Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 8, No. 07, July, 2022

The Influence of Nanoclay and Powdered Ceramic on the Mechanical Properties of Mortar

Noor R. Kadhim [1], Wail Asim M. Hussain [1*], Abdulrasool Th. Abdulrasool [1], Mohammed A. Azeez [1]

[1] *Civil Engineering Department, College of Engineering, University of Warith Al-Anbiyaa, Karbala, Iraq.*

Received 24 April 2022; Revised 22 June 2022; Accepted 27 June 2022; Published 01 July 2022

Abstract

The amount of concrete utilized worldwide has lately grown due to rising populations and urbanization. The gas emissions during cement manufacturing and the usage of common resources result in a significant environmental threat. As a result, researchers are attempting to minimize the amount of cement consumed by using waste materials while lowering building costs. This research aims to minimize the amount of cement used in concrete by partially replacing it with ceramic powder waste while also increasing the mechanical qualities of concrete mortar by substituting cement with nanoclay hydrophilic bentonite. Mortar samples were prepared using five different replacement percentages of cement by nanoclay, including 0, 2, 4, 6, and 8%, and two replacement percentages of cement by ceramic powder, including 0% and 20%. Compressive and flexural strength tests were performed on mortar samples for 7, 14, and 28 days of moist curing. The toughness was also measured for all mixes by measuring the area under the load-deflection curve. Also, water absorption and relative densities for all mortar mixes were measured. The results show that replacing cement with 2% nanoclay and 20% ceramic powder increases the flexural strength by 11%.

Keywords: Nano Clay; Waste Materials; Mechanical Properties; Mortar; Flexural Strength.

1. Introduction

The massive quantities of Portland cement production for construction result in a serious environmental pollution concern. As a result, one of the most pressing concerns is reducing cement usage by utilizing waste materials in concrete and maintaining concrete strength and durability. Using waste materials to substitute cement has a beneficial environmental impact since it reduces air pollution caused by cement manufacturing. In addition, it allows the waste to be used in concrete to overcome disposal issues. Sustainable concrete can be achieved by partially or completely replacing cement or aggregate content with waste materials generated by other industries [1]. So, using ceramic wastes in concrete has many positive environmental impacts by reducing cement consumption and landfill demand. This also decreases the price of concrete [2]. Some previous studies considered ceramic wastes to be pozzolanic materials [3-5]. On the other hand, a slight reduction in the mechanical performance of concrete is expected by using ceramic powder in concrete to partially replace cement content, especially with higher replacement percentages.

Consequently, to compensate for this reduction, some other materials can be mixed with concrete to improve the concrete's mechanical properties and maintain the eco-friendly aspect. Using nano-silica with ceramic powder improves the concrete's compressive strength and reduces its absorption capacity [6]. A small percentage of different types of nanomaterials can be used in ceramic concrete to improve or regain its mechanical properties and durability. This is attributed to nanomaterial reactivity since they have very small particle sizes, resulting in a huge surface area for the chemical reaction in the concrete matrix [7, 8].

* Corresponding author: wael.essam@uowa.edu.iq

http://dx.doi.org/10.28991/CEJ-2022-08-07-08

The nanomaterials such as nano-silica and nanoclay react with calcium hydroxide in the interfacial transition zone, increasing the C-S-H gel and improving the concrete's mechanical properties and durability [9]. Incorporating nanomaterials into concrete reduces cement usage, leading to decreased air pollution and increased concrete durability [10]. Recently, researchers' interest has been directed toward using nanoclay in concrete since it is available everywhere at a low cost and is an eco-friendly material. Hamed et al. (2019) [11] investigated the effects of using nanoclay as a partial replacement for cement by 5%, 7.5%, and 10%. It was added in two ways. The first was a normal addition to the concrete mix, and the other was a dispersion in water using a bath sonicator. The tests conducted were compressive strength, split tensile strength, flexural strength, slipping bond strength, and split bond strength. The results show that the optimum percentage of nanoclay in concrete for both mixing methods is 7.5%.

Hosseini et al. (2015) [12] studied the influence of nano-montmorillonite on the mechanical properties and durability of self-compacting concrete using small replacement percentages of 0.25%, 0.5%, 0.7%, and 1%. This study showed that using 0.5% nano-montmorillonite is the best for compressive strength, and using 0.75% nano-montmorillonite gives the highest tensile splitting test results. Previous studies investigating the effect of using nanoclay on concrete declared that there was an obvious enhancement in the properties of concrete [13, 14]. Some of these studies stated that the optimum percentage of nanoclay to replace cement is 1%, while others figured out that 6% is the optimum percentage [15]. Alani et al. (2021) [16] partially replaced cement with different percentages of nanoclay, including 2, 4, and 6%, and burnt limestone powder to produce self-compacting concrete. The findings indicated that nanoclay 6% was the optimum percentage, working perfectly as a filler and activator by reducing Ca $(OH)_2$ and increasing the formation of CSH gel. Mehrabi et al. (2021) [17] used recycled concrete aggregate instead of natural coarse aggregate and nanoclay to partially replace Portland cement. This study concluded that using 1-3% nanoclay considerably enhances concrete compressive strength.

There are insufficient studies investigating the usage of large amounts of ceramic powder wastes as partial replacing cement content in the concrete mix by adding other materials like nanomaterials to compensate for the expected decrease in concrete or mortar mechanical properties due to cement reduction. So this study aims to produce eco-friendly concrete with high mechanical properties by replacing some percentages of cement with ceramic powder and nanoclay.

2. Materials and Mix Proportion

Figure 1 shows the flowchart of the research methodology.

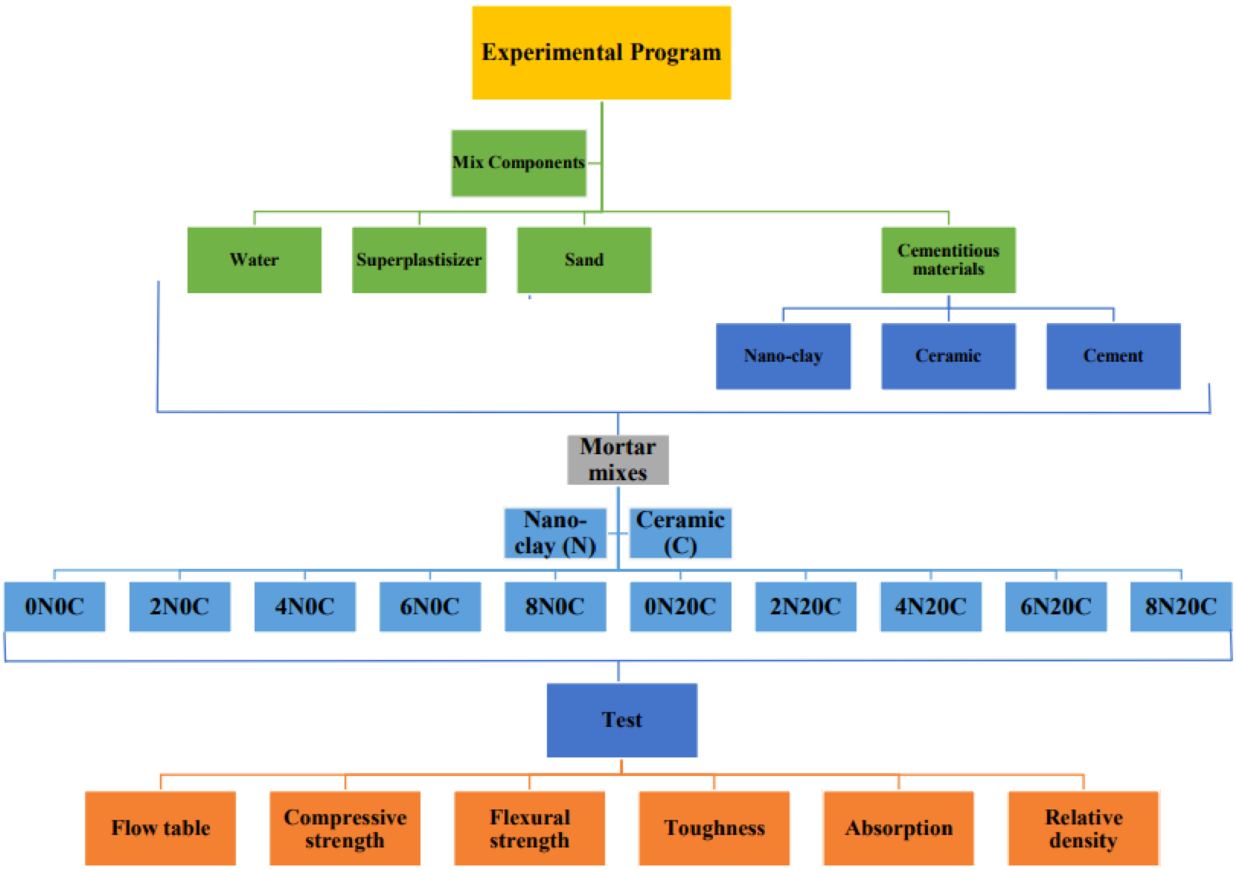

Figure 1. Research methodology flowchart

2.1. Ceramic Powder

Ceramic waste is generated in large quantities around the world. The ceramic wastes were collected from construction sites near Karbala city for this study. These wastes were ground by the Los Angeles Abrasion machine and then sieved. Only the ceramic powder passing through sieve number 200 was used in this study. According to several previous studies [18–20] on the optimum percentage of ceramic powder to replace cement content, it can be figured out that 20% is the optimum replacement percentage. While other studies stated that up to 40% of cement replacement by ceramic waste results in the highest mechanical characteristics and durability among the different percentages [21]. The chemical composition of ceramic powder is compared with that of ordinary Portland cement, as shown in Table 1.

Table 1. Chemical composition of ceramic powder compared with Portland cement

Chemical component (Oxide)	Ceramic powder	Ordinary Portland cement
Si	73.2	16.3
Fe	3.83	3.52
Al	18.2	4.25
Ca	1.3	68.2
K	2.66	0.22
Ti	0.43	0.47

2.2. Nanoclay

The used nano clay in this study is montmorillonite hydrophilic bentonite, the most common nanomaterial utilized by several industries. Its microstructure consists of layers of 1 nm silica tetrahededron connected with alumina octahedron coordinated by hydroxyl groups [22, 23]. The X-Ray analysis and the chemical composition of the nanoclay material are illustrated in Table 2.

Table 2. Nanoclay physical and chemical properties

Physical properties	
Appearance	Powder
Ph	2,5 - 3,5
Bulk density	300 - 370 kg/m3
Chemical composition	
O	52.6%
Si	18.5%
Fe	10.0%
Al	9.4%
Mg	2.3%
Na	2.0%
Ca	1.9%
K	1.7%
Ti	1.6%

2.3. Superplasticizer

The water-reducing admixture used in this study was Conplast SP432MS to keep the water-cement ratio and the flow constant, increasing the nanoclay replacement percentage.

2.4. Fine Aggregate

The sand used for all mortar mixes has a grading, as illustrated in Figure 2. So the used sand is in zone 2, according to Iraqi specifications No. 45.

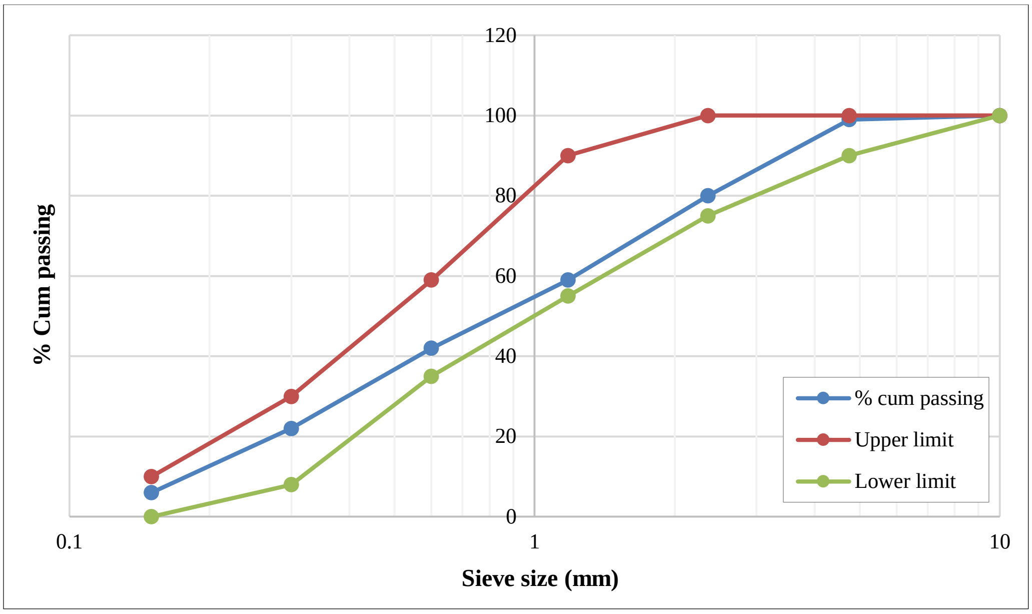

Figure 2. Fine aggregate grading with upper and lower limits

2.5. Mix Proportions

The experimental program of this study included measuring the compressive strength of concrete mortar cubes, the flexural strength, Load-deflection curve (toughness), absorption, and relative density. These tests were conducted after 7, 14, and 28 days of moist curing. So nine cubes with dimensions of 5×5 ×5 cm^3 of each concrete mortar mix for compressive strength and six prisms with dimensions of 4×4 ×16 cm^3 for each mix were used to test the flexural strength and toughness as shown in Figure 3. After testing, the broken prisms were weighted under three conditions to calculate the absorption and relative density, including SSD, water, and oven-dry. In addition, the flow of the fresh mortar mix was measured using the flow table, as shown in Table 3.

Figure 3. Mortar cubes and prisms molds

Table 3. Design of concrete mortar mix

Mix	Cement (g)	Sand (g)	Water (g)	Ceramic (g)	Nano Clay (g)	SP	Flow table (cm)
0N0C	1776	4884	861.36	0	0	0	19
2N0C	1740.5	4884	861.36	0	35.52	5	23.5
4N0C	1705	4884	861.36	0	71.04	5	20
6N0C	1669.5	4884	861.36	0	106.6	7	19
8N0C	1633.9	4884	861.36	0	142.1	10	18.5
0N20C	1420.8	4884	861.36	355.2	0	5	23
2N20C	1392.4	4884	861.36	348.1	35.52	5	21.5
4N20C	1364	4884	861.36	341	71.04	5	19
6N20C	1335.6	4884	861.36	333.9	106.6	7	18.5
8N20C	1307.2	4884	861.36	326.8	142.1	10	17.5

3. Results and Discussion

3.1. Compressive Strength

The compressive strength for each mix and three curing times was measured using the compression testing machine for three cube samples as shown in Figure 4. The average is calculated as shown in Figure 5.

Figure 4. Compressive strength machine

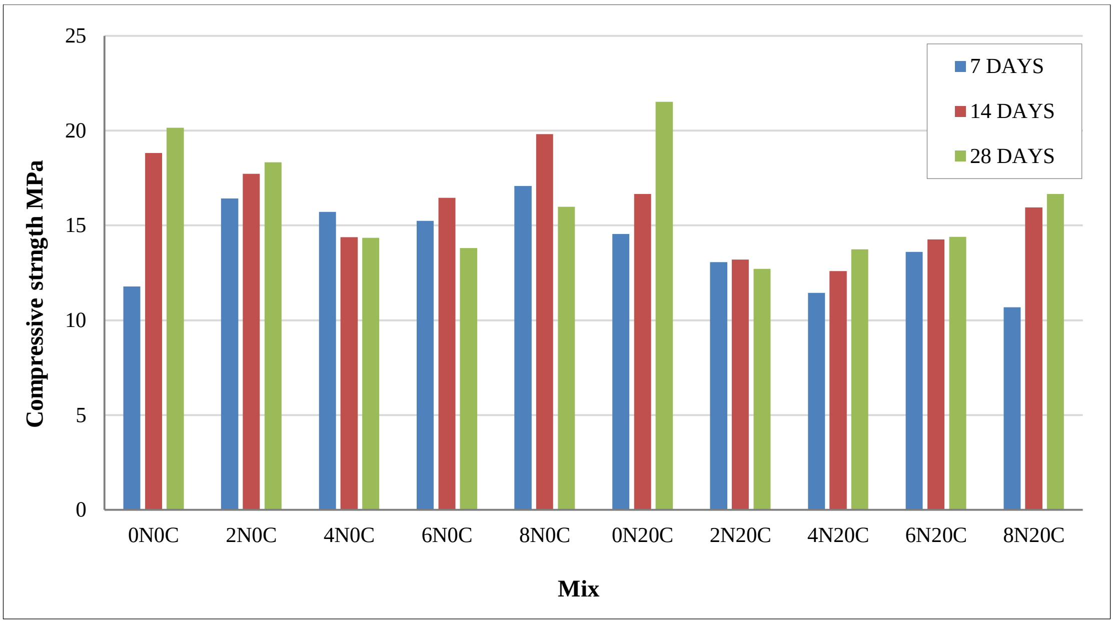

Figure 5. Compressive strength for all mortar mixes for three curing times

It can be figured out that using the nanoclay alone as replacement of the cement content after seven days of moist curing increased the compressive strength of all mixes (Figure 5). Also, the maximum increment was 45% for an 8% replacement compared to the control sample. While compressive strengths are reduced when using ceramic powder with nanoclay after seven days of moist curing. The maximum reduction was 26.5% for the 8% replacement with ceramic powder, which can be acceptable compared to the control sample. For 14 days of moist curing, the compressive strength decreases with the enhancement of nanoclay percentage until 4% for with and without ceramic. On the other hand, the higher replacement percentages under 14 days of moist curing increase the compressive strength to 5.3 % for 8% nanoclay only. They are slightly reduced to 3.4% using 8% nanoclay with ceramic powder compared to the reference sample. The trend of the compressive strength after 28 days of moist curing for using replacement of cement by the nanoclay alone decreases slightly by 2%. Also, more reduction can be noticed in 4% and 6% replacements while replacement increases by 8%. However, it is less than the reference sample by 20 %. Using nanoclay with ceramic after 28 days of curing results in a high reduction of 2%. Then, the compressive strength increases gradually to 16.66 MPa, which is lower than the control sample by 22.6%. From the result of Figure 5, it can be concluded that according to compressive strength, 2% replacement of cement by nanoclay alone is the best percentage among the other mortar mixes. Economically, the compressive strength mortar mixed with 8% with or without ceramic is acceptable, and the reductions were minimal compared to replacement-free mortar.

Compared to the previous studies, the compressive strength after seven days of moist curing is reduced from 25.15 MPa to 20.1 MPa when replacing 20% of cement with waste ceramic powder [6]. Using nano-silica with ceramic powder to replace cement content brings back the compressive strength similar to the control sample. While in this study, nanoclay results in higher compressive strength when used with ceramic in the concrete mixture.

3.2. Flexural Strength

Obviously, for seven days of curing, there is a slight gradual reduction in the flexural strength of concrete mortar with increasing the nanoclay replacement percentage (Figure 6). The flexural strength of mortar after seven days of curing with 8% nanoclay and without ceramic powder is equal to 3.15 MPa, which is less than the reference sample by 16%. Also, the flexural strength after seven days of curing of mortar with 8% nanoclay and 20% ceramic powder is equal to 2.64 MPa, which is less compared to the reference mortar sample of 20% ceramic by 13%.

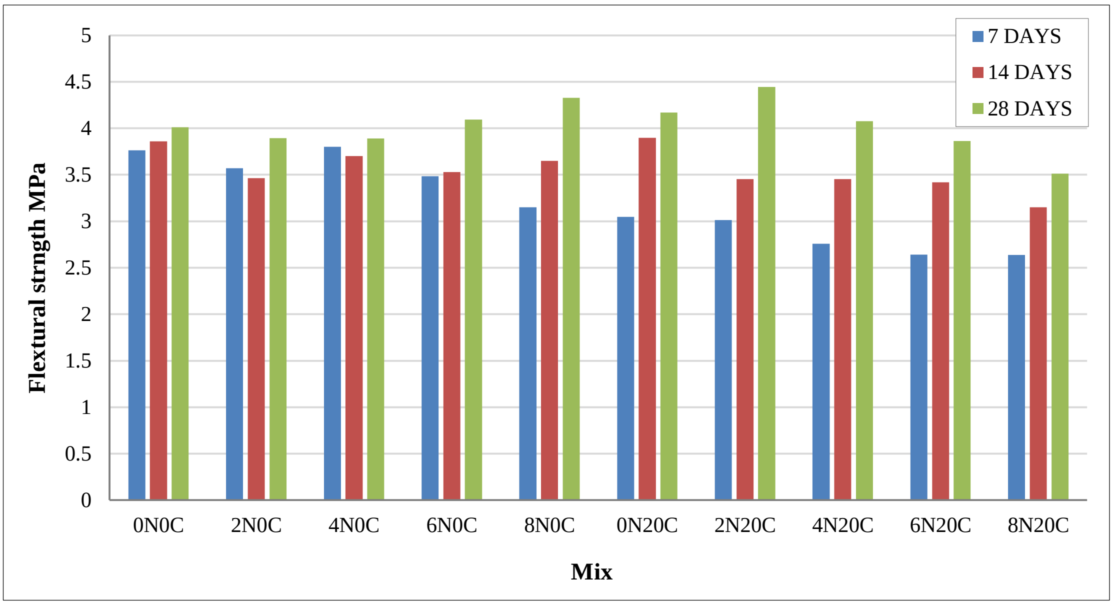

Figure 6. Flexural strength for all mortar mixes for three curing times

After 14 days of moist curing, the flexural strength results show that increasing the percentage of nanoclay without ceramic powder maintains almost the same flexural strength with a very little reduction, i.e., 5% only for 8% nanoclay mortar. The flexural strength of mortar samples containing 20% ceramic powder decreases as the percentage of nanoclay replacement increases. The flexural strength of the 8% nanoclay with 20% ceramic powder was 3.15, which was lower by 19% than the flexural strength of the reference sample with 20% ceramic powder.

The results of the flexural strength after 28 days (8%), as illustrated in Figure 6, were very good compared to the reference samples without nanoclay. The flexural strength was 4.33 MPa with an increment of 8% compared to the reference mortar sample. Besides that, the flexural strength of mortar with 2% nanoclay and 20% ceramic powder was equal to 4.44 MPa, which was the maximum among all other mortar samples.

The flexural strength results in Figure 6 show that using nanoclay without ceramic powder enhances the flexural strength after 28 days of curing. On the other hand, for ceramic mortar, the best percentage of nanoclay was 2%. Increasing the percentage of nanoclay decreases flexural strength. Compared to the reference mortar sample, the 2% nanoclay with 20% ceramic increases flexural strength by 11%.

3.3. Toughness (Load-Deflection Curve)

The deflection was measured during the flexural strength test by a dial gauge attached to the mortar prism samples. The reading of the dial gauge and the load were video-captured and then analyzed to draw the load-deflection curve. After that, the area under this curve was calculated to indicate the toughness according to ASTM C-1018. Figure 7 shows that the toughness of the mortar mix of 6% nanoclay has the highest level among the other mortar samples without ceramic powder after seven days of moist curing.

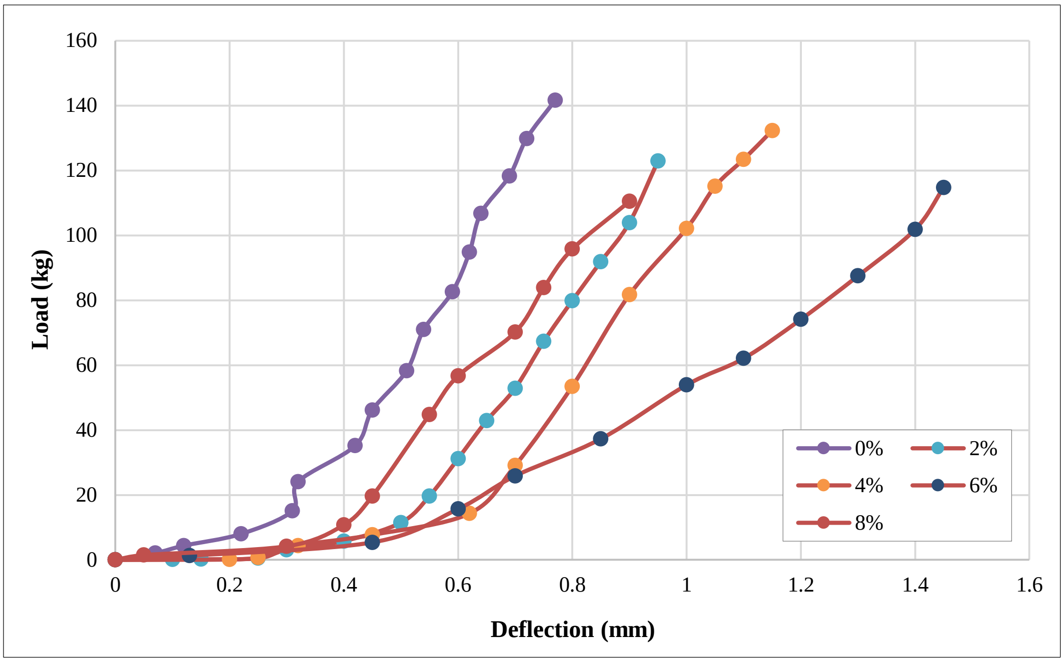

Figure 7. Load-deflection curve for mortar mixes without ceramic after seven days of curing

Figure 8 indicates that mortar samples with 4% nanoclay have the maximum toughness compared to mortar samples without ceramic powder.

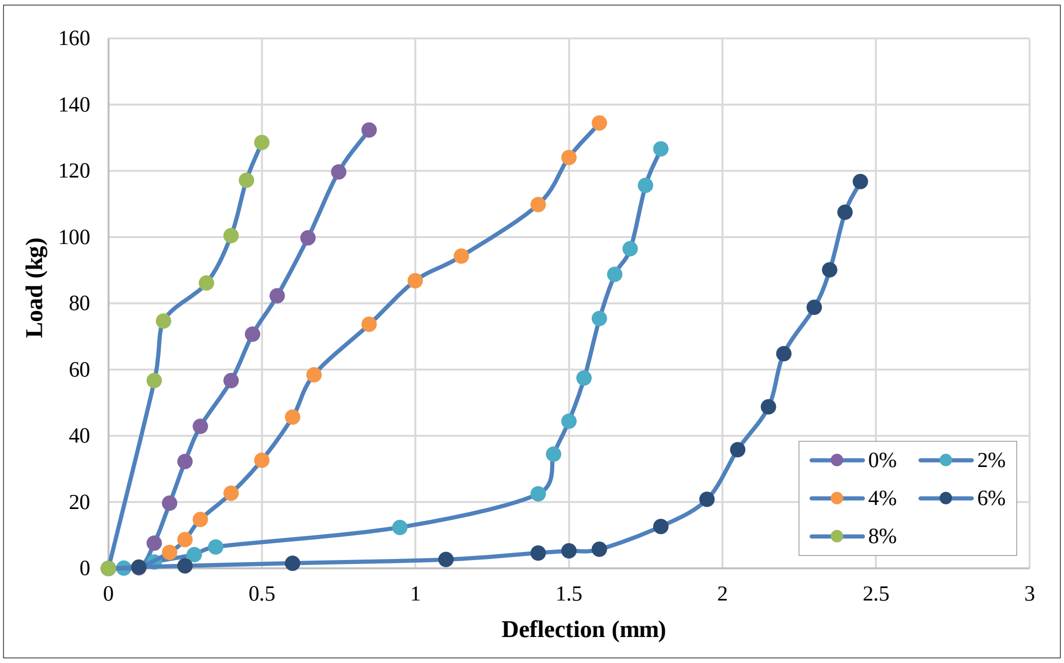

Figure 8. Load-deflection curve for mortar mixes without ceramic after 14 days of curing

Figure 9 demonstrates that mortar samples with 4 % nanoclay have the highest area under the load-deflection curve for samples without ceramic powder after 28 days of moist curing.

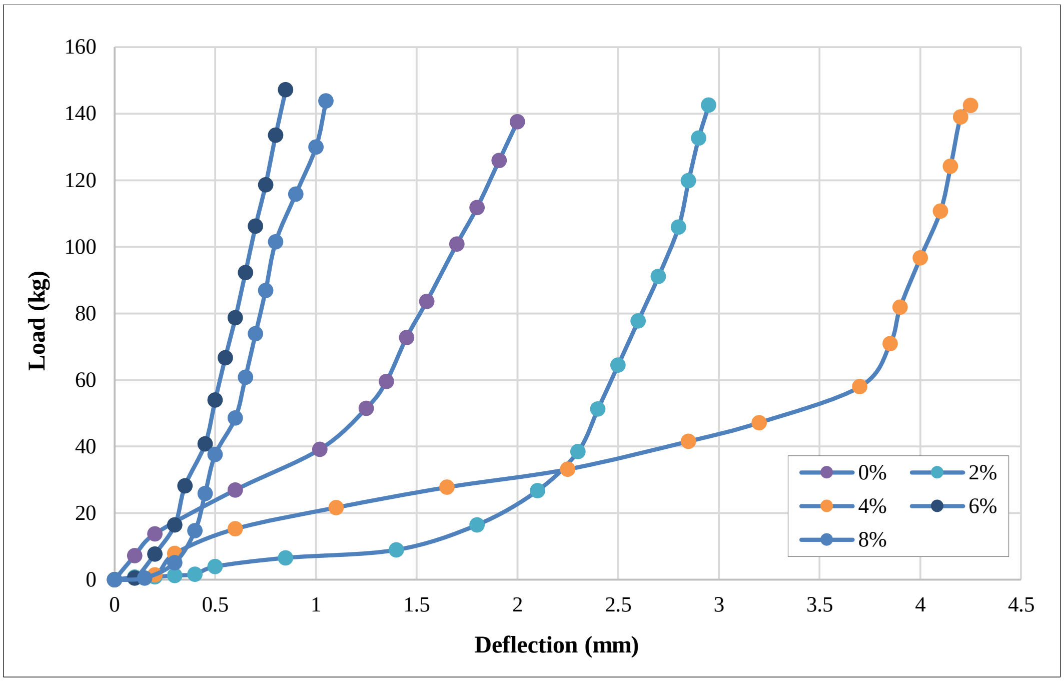

Figure 9. Load- deflection curve for mortar mixes without ceramic after 28 days of curing

Figure 10 shows the toughness of mortar samples with ceramic powder replacing 20% of the weight of cement with different percentages of nano clay after seven days of curing. The results show that 2% nano clay has the highest toughness.

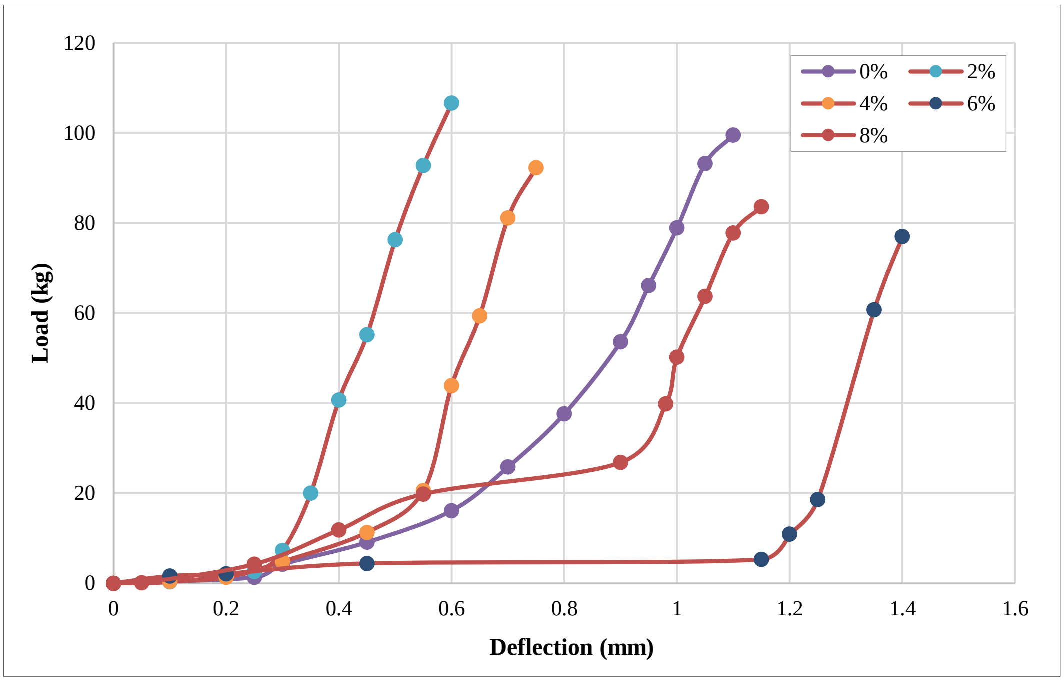

Figure 10. Load-deflection curve for mortar mixes with 20% ceramic after seven days of curing

While after 14 days, as shown in Figure 11, the toughness of the mortar samples with 8% nanoclay and 20% ceramic powder was significantly higher than the other mortar mixes.

From Figure 12, using nanoclay 2% in a mortar with ceramic powder increases the toughness after 28 days of moist curing. But the toughness was reduced for the other percentages of nanoclay with ceramic powder compared to the reference sample toughness.

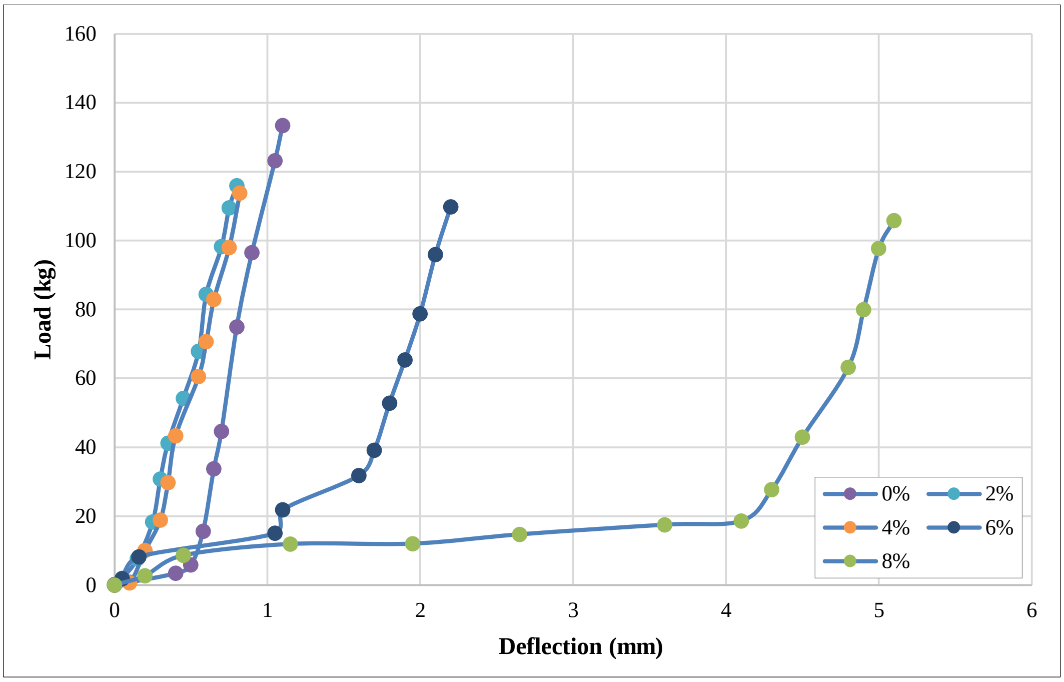

Figure 11. Load-deflection curve for mortar mixes with 20% ceramic after 14 days of curing

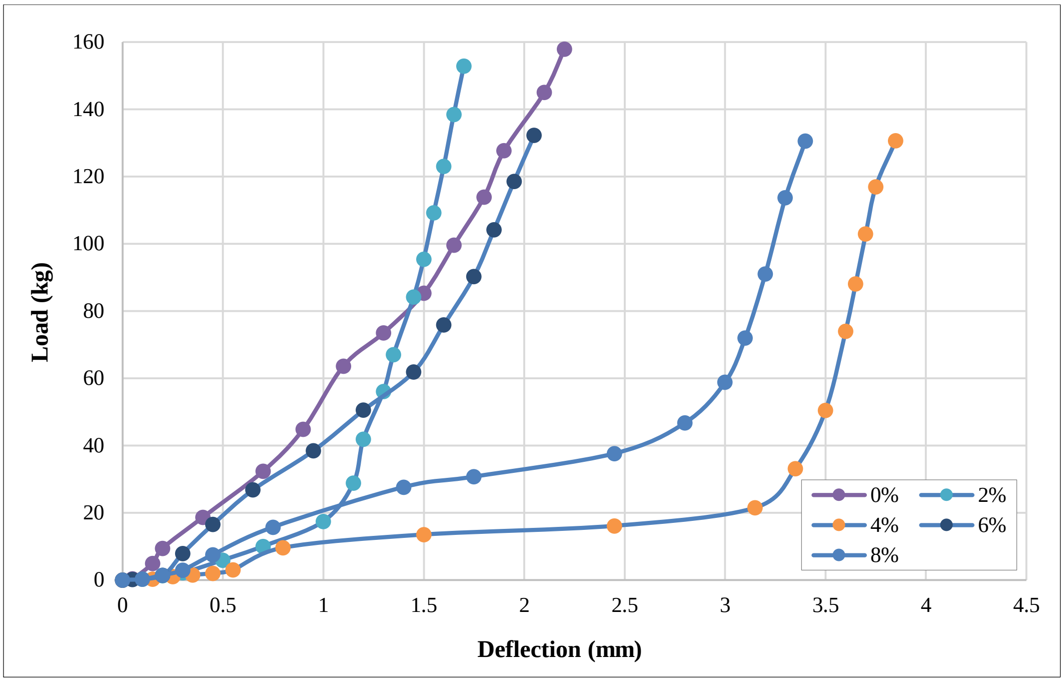

Figure 12. Load-deflection curve for mortar mixes with 20% ceramic after 28 days of curing

3.4. Absorption

The absorption of hardened concrete mortar samples after conducting the flexural test was measured for each mix with the three curing times, as shown in Figure 13. The absorption was calculated according to ASTM C127.

From Figure 13, it can be concluded that the absorption of 7-day curing samples without ceramic powder decreases from 13.3% in the reference mix to 12.2% for the 4% nanoclay and then increases to 13.7% for the 8% nanoclay. While after 14 days and 28 days, the absorption was approximately similar to the reference samples. For mortar-containing ceramic powder, the absorption increases as the nanoclay percentage enhances. So, after 28 days of curing, the 8% nanoclay absorption was greater by 3.6% than the control sample.

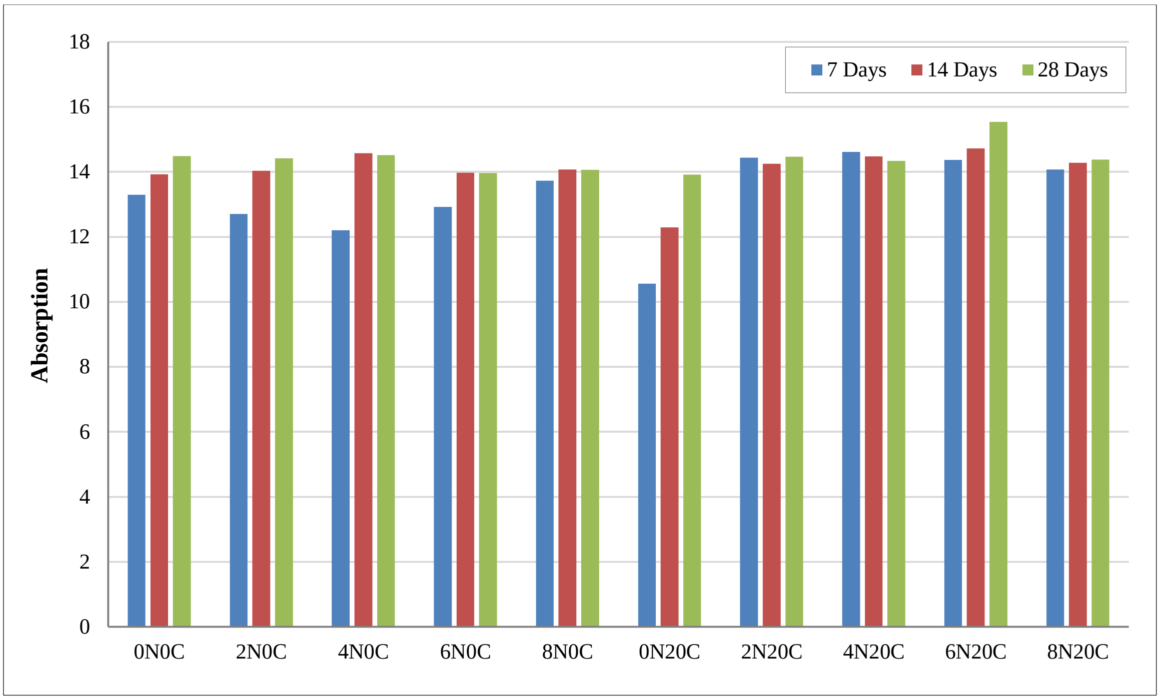

Figure 13. Absorption for hardened mortar samples of all mixes

3.5. Relative Density

The relative densities of all prism mortar samples were measured according to ASTM C127 by measuring the weight of the fractured prisms from the flexural test in water, SSD, and oven-dry for all concrete mortar mixes with the three different curing times.

Figure 14 illustrates the relative density of all hardened concrete mortar mixes for the three curing times. Using 2% nanoclay without ceramic powder appears to have the highest relative density for 7, 14, and 28 days of curing. After 28 days of curing, the enhancement of relative density was 3.3% more than in the control sample. On the other hand, the relative density decreases for mortar samples of 20% ceramic powder as the nanoclay percentage increases. Except for 2% and 6%, the relative density was the same as the reference mortar sample.

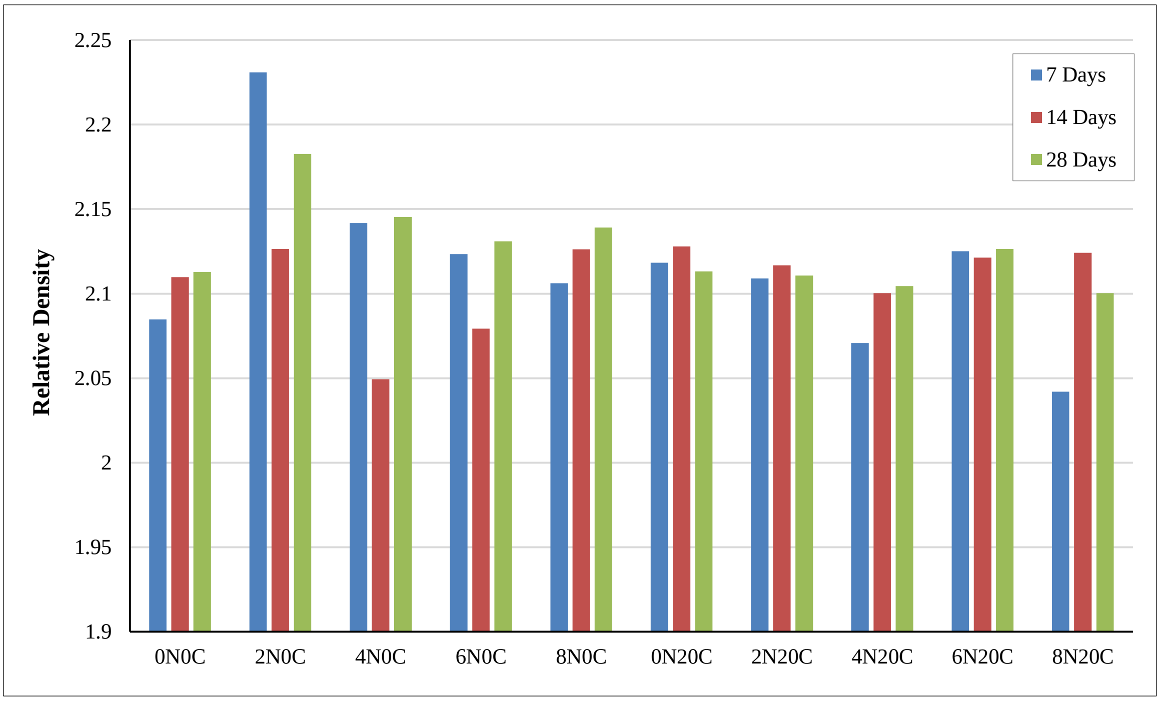

Figure 14. Relative density for hardened mortar samples of all mixes

4. Conclusions

From this study, it can be concluded that

- Increasing the percentage of nanoclay in the mortar mix decreases the workability of concrete, leading to an increased number of used superplasticizers to achieve the same flow.
- According to the compressive strength, the best concrete mortar mix resulted from using 0% nanoclay with 20% ceramic powder. This is because the inactivated nanoclay with ceramic powder increases the proportion of materials finer than 200 microns. This can lead to a decrease in the cohesion of the binder in aggregates.
- The highest result was obtained for concrete mortar mixes of 2% nanoclay with 20% ceramic powder for flexural strength. Also, using 2% nanoclay without ceramic has an acceptable flexural strength.
- Using small percentages such as 2% nanoclay in a concrete mix without ceramic powder results in the highest toughness among the other mortar mixes. While, using 8% ceramic powder results in the highest toughness compared to the other ceramic mortar mixes.
- The optimum concrete mortar mix with the highest enhancement in the mechanical properties tested in this study was 0% nanoclay with 20% ceramic powder. This mortar mix satisfies the eco-friendly aspect by reducing the consumption of cement and is more economical than ordinary concrete mortar mixes.

5. Declarations

5.1. Author Contributions

N.R.K., W.A.M.H., A.Th.A. and M.A.A. contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Meyer, C. (2009). The greening of the concrete industry. Cement and Concrete Composites, 31(8), 601–605. doi:10.1016/j.cemconcomp.2008.12.010.

[2] Pacheco-Torgal, F., & Jalali, S. (2010). Reusing ceramic wastes in concrete. Construction and Building Materials, 24(5), 832–838. doi:10.1016/j.conbuildmat.2009.10.023.

[3] Naceri, A., & Hamina, M. C. (2009). Use of waste brick as a partial replacement of cement in mortar. Waste Management, 29(8), 2378–2384. doi:10.1016/j.wasman.2009.03.026.

[4] Lavat, A. E., Trezza, M. A., & Poggi, M. (2009). Characterization of ceramic roof tile wastes as pozzolanic admixture. Waste Management, 29(5), 1666–1674. doi:10.1016/j.wasman.2008.10.019.

[5] Binici, H. (2007). Effect of crushed ceramic and basaltic pumice as fine aggregates on concrete mortars properties. Construction and Building Materials, 21(6), 1191–1197. doi:10.1016/j.conbuildmat.2006.06.002.

[6] Heidari, A., & Tavakoli, D. (2013). A study of the mechanical properties of ground ceramic powder concrete incorporating nano-SiO2 particles. Construction and Building Materials, 38, 255–264. doi:10.1016/j.conbuildmat.2012.07.110.

[7] Naji, H. F., Khalid, N. N., & Alsaraj, W. K. (2020). Influence of nanoclay on the behavior of reinforced concrete slabs. IOP Conference Series: Materials Science and Engineering, 870(1), 12107. doi:10.1088/1757-899X/870/1/012107.

[8] Gamal, H. A., El-Feky, M. S., Alharbi, Y. R., Abadel, A. A., & Kohail, M. (2021). Enhancement of the concrete durability with hybrid nano materials. Sustainability (Switzerland), 13(3), 1–17. doi:10.3390/su13031373.

[9] Mohamed, A. M. (2016). Influence of nano materials on flexural behavior and compressive strength of concrete. HBRC Journal, 12(2), 212–225. doi:10.1016/j.hbrcj.2014.11.006.

[10] Saloma, Nasution, A., Imran, I., & Abdullah, M. (2015). Improvement of concrete durability by nanomaterials. Procedia Engineering, 125, 608–612. doi:10.1016/j.proeng.2015.11.078.

[11] Hamed, N., El-Feky, M. S., Kohail, M., & Nasr, E. S. A. R. (2019). Effect of nano-clay de-agglomeration on mechanical properties of concrete. Construction and Building Materials, 205, 245–256. doi:10.1016/j.conbuildmat.2019.02.018.

[12] Hosseini, P., Afshar, A., Vafaei, B., Booshehrian, A., Molaei Raisi, E., & Esrafili, A. (2017). Effects of nano-clay particles on the short-term properties of self-compacting concrete. European Journal of Environmental and Civil Engineering, 21(2), 127–147. doi:10.1080/19648189.2015.1096308.

[13] Mirgozar Langaroudi, M. A., & Mohammadi, Y. (2018). Effect of nano-clay on workability, mechanical, and durability properties of self-consolidating concrete containing mineral admixtures. Construction and Building Materials, 191, 619–634. doi:10.1016/j.conbuildmat.2018.10.044.

[14] Mansi, A., Sor, N. H., Hilal, N., & Qaidi, S. M. A. (2022). The Impact of Nano Clay on Normal and High-Performance Concrete Characteristics: A Review. IOP Conference Series: Earth and Environmental Science, 961(1), 12085. doi:10.1088/1755-1315/961/1/012085.

[15] Rashad, A. M. (2013). A synopsis about the effect of nano-Al2O3, nano-Fe2O3, nano-Fe3O4 and nano-clay on some properties of cementitious materials - A short guide for Civil Engineer. Materials and Design, 52, 143–157. doi:10.1016/j.matdes.2013.05.035.

[16] Alani, N. Y., Al-Jumaily, I. A., & Hilal, N. (2021). Effect of nanoclay and burnt limestone powder on fresh and hardened properties of self-compacting concrete. Nanotechnology for Environmental Engineering, 6(1). doi:10.1007/s41204-021-00114-3.

[17] Mehrabi, P., Shariati, M., Kabirifar, K., Jarrah, M., Rasekh, H., Trung, N. T., Shariati, A., & Jahandari, S. (2021). Effect of pumice powder and nano-clay on the strength and permeability of fiber-reinforced pervious concrete incorporating recycled concrete aggregate. Construction and Building Materials, 287, 122652. doi:10.1016/j.conbuildmat.2021.122652.

[18] Mohammadhosseini, H., Lim, N. H. A. S., Tahir, M. M., Alyousef, R., Samadi, M., Alabduljabbar, H., & Mohamed, A. M. (2020). Effects of Waste Ceramic as Cement and Fine Aggregate on Durability Performance of Sustainable Mortar. Arabian Journal for Science and Engineering, 45(5), 3623–3634. doi:10.1007/s13369-019-04198-7.

[19] Huseien, G. F., Sam, A. R. M., Shah, K. W., Mirza, J., & Tahir, M. M. (2019). Evaluation of alkali-activated mortars containing high volume waste ceramic powder and fly ash replacing GBFS. Construction and Building Materials, 210, 78–92. doi:10.1016/j.conbuildmat.2019.03.194.

[20] Balamuralikrishnan, R., & Saravanan, J. (2021). Effect of Addition of Alccofine on the Compressive Strength of Cement Mortar Cubes. Emerging Science Journal, 5(2), 155–170. doi:10.28991/esj-2021-01265.

[21] Kulovaná, T., Vejmelková, E., Keppert, M., Rovnaníková, P., Keršner, Z., & Černý, R. (2016). Mechanical, durability and hygrothermal properties of concrete produced using Portland cement-ceramic powder blends. Structural Concrete, 17(1), 105–115. doi:10.1002/suco.201500029.

[22] Forbes, T. Z. (2015). Occurrence of nanomaterials in the environment. Nanomaterials in the Environment, 179–218, American Society of Civil Engineering (ASCE), Reston, United States. doi:10.1061/9780784414088.ch07.

[23] Asim Mohammad Hussain, W., Thamer Abdulrasool, A., & N Kadhim, Y. (2022). Using Nanoclay Hydrophilic Bentonite as a Filler To Enhance the Mechanical Properties of Asphalt. Journal of Applied Engineering Science, 20(1), 300–304. doi:10.5937/jaes20-35111.