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Investigating the effects of nano-blast furnace slag powder on the behaviour of composite cement materials

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ABSTRACT

Purpose: Attributable to the depletion of raw materials and for sustainability purposes in construction works. Therefore, this study looked into the effects of nano blast furnace slag (BFS) on the microstructure, mechanical properties, and durability of mortar. BFS was substituted for cement at various weight percentages of 0, 1, 1.5, 3, 5, and 7%.

Design/methodology/approach: A suspension of water and Nano blast furnace slag was made using ultrasonic mixers to prepare the samples. The suspension was combined with cement and sand using 1 cement, 0.5 water, and 2.75 sand in the mixture to make cement mortar. The mixture was then shaped, left in the mould for 24 hours, and then allowed to cure for 7, 14, 28, 60, and 91 days. SEM was used to investigate the microstructure before and after cement replacement. The mechanical characteristics were evaluated by testing the compressive strength and the surface hardness. While the durability was assessed using the water absorption ratios.

Findings: The results revealed that increasing the BFS in the mortar improved mechanical characteristics and durability by up to 3% of BFS. Replacing Nano-blast furnace slag for a portion of the cement is a proposed solution to address the problems of environmental pollution and resource consumption caused by cement production.

Research limitations/implications: Another sustainable material needs to be used for additional investigation. We may evaluate more properties and use different weight percentages.

Practical implications: Each year, a significant amount of slag is produced as a result of the iron industry, endangering the environment. There have been numerous initiatives to reduce slag's negative environmental consequences. Using slag to replace some of the cement is one of the options to eliminate this byproduct and reduce excessive cement use.

Originality/value: This study investigates the possibility of using a blast furnace blast within the Nanoscale to replace some of the cement used in the construction due to the positive impact on the environment to get rid of industrial byproducts and decrease the use of cement.

Keywords: Environmentally friendly cement, Nano-blast furnaces slag, Cement substitute, Compressive strength, Water absorption

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PROPERTIES

1. Introduction

The need for material resources for the building of civil engineering projects has increased, posing a threat to the available natural resources [1]. Cement output is anticipated to increase significantly in the future decades to meet the continuously growing world population [2]. In terms of environmental concerns, cement production emits CO_2, which can contribute to the greenhouse effect and air pollution [3]. Furthermore, the cement industry requires a lot of energy, which accounts for 40%–60% of overall cement production costs [4]. Finding a different approach to reduce the excessive use of natural resources is a more efficient way to address this issue [5]. The cement industry is under enormous force to produce significant efforts to minimize pollution and energy use. Enhancing cement manufacturing is insufficient to address the aforementioned issues. Using supplemental materials to substitute cement partially is an efficient approach for decreasing pollutant emissions and energy consumption in the cement manufacturing process. Using ultra-small particles resulted in the most significant improvement in concrete performance. The high density of binder ingredients was credited with the systems' excellent performance [6].

Slag from blast furnaces is a byproduct of iron manufacturing. Iron production produces a large amount of slag each year, posing a severe environmental threat. Various efforts have been made to mitigate the environmental effects of slag [7]. Slag as a filler or pozzolanic element in concrete manufacturing is one of these choices [8]. Flower and Sanjayan [9] showed that replacing forty per cent of Portland cement with blast furnace slag can reduce carbon dioxide emissions by about 22 percent as compared to normal concrete.

Furthermore, blast furnace slag benefited concrete's mechanical characteristics and durability. Nevertheless, Ryu et al., and Yazıcı [10,11] reported a delay in hydration rate and low early mechanical strength when substituting cement with blast furnace slag. At the same time, Li et al. [12] suggested that blast furnace slag integration in cement should be no more than 30%, according to their study. On the other hand, Oner and Akyuz [13] showed that more than 55% of blast furnace slag has a negative impact on strength. Jiang et al. investigated the replacement of 70% of low cement clinker with super fine blast furnace slag and nano-silica. Their results revealed the compressive strength enhancement compared with the control samples for all the curing rates. The resulting cement has an improved pore structure by reducing large pores to less than 3% of the structure [14].

Sadawy and Nooman [8] studied the effect of incorporating blast furnace slag up to 5% of the weight. They found that introducing blast furnace slag helps get more dense material and improves mechanical properties, durability, and corrosion resistance.

Atiyah et al. evaluated the addition of up to 5% of nano blast slag on the porosity, mechanical properties and microstructure of cement mortar. They found that as the percentage of slag increased, the mechanical properties improved, and the porosity decreased [15]. Srikanth et al. replaced 30,60, and 70% of cement with blast furnace slag. According to their results, 30% replacement achieved the best compressive strength and durability properties [16].

In this study, a superfine blast furnace slag was employed for cement to make more effective use of blast furnace slag in developing cement-based composite material. The resulting composite's mechanical properties were researched to determine the slag's acceptable concentration. Furthermore, durability and microstructure were studied.

2. Materials and methods

This study obtained Type I Portland cement from the Al-Mass factory. Fine aggregates are particles smaller than a grain of sand or crushed stone and are often sourced from natural sand or crushed stone (4.75 mm).

Blast furnace slag was produced in nano-scale sizes using a Planetary Ball Mill (PBM). Then, SEM was used to characterize the grain size of blast furnace slag to ensure that it could be classified as nano-scale materials. Table 1 illustrates the composition of blast furnace slag.

The following procedure was followed to prepare the mortar: First, ultrasonic mixers were used to prepare a suspension of water and Nano blast furnace slag. The slag particles were mixed with water at room temperature for 20 min to get the homologized mixture. The suspension was then mixed with cement and sand to prepare cement mortar. The mixing ratio was 1 cement: 0.5 water: 2.75 sand. After that, the mixture was moulded and kept in the mould for 24 hr. and then cured for 7, 14, 28, 60 and 91 days.

Table 1.
The composition of blast furnace slag

CaO%	SiO_2%	Al_2O_3%	MnO%	Fe_2O_3%	SO_3%	MgO%	Reside.%
2.24	68.8	18.63	4.3	4.7	0.01	---	1.1

Mortar cubes of (50x50x50) mm were tested for compressive tests using an ELE machine and a loading rate of 1.5mm/min. The compressive test was performed according to ASTM C109/C109M–07 [17]. A shore hardness tester was used to test the surface hardness of the specimens, which was done according to ASTM D2240 [18]. SEM analysis was used to investigate the micro-structure of the mortar. Water absorption was evaluated using 20 mm cubic samples according to ASTMC642-2010 [19]. Equation 1 was used to determine the water absorption percentage.

$$W\% = \frac{w_s - w_{od}}{w_{od}} \times 100 \quad (1)$$

3. Results and discussion

Mortar specimens were tested before and after replacing 1, 1.5, 3, 5, and 7 % of cement by slag using different curing times, Figure 1. Compressive strength increased as a result of incorporating blast furnace slag using substituting percentages of 1, 1.5, and 3% as compared with the control values for all the curing times. For example, the compressive strength increased from 32 MPa for the control value to 46 MPa for 3% replacement after 90 days of curing. This enhancement may be due to blast furnace slag's filling effect, which produces dense mortar. Moreover, the compressive strength of all samples improves with the curing duration due to cement hydration. This behaviour agrees with Sadawy, Nooman [8] and Jiang et al. [14] and Atiyah et al. [15].

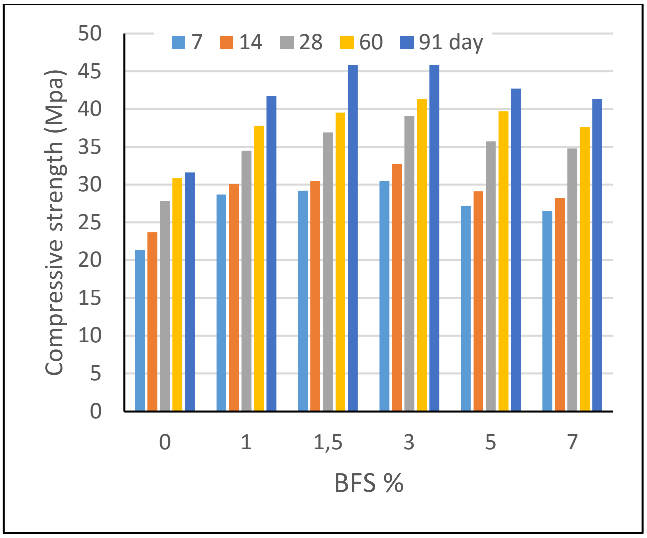

Fig. 1. Results of compressive testing with different percentages of BFS and different curing times

On the contrary, the strength values decreased when substituting cement by 5% and 7% of BFS. Although, the compressive strength of the 5% and 7% is still higher than the control values. The compressive strength values were 43 MPa and 41 MPa for 5%, and 7% replacement percentages, respectively. As compared to 32 MPa for the control specimen at 90 curing age. The compressive strength may decrease because of the C-S-H decrement and the nanoparticle agglomeration. Jiang et al. [14] reported that adding BFS increases the paste compactness and enhances the bonding strength, which may be the reason for enhancing the compressive strength after adding BFS. Sadawy and Nooman's [8] results showed that the compressive strength of the control was lower than the BFS cement because of the effect of BFS in closing pores to produce a more dense structure.

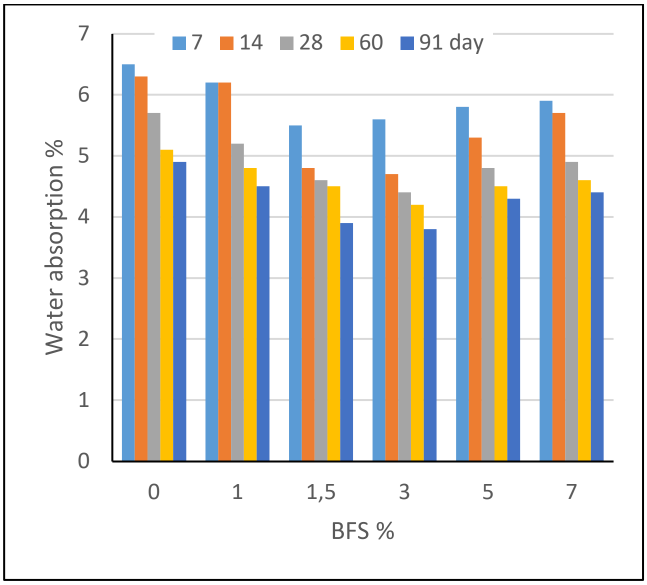

Fig. 2. Results of water absorption % with different percentages of BFS and different curing times

Water absorption and porosity combined value will indicate how long a mortar or concrete will last if water fills the spaces in the mortar and saturates the matrix pores. The water absorption results are shown in Figure 2. The water absorption decreased slightly from 4.8% to 4.2% after 90 days of curing for a 1% substitution percentage. Approximately similar water absorption values were obtained for both 1.5 and 3 % replacement. It was about 4% after 90 days of curing. This may be due to the filling effect of ultra-fine blast furnace slag particles, which reduces the mortar's voids and produces a dense structure. Similar results were obtained by Jiang et al. [14] and Atiyah et al. [15]. They found that the resulting mortar was more dense.

The water absorption values began to increase as the values of replacing percentages reached 5 and 7%. This could be due to the Nanoparticles aggregating together, leading to more voids. This aggress with Srikanth et al. They claimed that increasing the substitution % above the optimal point increased the mortar's porosity [16].

The results of the surface hardness are shown in Figure 3. The hardness values increase slightly by about 1% for 1% replacement compared to the control values. The ultra-fine BFS particles produce denser mortar with fewer voids. More enhancement was achieved for the replacement levels of 1.5 and 3 % BFS. Replacement values of 5 and 7 per cent of BFS resulted in a slight reduction in hardness values. This could be due to BFS aggregation and poor dispersion, resulting in the presence of voids.

The microstructure of the control sample and the samples that contained 3% and 5% of BFS were examined using SEM, Figures 4-6. Nano blast furnace slag powder was used

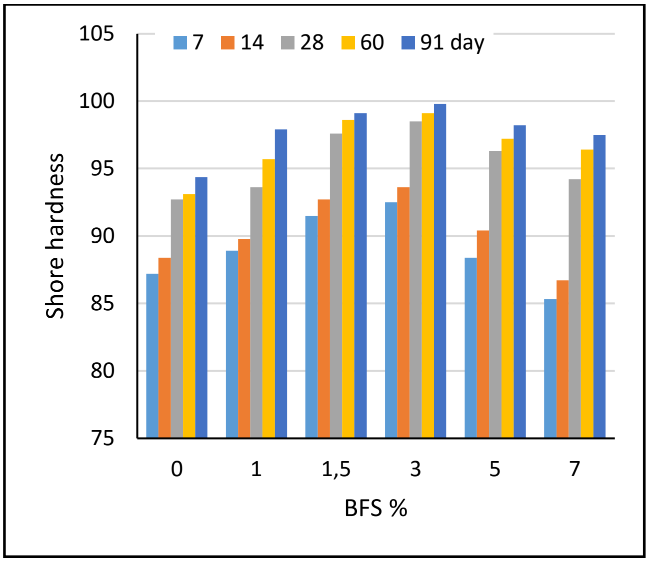

Fig. 3. Results of shore hardness with different percentages of BFS and different curing time

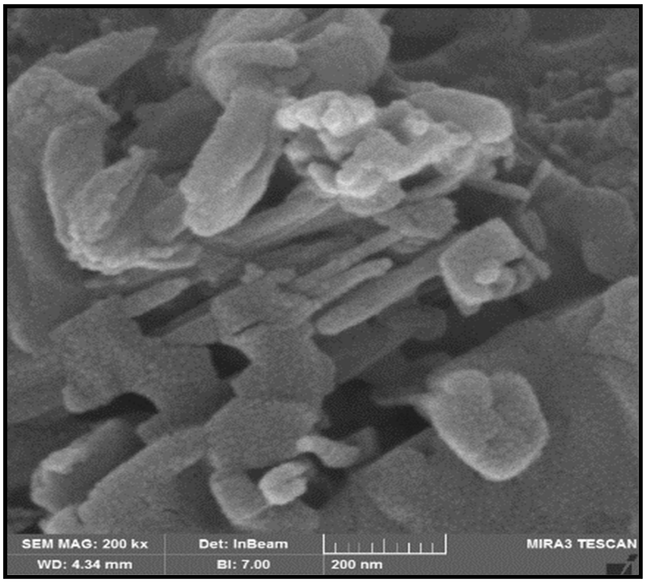

Fig. 4. The SEM image for the control mortar mix at 91 days

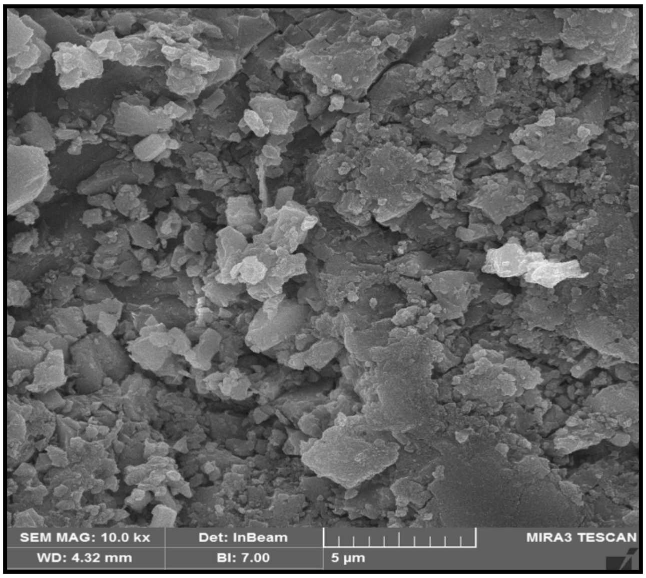

Fig. 5. The SEM image for 3% BFS modified mortar mix at 91 days

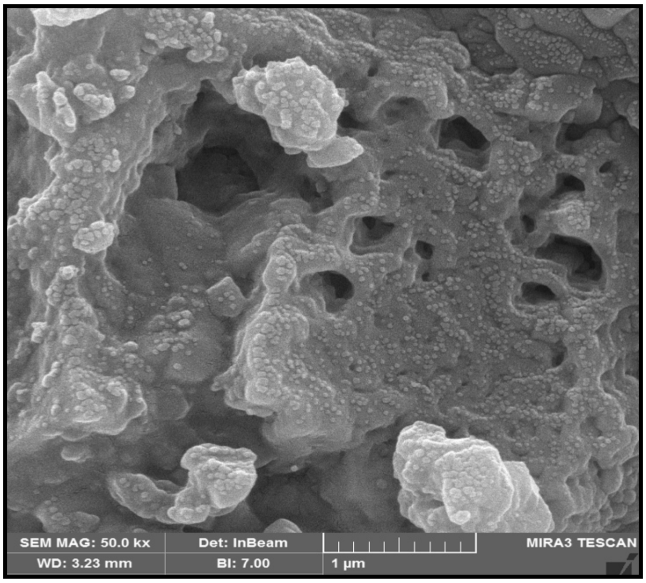

Fig. 6. The SEM image for the 5% BFS modified mortar mix at 91 days

as porosity filler, leading to a denser mortar, as shown in Figure 5. Using a higher amount of BFS leads to more voids because of the agglomeration effect of the Nanoparticles, as shown in Figure 6.

4. Conclusions

The following are some possible conclusions based on the findings of this investigation:

- Based on the SEM images, incorporating BFS was employed to fill the voids and promoted C-S-H formation. As a result, the mortar becomes more hydrated and dense. However, 5% of BFS causes an increment in the voids because of the agglomeration of the nanoparticles due to the high surface energy.
- Test groups with up to 3%BSF obtained higher compressive strength than the control. Adding more BSF groups up to 3% where the compressive values started to decline. Although, the strength values are still higher than the control. Similarly, Hardness values were better for the samples containing up to 3% of BFS
- The water absorption was slightly reduced for the samples containing up to 3% BFS.

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References

[1] V. Sharma, A. Kumar, A. Kaur, Sustainable deployment of crushed concrete aggregates strengthened with cement and sand, Archives of Materials Science and Engineering 113/1 (2022) 19-34. DOI: https://doi.org/10.5604/01.3001.0015.6970

[2] J. Li, W. Zhang, C. Li, P.J.M. Monteiro, Green concrete containing diatomaceous earth and limestone: Workability, mechanical properties, and life-cycle assessment, Journal of Cleaner Production 223 (2019) 662-679. DOI: https://doi.org/10.1016/J.JCLEPRO.2019.03.077

[3] I.F. Nasser, M.A. Ali, M. J. Kadhim, Mechanical properties and microstructure of alkali activated mortar containing unexpanded clay, Archives of Materials Science and Engineering 113/2 (2022) 56-68. DOI: https://doi.org/10.5604/01.3001.0015.7018

[4] A. Schöler, B. Lothenbach, F. Winnefeld, M. Zajac, Hydration of quaternary Portland cement blends containing blast-furnace slag, siliceous fly ash and limestone powder, Cement and Concrete Composites 55 (2015) 374-382. DOI: https://doi.org/10.1016/J.CEMCONCOMP.2014.10.001

[5] N. Sharma, M. Singh Thakur, P.L. Goel, P. Sihag, A review: sustainable compressivestrength properties of concrete mixwith replacement by marble powder, Journal of Achievements in Materials and Manufacturing Engineering 98/1 (2020) 11-23. DOI: https://doi.org/10.5604/01.3001.0014.0813

[6] L.P. Singh, D. Ali, U. Sharma, Studies on optimization of silica nanoparticles dosage in cementitious system, Cement and Concrete Composites 70 (2016) 60-68. DOI: https://doi.org/10.1016/J.CEMCONCOMP.2016.03.006

[7] A. Bouaziz, R. Hamzaoui, S. Guessasma, R. Lakhal, D. Achoura, N. Leklou, Efficiency of high energy over conventional milling of granulated blast furnace slag powder to improve mechanical performance of slag cement paste, Powder Technology 308 (2017) 37-46. DOI: https://doi.org/10.1016/J.POWTEC.2016.12.014

[8] M.M. Sadawy, M.T. Nooman, Influence of nano-blast furnace slag on microstructure, mechanical and corrosion characteristics of concrete, Materials Chemistry and Physics 251 (2020) 123092. DOI: https://doi.org/10.1016/J.MATCHEMPHYS.2020.123092

[9] D.J.M. Flower, J.G. Sanjayan, Green house gas emissions due to concrete manufacture, The International Journal of Life Cycle Assessment 12/5 (2007) 282-288. DOI: https://doi.org/10.1065/LCA2007.05.327

[10] D.-W. Ryu, W.-J. Kim, W.-H. Yang, J.-H. You, J.-W. Ko, An Experimental Study on the Freezing-Thawing and Chloride Resistance of Concrete Using High Volumes of GGBS, Journal of the Korea Institute of Building Construction 12/3 (2012) 315-322. DOI: https://doi.org/10.5345/JKIBC.2012.12.3.315

[11] H. Yazici, The effect of curing conditions on compressive strength of ultra high strength concrete with high volume mineral admixtures, Building and Environment 42/5 (2007) 2083-2089. DOI: https://doi.org/10.1016/J.BUILDENV.2006.03.013

[12] Q.L. Li, M.Z. Chen, F. Liu, S.P. Wu, Y. Sang, Effect of superfine blast furnace slag powder on properties of cement-based materials, Materials Research Innovations 19/S1 (2015) S1-168–S1-171. DOI: https://doi.org/10.1179/1432891715Z.0000000001397

[13] A. Oner, S. Akyuz, An experimental study on optimum usage of GGBS for the compressive strength of

concrete, Cement and Concrete Composites 29/6 (2007) 505-514. DOI: https://doi.org/10.1016/J.CEMCONCOMP.2007.01.001

[14] W. Jiang, X. Li, Y. Lv, D. Jiang, Z. Liu, C. He, Mechanical and hydration properties of low clinker cement containing high volume superfine blast furnace slag and nano silica, Construction and Building Materials 238 (2020) 117683. DOI: https://doi.org/10.1016/J.CONBUILDMAT.2019.117683

[15] A.A. Atiyah, S.A. Salih, A.S. Kadhim, Properties of self-compacting mortar containing nano blast furnace slag, IOP Conference Series: Materials Science and Engineering 737 (2020) 012054. DOI: https://doi.org/10.1088/1757-899X/737/1/012054

[16] S. Srikanth, C.B.R. Krishna, T. Srikanth, K.J.N. Sai Nitesh, V. Swamy Nadh, S. Kumar, S. Thanappan, Effect of Nano Ground Granulated Blast Furnace Slag (GGBS) Volume % on Mechanical Behaviour of High-Performance Sustainable Concrete, Journal of Nanomaterials 2022 (2022) 3742194. DOI: https://doi.org/10.1155/2022/3742194

[17] ASTM C109/C109M. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens). Available from: https://www.astm.org/c0109_c0109m-08.html (accessed Aug. 09, 2022).

[18] ASTM D2240. Shore Hardness. Available from: https://www.intertek.com/polymers/testlopedia/shore-hardness-astm-d2240/ (accessed Aug. 09, 2022)

[19] ASTM C642-21. Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. Available from: https://www.astm.org/c0642-21.html (accessed Aug. 09, 2022).