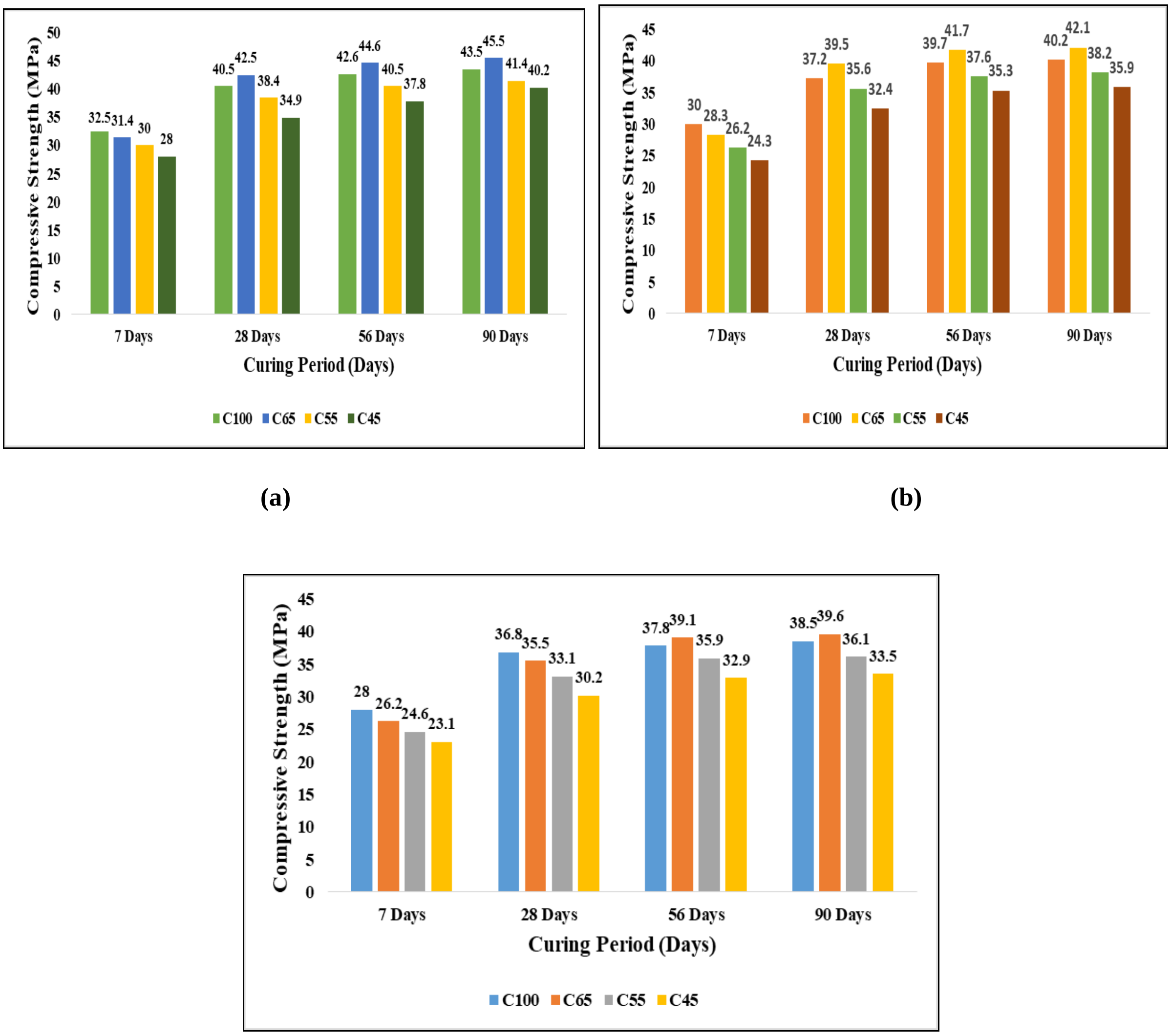
3. RESULT AND DISCUSSION

The correlation between compressive strength and changess in the water-to-binder (w/b) ratio, along with changes in Fly Ash and Slag proportions, is illustrated in the subsequent section. This demonstrates the compressive strength of the samples prepared with various mixes at curing periods of 7 days, 28 days, 56 days, and 90 days, respectively.

Figure 5. (a), illustrates the compressive strength results for a w/b ratio of 0.30. At 7 days of curing C100 (plain concrete) shows higher strength (32.5 Mpa) than other samples, which occurs due to the slower initial hydration kinetics of fly ash and slag as compared to ordinary portland cement (Wardhono et al., 2015). Fly ash and slag have pozzolanic and latent hydraulic properties, respectively, which result in a slower rate of strength gain initially (Smith & Collis, 2001). After 28 days of curing it is seen that C65 exhibits the highest strength value of 42.5 Mpa, which is 5% higher than plain concrete (C100). This increase can be attributed to the continued pozzolanic reaction of fly ash and the hydraulic activity of slag, which contribute to the formation of additional C-S-H (calcium silicate hydrate) gel, a primary strength-contributing phase in concrete (Mehta & Monteiro, 2014). The trend continues up to 90 days, indicating the long-term benefits of these supplementary cementitious materials (SCMs). Also, it is seen that with the increase in % of fly ash and slag (C55 and C45) compressive strength is reduced & remains lower than the plain Concrete (C100) during the entire curing period. At 90 days curing both C55 and C45 were showing 9.9% and 13.18% lesser strength than C65. This reduction in strength is observed, likely due to the dilution effect and the slower reaction rate of these SCMs at higher replacement levels (Thomas, 2007).

Figure 5. (b), demonstrates compressive strength for a w/b ratio of 0.35. A decrease in compressive strength is seen in all the four different specimens. This decrease can be associated with the higher water content, which can lead to a more porous and less dense microstructure in the hardened concrete (Neville, 1995). At 90 days curing C65 showing 42.1 Mpa, which is 8% smaller than the strength gain in w/b ratio of 0.30. Here the previous trend of strength development is seen. C65 shows better strength at higher curing periods after 28 days persists, underscoring the effectiveness of the fly ash-slag blend in enhancing long-term strength, likely due to the continued formation of secondary C-S-H from the pozzolanic reaction (Bijen, 1996). Initially (7 Days curing) C100 shows better performance. At 90 days of curing C65 showed a strength value of 42.1 Mpa, which is approximately 49 % higher than 7 days curing. C55 and C45 showed identical performance lower than C100 during the full curing period.

From figure 5. (c), for a w/b ratio of 0.40, plain concrete (C100) shows better performance up to 28 days. The delayed strength gain in C65 beyond 28 days, despite the higher w/b ratio, suggests that the pozzolanic and hydraulic reactions of fly ash and slag continue to contribute to strength development, albeit at a slower rate due to the increased water content (Detwiler et al., 1996).

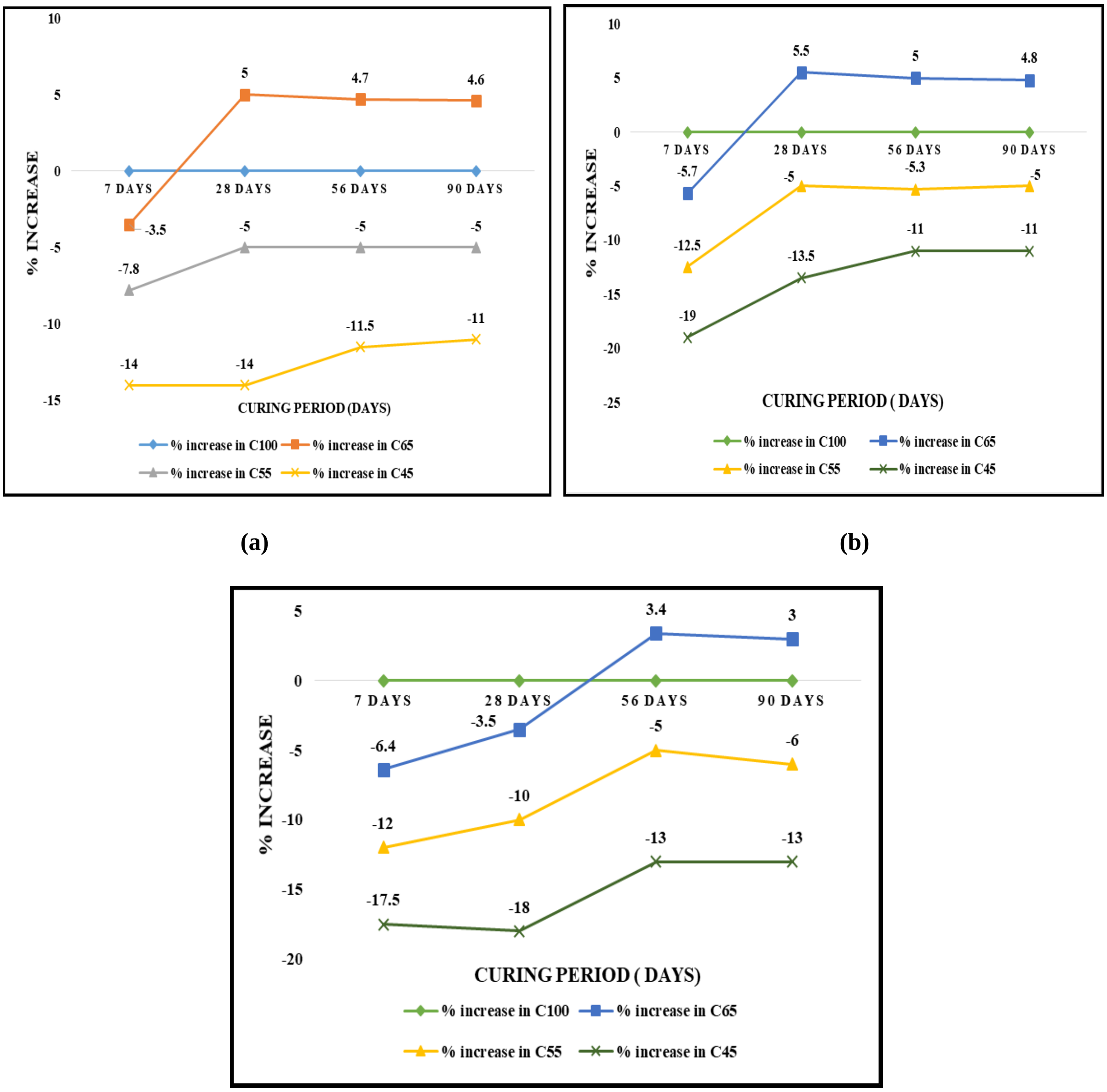


(a) **(b)**

(c)

Figure 5: Compressive Strength vs Curing Period for w/b 0.30 (a), 0.35 (b), and 0.40 (c)

According to Figure 6. (a), C65 showing a compressive strength which has initially decreased. An increase of roughly 5% is noticed after 28 days of curing, and this trend continues for the full 90 days. In (b), it's evident that the initial decrease in compressive strength is observed in the case of C65. Subsequently, a gradual increase of approximately 5.5% is noted during the 28-day curing period, and this pattern persists throughout the entire 90-day duration. The strength of C55 and C45 both decreases. However, this trend suggests a limit to the beneficial effects of increasing SCM content, possibly due to factors such as particle size distribution, availability of calcium hydroxide for the pozzolanic reaction, and overall mix design (Lothenbach et al., 2011). Finally, according to (c), C65's compressive strength has initially decreased. An increase of roughly 3.4% is observed after 56 days of curing, and this trend continues for the full 90 days. At 90 days of curing this rate is 3%.



(a) **(b)**

(c)

Figure 6: % increase vs Curing period for w/b 0.30 (a), 0.35 (b), and 0.40 (c)

4. CONCLUSIONS

The present study aimed to conduct an experimental investigation to determine the compressive strength impact of partially replacing cement with fly ash and slag. Based on this research, the following findings could be made:

1. C65 exhibits better performance after 28 days of curing till the 90-day curing period for all three w/b ratios.

2. Strength decreases when fly ash and slag percentages rise more than 10% and more than 25%, respectively.

3. Both C55 and C45 show lower strength than C100 (plain concrete) for all three w/b ratios of 0.30, 0.35, and 0.40 respectively.

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REFERENCES

Amran, M., Murali, G., Khalid, N. H. A., Fediuk, R., Ozbakkaloglu, T., Lee, Y. H., Haruna, S., & Lee, Y. Y. (2021). Slag uses in making an ecofriendly and sustainable concrete: A review. *Construction and Building Materials*, *272*, 121942. https://doi.org/10.1016/j.conbuildmat.2020.121942

Amran, Y. H. M., Alyousef, R., Alabduljabbar, H., & El-Zeadani, M. (2020). Clean production and properties of geopolymer concrete; A review. *Journal of Cleaner Production*, *251*. https://doi.org/10.1016/j.jclepro.2019.119679

Benhelal, E., Zahedi, G., Shamsaei, E., & Bahadori, A. (2013). Global strategies and potentials to curb CO2 emissions in cement industry. *Journal of Cleaner Production*, *51*, 142–161. https://doi.org/10.1016/j.jclepro.2012.10.049

Bijen, J. (1996). Benefits of slag and fly ash. *Construction and Building Materials*, *10*(5), 309–314.

Detwiler, R. J., Bhatty, J. I., & Battacharja, S. (1996). *Supplementary cementing materials for use in blended cements* (Issue R&D Bulletin RD112T,).

Giergiczny, Z. (2019). Fly ash and slag. *Cement and Concrete Research*, *124*(July). https://doi.org/10.1016/j.cemconres.2019.105826

Hosan, A., & Shaikh, F. U. A. (2021). Compressive strength development and durability properties of high volume slag and slag-fly ash blended concretes containing nano-CaCO3. *Journal of Materials Research and Technology*, *10*, 1310–1322. https://doi.org/10.1016/j.jmrt.2021.01.001

Lothenbach, B., Scrivener, K., & Hooton, R. D. (2011). Supplementary cementitious materials. *Cement and Concrete Research*, *41*(12), 1244–1256.

Mehta, P. K., & Monteiro, P. J. M. (2014). *Concrete: microstructure, properties, and materials*. McGraw-Hill Education.

Neville, A. M. (1995). *Properties of concrete* (Vol. 4). Longman London.

Shaikh, F. U. A. (2016). Mechanical and durability properties of fly ash geopolymer concrete containing recycled coarse aggregates. *International Journal of Sustainable Built Environment*, *5*(2), 277–287. https://doi.org/10.1016/j.ijsbe.2016.05.009

Siddique, R., & Bennacer, R. (2012). Use of iron and steel industry by-product (GGBS) in cement paste and mortar. *Resources, Conservation and Recycling*, *69*, 29–34. https://doi.org/10.1016/j.resconrec.2012.09.002

Singh, B., Ishwarya, G., Gupta, M., & Bhattacharyya, S. K. (2015). Geopolymer concrete: A review of some recent developments. *Construction and Building Materials*, *85*, 78–90. https://doi.org/10.1016/j.conbuildmat.2015.03.036

Smith, M. R., & Collis, L. (2001). *Aggregates: sand, gravel and crushed rock aggregates for construction purposes*.

Thomas, M. D. A. (2007). *Optimizing the use of fly ash in concrete* (Vol. 5420). Portland Cement Association Skokie, IL, USA.

Wardhono, A., Law, D. W., & Strano, A. (2015). The strength of alkali-activated slag/fly ash mortar blends at ambient temperature. *Procedia Engineering*, *125*, 650–656. https://doi.org/10.1016/j.proeng.2015.11.095

Zareei, S. A., Ameri, F., Bahrami, N., Shoaei, P., Musaeei, H. R., & Nurian, F. (2019). Green high strength concrete containing recycled waste ceramic aggregates and waste carpet fibers: Mechanical, durability, and microstructural properties. *Journal of Building Engineering*, *26*(August), 100914. https://doi.org/10.1016/j.jobe.2019.100914