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Utilization of nanomaterials and ceramic waste for sustainable environmental protection

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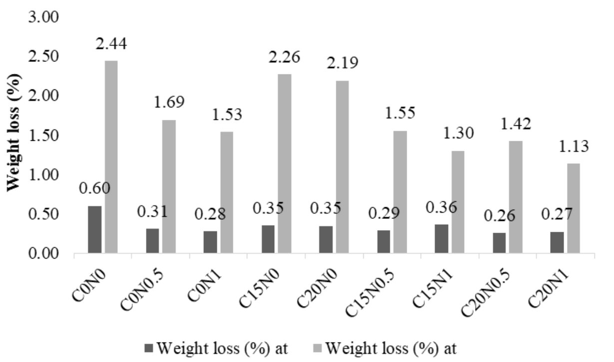
Graphical abstract



Abstract

The amount and type of waste are increasing due to population growth. Many harmful materials have been in the atmosphere for a very long times. This causes a crisis in the waste disposal and thereby contributes to environmental issues. Recycling concrete manufacturing waste materials not only offers a resource for producing concrete of top standard but also aids in correctly addressing the issue of waste disposal. Due to the leftover ceramic powder's high resistance and inability to be processed by any recycling process, using it in concrete is a good use for it. Using powdered ceramic waste in concrete as a pozzolana, their strength and water absorption were explored. The samples were made with 15% and 20% porcelain dust waste substitutes. Simultaneous effects were determined by using 0.5% and 1% nano-alumina and 15% and 20% waste ceramic powder. compression power, tests for water absorption, and weight and strength loss tests were accomplished. After 7 and 28 days of curing for nano-alumina at 0.5%, the increases in compressive strength are 11.46% and 10.22%, respectively. After 7 and 28 days of curing for 1% of the nano-alumina, the increases in compressive strength are 16.25% and 14.73%, respectively. The findings indicate that the compressive strength of the concrete is not significantly harmed by the inclusion of ceramic waste up to 20%. Additionally, the use of pozzolana, ceramic waste powder, and nano-alumina increases compressive strength while lowering the ability to absorb water. Consequently, nano-alumina can enhance the impacts of ceramic waste powder on concrete's characteristics.

Keywords: Ceramic waste, nano-alumina, compressive strength, water absorption, weight and strength loss

1. Introduction

One of the most widely used building materials in the world, concrete is produced in tonnes year. This is also responsible for the massive environmental trace of the concrete industry. Because the production process of Portland cement clinker devours a great amount of energy and has a significant ecological effect, including massive quarries for raw materials, which require 1.7 tons to generate 1 ton of clinker and emit greenhouse gases and with some other gases into the surrounding. Per tonne of clinker produced, 850 kg of carbon dioxide is released (Gartner, 2004; Meyer, 2013; Heidari and Tavakoli, 2013). Natural resources are under stress as a result of the quickening growth in human population and social development. As a result, natural resource use is always rising. The use of natural resources can be decreased because to developments in concrete technology (Raval *et al.*, 2013; Gautam *et al.*, 2020). They are compelled to concentrate on recovering, repurposing, and discovering other alternatives for natural resources. Utilizing alternative materials results in lower costs, less energy use, arguably superior products, and reduced environmental risk. For major projects requiring significant amounts of cement, it's crucial to diminish the required extent of Portland cement without lowering the effectiveness of the concrete.

Concrete could be made with ceramic waste powder instead of traditional components (Vasoya and Varia, 2015). Although most of the ceramic waste is recycled in the civil field most of the ceramic waste is non-recyclable in most facilities especially the waste ceramic powder from ceramic product manufacturing (El Dieb and Kanaan, 2018). Indian ceramics have been produced at a rate of 100 million tonnes annually in recent years. 15% to 30% of trash produced in the ceramics sector comes from overall output. Everywhere in the world, ceramic is utilised. Despite designated dumping places, dust from ceramic industries often ends up in pits or empty lots close to their units. (Raval *et al*., 2013) The ecosystem is seriously affected by this, and in the summer, dust accumulates, endangering agriculture, public health, and the occupation of large tracts of land. Ceramic powder can also have a negative impact on public health when it comes into contact with groundwater. The ceramics sector is under pressure to develop a disposal method as ceramic waste increases daily. Because of this, the use of pozzolanic materials in various sectors, particularly in the building, farming, glass, and paper industries, can aid in environmental protection. The concrete design and a greener surrounding will result from that the custom of mineral industry waste in the manufacturing of concrete. The debris can be reprocessed into concrete and mortar as an alternative to cement and collective since it contains silica and alumina (fine and coarse). It has various benefits, including methods for waste management. aids in achieving community progress that is sustainable. Using it as a replacement for Portland cement will lower CO2 emissions into the environment. Strengthening over a particular alternate range. The use of ceramic waste reduces the cost of construction (El Dieb and Kanaan, 2018). Concrete has been the most widely used building material for more than a century. There are now active studies targeted at enhancing concrete constructions (which are even more resistant). The use of nanoparticles to change concrete is one of the emerging research directions. The ability to build new structures on a very small scale utilising instruments and processes that enable the grabbing and manipulation of matter at the nanoscale, typically.1 to 100 nm, is known as nanotechnology (Nagare *et al*., 2017; Santosh and Madhavi, 2015; Silvestrea *et al*., 2015). Nanotechnology is also used for design and construction processes. Nanotechnology will enhance existing construction materials and generate products with their properties (Mahmood and Kockal, 2021). Different structural materials, for instance, with special qualities like lighter, stronger compounds, fire insulators, sound absorbers, low maintenance coatings, nanoscale sensors, solar cells, etc., Polymers, metals, pottery, compounds, and semiconductor materials are different categories of material science. Nanoparticles is a field that focuses on a material science-based approach to nanotechnology. Recently, novel materials with advantageous features compared to standard materials have been created through study in material science and nanotechnology. (Hakamy, 2020; Ismael *et al*., 2016). Nanoparticles have a greater surface and volume ratio compared to their micro counterparts, so advanced hydration should be provided, which can lead to higher initial and final strength. High mechanical strength and high durability structural components are needed for modern concrete infrastructure (Long *et al*., 2016). Combining nanoparticles with cement-based materials to improve their mechanical characteristics is one approach. These nanomaterials include carbon nanotubes (CNTs), graphene, and graphene oxide, as well as nanosilica (nano-SiO2), nanoalumina (nano-Al2O3), nanoferric oxide (nano-Fe2O3), nanotitanium oxide (nano-TiO2), and nanographene. In addition to other reinforcing components including glass, rice husk powder, steel fibres, and ash, these nanoparticles can be added to cement (Bautista-Gutierrez *et al*., 2019; Khita *et al*., 2015; Niewiadomsk, 2015). Using these materials in the ideal sizes can increase the compressive, tensile, and flexural strength of cement-based materials as well as their water absorption and workability. Limiting the washability of underwater concrete is one of the benefits of using nanoparticles in concrete technology (Grzeszcyk *et al*., 2019). The impact of suitable nanoparticle additions can also enhance the concrete's freeze-thaw resistance (Ebrahimi *et al*., 2018) and frost resistance (Behfarnia and Salemi, 2013). Acceptable nanoparticles may be added to concrete for pavement to boost its resistance to abrasion (Li *et al*., 2006). In addition to assessing the pozzolanic activity of ceramic waste powder and its potential usage in concrete as a partial cement substitute, the objective of this study is to assess the effects of including nano-alumina and ceramic waste powder.

2. Materials and its properties

2.1. Ceramic waste

Ceramic waste cannot be recycled using any of the currently used processes because it is robust, incredibly strong and impervious to physical, chemical, and biological degradation agents. Waste is created throughout decorating and polishing ceramic. From the overall amount of raw materials consumed, 15 to 30 percent of waste is thought to be produced. Finding a purpose for the generated ceramic waste is particularly challenging. Concrete can benefit from the use of ceramic waste powder to increase its strength and other durability characteristics (Heidari and Tavakoli, 2013; Raval *et al*., 2013; Gautam *et al*., 2020; Pacheco-Torgal and Jalali, 2010), Ahmad *et al*., 2015). It can function as a supplement to generate various potentials of concrete by partially replacing fine sand or cement, respectively. Ceramic sanitary ware and ceramic stoneware tiles were employed to make the waste ceramic powder for this investigation. A crusher was used to crush the cracked fragments. The powders that resulted were put through a 75-lm (200 mesh) screen. The cement paste's Ca $(OH)_2$ reacts with the SiO_2 and Al_2O_3 in ceramic waste powder to create crystalline Calcium-aluminate hydrate (C-A-H) and low-density Calcium-silicate hydrate (C-S-H) gel, which fills the concrete's micropores, strengthens the bond between the aggregates' interfaces, decreases permeability, and increases durability. Table 1 displays the parameters of ceramic waste powder.

2.2. Nano-alumina

When calcium silicates are hydrated, calcium hydroxide is created, which reacts with the alumina (Al2O3) component. A pozzolanic reaction's rate is inversely correlated with the reaction's available surface area. Because of its high specific area, acid-base characteristics, mechanical stability, and thermal stability, nano-Al2O3 has a wide range of applications in the absorption and catalytic sectors (Nagare *et al*., 2017; Muhd Norhasri *et al*., 2017; Nazari *et al*., 2010; Kewalramani and Syed, 2018). The inclusion of high-purity nano- Al_2O_3 develops the belongings of concrete based on higher split tensile strength and flexibility. Nano alumina acts as a dispersing agent on cement elements. Having a typical particle size of 15 nm, the maximum range of nano-Al2O3 particles in the cement concrete mix can be altered up to 2.0%. With a change of 1.0%, the optimal concentration of nano-Al2O3 particles is attained (Orakzai, 2021). Table 2 displays the nano-characteristics of alumina's.

Table 1. Properties of Ceramic waste powder

Properties	Observed Values
Moisture Content (%)	0.2
Particular Surface Area (m^2/g)	34.1
Particle Size (mm)	< 0.0075
Density (g/cm^2)	2.57

Table 2. Chemical Properties of Nano-alumina

Properties	Observed Values
Particular Surface Area (m^2/g)	120 – 140
Particle Size (nm)	30 - 45
PH Value	6
Al_2O_3 (%)	99.7
CaO (%)	0.0016
Fe_2O_3 (%)	0.0034
M_gO (%)	0.001
SiO_2 (%)	0.04
Loss on drying (%)	0.47
Loss of ignition (%)	0.66
Carbon Content	0.1

Table 3. Properties of Cement

Properties		Permissible values as per IS Code	Obtained Values
Fineness (%)		< 10	6.65
Setting Time (min)	Initial curing Time	30	28
	Final curing Time	600	600
Soundness (mm)		10	8
Specific Gravity		3.1 - 3.16	3.16
Standard Consistency (%)		25 - 35	27.4
Particular Surface Area (m^2/g)		> 0.225	0.35

Table 4. Characteristics of Fine Aggregate

Properties	Permissible values as per IS Code	Obtained Values
Specific Gravity	2.65 - 2.67	2.59
Grading Zone	-	II
Fineness modulus	2.5 - 3.0	2.59
Water Absorption (%)	< 3	1
Bulk Density (Kg/m^3)	1200 - 1750	1753

Table 5. Characteristics of Coarse aggregate

Properties	Permissible values as per IS Code	Obtained Values
Specific Gravity	2.5 - 3	2.55
Maximum Size (mm)	< 40	25
Fineness modulus	5.5 - 8.0	6.88
Water Absorption (%)	< 2	0.4
Bulk Density (Kg/m^3)	1200 - 1750	1598
Aggregate Impact Value (%)	< 45	15.17

2.3. Cement

It was constructed using widely obtainable OPC 53 Grade cement that complied with IS 12269:1987. Table 3 displays the OPC cement's specifications.

2.4. Aggregate

The aggregates used in concrete were the commercially available fine sand and coarse gravel. Following the test procedures outlined in the Indian Standard (IS) code, the following parameters were specified: water soaking up, dispersion of particle sizes, aggregate density, and fineness modulus. Tables 4 and 5 exhibit the physical characteristics of the fine aggregate and rough mixture, respectively.

Table 6. Concrete Mix proportions as per IS 10262:2009

Properties	Specimens								
	C0N0	**C0N0.5**	**C0N1**	**C15N0**	**C20N0**	**C15N0.5**	**C15N1**	**C20N0.5**	**C20N1**
Cement (Kg/m^3)	360	358.2	356.4	306	288	304.2	302.2	286.2	284.4
Ceramic waste powder (Kg/m^3)	0	0	0	54	72	54	54	72	72
Nano Alumina (Kg/m^3)	0	1.8	3.6	0	0	1.8	3.6	1.8	3.6
W/C	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
Fine Aggregate (Kg/m^3)	673	673	673	673	673	673	673	673	673
Coarse aggregate (Kg/m^3)	1177	1177	1177	1177	1177	1177	1177	1177	1177
Super plasticizer (%)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

Table 7. Results of Slump test

Specimen	C0N0	C0N0.5	C0N1	C15N0	C20N0	C15N0.5	C15N1	C20N0.5	C20N1
Slump value (mm)	90	90	85	90	85	85	80	80	70

3. Mix proportions

Nine different kinds of specimens were created in total. The C0N0 specimen was created as a control sample. The control specimens were constructed using cement, water, and natural aggregates. Different concentrations of Nano-Al2O3 particles and ceramic waste powder were used to create the specimens. The combinations were created using cement replacements of 0.5% and 1.0% by weight Nano-Al2O3 and 15% and 20% by weight ceramic waste powder. Table 6 displays the Mix percentages. The addition of Nano– Al_2O_3 and Ceramic waste powder can also be increased but it is not effective and lower the strength of the concrete and suffer excessive self-desiccation and cracking, although this was not observed in this study.

4. Preparation of test specimens

In a drum mixer, the concrete mixes were blended in line with IS: 516 -1959. Standard test method conducted in accordance with IS: 1199-1959 was used to gauge how easily the fresh concrete could be worked. Cement, pozzolana, and water were then added after mixing the coarse and fine mixture, together with the necessary quantity of superplasticizer. During the final minute of mixing, one-fifth of the superplasticizer is always maintained and added. Only when nanoparticles can achieve greater dispersion is it possible for cement mixtures to have a higher degree of hydration. Due to their high surface energy, nanoparticles are difficult to disperse uniformly (Pacheco-Torgal *et al*., 2013). In the earlier investigations, Nano alumina was separately mixed for 1 to 3 minutes with a rapid water speedo address this issue before being added to the combination. The mixture was then supplemented with the fully dissolved particles. The test samples was crushed on a shaking table after being cast in steel cube growths measuring 150mm X 150mm X 150mm. After 24 hours, the samples were removed from the steel cube casings. The samples were setting in cure tanks with water at 21 °C till testing. The procedures for casting, abstraction, and curing followed IS: 516-1959.

5. Experimental results and discussion

The examination was acted upon to examine the behaviour of concrete for more effective results and to ascertain the strength under compression and water holding capacity, and acid resistance of concrete containing Nano-alumina and ceramic dust waste. The concrete's durability, measured in Mpa (MPa), varied with different mixes. The following tables display the results for concrete setting for 7 and 28 days. In each case of this study, the values represent the average of the three trials.

5.1. Compressive strength test

Three samples computing 15 cm x 15 cm x 15 cm were evaluated for strength of concrete at two different ages—7 and 28 days. The typical of the identical three samples is presented as strength of concrete in each phase. A universal test machine that conformed to IS: 516-1959 standard was used to crush all specimens at a rate of roughly 0.25 MPa/s while under load control. Figure displays the typical outcomes from the test compaction tests conducted at 7 and 28 days. The results of the sag test are presented in the table, and they exhibit that the values get lower as nano-alumina and ceramic waste powder are added. There is a plastic consistency to all Mix amounts. Table 7 displays the Slump value for each concrete combination.

Finally, Table 8 displays the growth of compressive strength for each concrete combination. The obtained results indicate that with large differences at 7 days and smaller differences at 28 days, In Table 8. We can observe that as the amount of ceramic waste powder in the concrete rose, the compression resistance fell. Ceramic waste solely serves as a supplement and is not vulnerable to pozzolanic reactions during the early curing stages. The imbalanced cementitious response in the concrete and the early C-S-H gel development, which was influenced by the components in the ceramic waste, are the main causes of the drop in the 7-day compression resistance. Al is absorbed by calcium silicate hydrate (C-S-H) during the hydration process to create the C-(A)-S-H gel, which also aids in the formation of compressive strength (Nazari *et al*., 2010; Kewalramani and Syed, 2018; Orakzai, 2021; Pacheco-Torgal *et al*., 2013; Joshaghani *et al*., 2020). As can be seen in Figures 1 and 2, the compressive strength rose as the quantity of nano-alumina in the concrete raised. When calcium silicates are hydrated, calcium hydroxide is created, which reacts with the alumina (Al2O3) component. The rise in compressive strength at 7 days is greater than the increase at 28 days because of its early responsiveness.

Although it was most potent in samples with only ceramic waste powder, the cementitious effect of nano-Al_2O_3 on compression resistance was discovered in older samples. The concrete which has both ceramic waste powder and nano-Al2O3 (Specimens C15N0.5, C15N1, C20N0.5 and C20N1) has little higher compared to control concrete (Specimens C0N0). The ceramic waste powder and nano-Al2O3 are positively influence the properties of the concrete, when they are added together. Because they balance one another out, the inclusion of nano-Al2O3 improves electrolytes release and crystalline growth in CH and C-S-H while decreasing the harmful effects of silica and aluminum chloride were separated from the ceramic waste. As a result, nano-Al_2O_3 boosts the cement's hydration reaction and produces more hydrated crystals.

Table 8. Compressive strength

Specimen	Average Compressive Strength (Mpa)		Variations in compressive strength (%)	
	7 Days	28 Days	7 Days	28 Days
C0N0	29.85	40.72	0	0
C0N0.5	33.27	45.6	11.46	11.98
C0N1	34.7	46.93	16.25	15.25
C15N0	25.97	37.12	-12.99	-8.84
C20N0	23.93	34.29	-19.83	-15.79
C15N0.5	30.86	41.98	3.38	3.09
C15N1	33.18	44.44	11.15	9.14
C20N0.5	28.29	39.62	-5.23	-2.7
C20N1	30.08	42.13	0.77	3.46

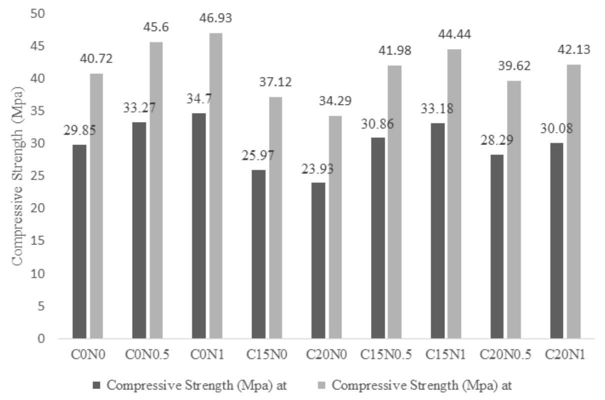


Figure 1. Compressive strength of specimens

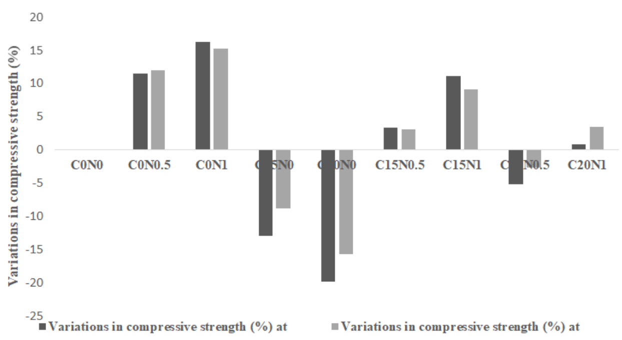


Figure 2. Variations in compressive strength

5.2. Water absorption Test

Table 9 displays the water soaking up (%) for each specimen. Figure 3 shows that concrete with nano-Al2O3 added (Specimens C0N0.5 and C0N1) absorbs water substantially less than control concrete (Specimen C0N0). The small nano-Al2O3 functions as a filler to expand its density, filling the in-between areas inside the hard microstructure of concrete's skeleton, which is the principal factor behind the decline in moisture absorption. The pozzolanic effect, which occurs when nano-Al2O3 combines with calcium hydrate created by the hydration of calcium silicate inside the cement to improve the bonding strength, is the secondary cause. This action raises compressive strength and lowers the capacity of the concrete to absorb water. The addition of ceramic waste powder to concrete (Specimens C15N0 and C20N0) also gives less water absorption than control concrete (Specimen C0N0). Due to the capacity to absorb water, ceramic waste powder is less compared to cement particles and ceramic waste powder mostly consists of crystalline particles. The concrete which has both nano-Al_2O_3 and ceramic waste powder (Specimens C15N0.5, C15N1, C20N0.5 and C20N1) has very lower water absorption compared to specimens C0N0, C0N0.5, C0N1, C15N0, and C20N0.

Table 9. Water absorption

Specimen	C0N0	C0N0.5	C0N1	C15N0	C20N0	C15N0.5	C15N1	C20N0.5	C20N1
Water absorption (%)	5.95	5.33	5.03	5.41	5.16	5.17	4.83	4.97	4.77

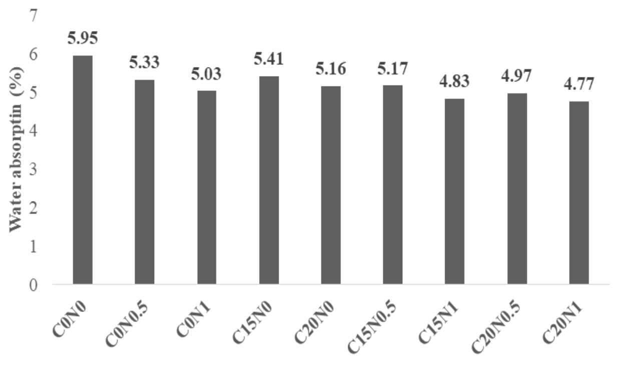


Figure 3. Water absorption of specimens

5.3. Acid attack test

In this test, the weight and strength loss of the concrete are investigated. Hydrochloric acid (HCL) is used for the acid attack test because it not only affects the concrete's strength and endurance but also occurs naturally. The high alkalinity of Portland cement causes the corrosive assault on the concrete. Damage to the concrete starts at the surface and progresses inwards (Obilade, 2018; Vedaiyan and Balajee, 2022; Rashed *et al*. 2022; Mir and Shrivastava, 2022; Yusuf *et al*. 2019; Shanmugam *et al*. 2020). Acids attack concrete by dissolving cement mixtures The chemical reaction yields calcium compounds that are water-soluble, which are then seeped away, leaving the aggregate. For this test, we immerse the concrete cube specimens in 5% concentration of HCl solution. Generally, after the acid attack test the concrete cube strength and weight are going to be reduced in such a way that concrete cubes which are immersed in the acid solution for more days will exhibit additional loss than the strength loss and weight loss values of cubes which are in the acid solution for less time, whereas the strength and weight values are gained for concrete cubes with the increase of age when they aren't immersed in 5% HCl solution. So therefore these weights and flexural capacities values after the acid attack test for 7 & 28 days were compared with the weights and compressive strengths of concrete cubes which aren't immersed in acid solution, at their corresponding ages. So from the difference in weight loss and strength loss values among concrete cubes created with nano-alumina and ceramic waste powder to determine which concrete specimen has better durability. Tables 10 and 11 respectively demonstrate the weight loss and flexural capacities reduction of the samples.

In Figures 4 and 5, it indicate that the concrete which contains ceramic waste (Specimens C15N0 and C20N0) shows less weight loss and strength loss compared to control concrete. Because ceramic waste powder contains alumina and silicon carbide materials are particularly highly resistant to chemicals, but they only resist to a certain degree (Kewalramani and Syed, 2018). Concrete specimens C0N0.5 and C0N1 that include nano-alumina exhibit significantly less weight loss and strength loss than concrete specimens C15N0 and C20N0. Al_2O_3, often known as aluminium oxide or alumina, comprises oxide ions and interacts with acids in a manner similar to that of sodium or magnesium oxides. Aluminum oxide reacts with hot dilute hydrochloric acid to give an aluminum chloride solution. But the alumina (Al_2O_3) is poorly dissolved in HCl.

Table 10. Weight loss

Specimen	Initial Weight (Kg)		Weight at refined age (Kg)		Weight loss (%)	
	7 days	28 days	7 days	28 days	7 days	28 days
C0N0	7.982	8.123	7.934	7.925	0.60	2.44
C0N0.5	7.722	8.039	7.698	7.903	0.31	1.69
C0N1	7.843	7.958	7.821	7.836	0.28	1.53
C15N0	8.046	8.172	8.018	7.987	0.35	2.26
C20N0	8.113	8.042	8.085	7.866	0.35	2.19
C15N0.5	7.957	7.926	7.934	7.803	0.29	1.55
C15N1	8.071	7.773	8.042	7.672	0.36	1.30
C20N0.5	7.836	8.082	7.816	7.967	0.26	1.42
C20N1	8.065	8.031	8.043	7.940	0.27	1.13

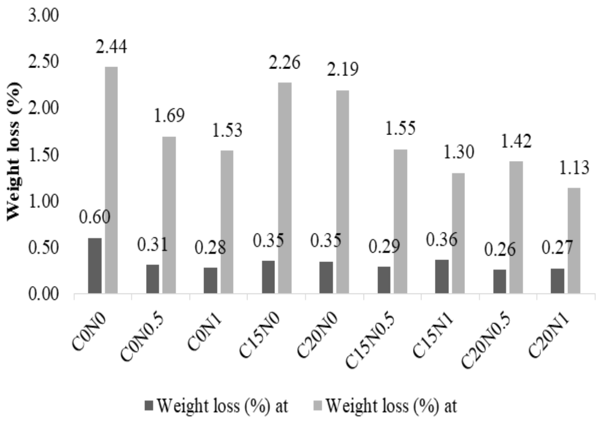


Figure 4. Weight loss of specimens

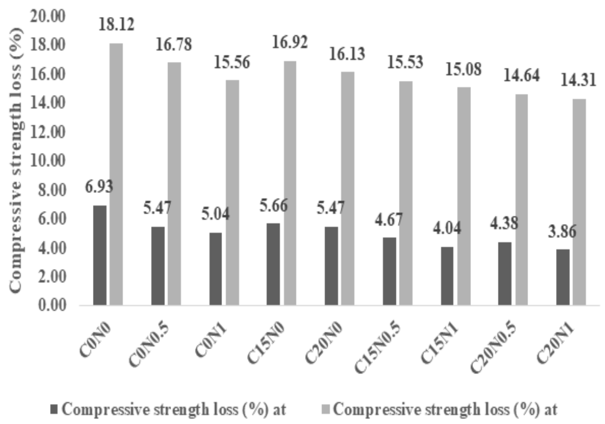


Figure 5. Compressive strength loss of specimens

Table 11. Compressive strength loss

Specimen	Compressive Strength (Mpa)		Compressive Strength at refined age (Mpa)		Compressive strength loss (%)	
	7 days	28 days	7 days	28 days	7 days	28 days
C0N0	29.85	40.72	27.78	33.34	6.93	18.12
C0N0.5	33.27	44.88	31.45	37.35	5.47	16.78
C0N1	34.7	46.72	32.95	39.45	5.04	15.56
C15N0	25.97	37.12	24.50	30.84	5.66	16.92
C20N0	23.93	34.29	22.62	28.76	5.47	16.13
C15N0.5	30.86	41.98	29.42	35.46	4.67	15.53
C15N1	33.18	44.44	31.84	37.74	4.04	15.08
C20N0.5	28.29	39.62	27.05	33.82	4.38	14.64
C20N1	30.08	42.13	28.92	36.1	3.86	14.31

Alumina can be utilised as a reactor material in the Supercritical Water Oxidation (SCWO) process because it is resistant to corrosive aqueous solutions. So that’s why acid resistance is high in specimens C0N0.5 and C0N1. The concrete which contains both nano-alumina and ceramic waste powder (Specimens C15N0.5, C15N1, C20N0.5 and C20N1) shows more resistance to acid attack compared to other specimens.

6. Conclusions

The research explored the use of nano-alumina, ceramic waste powder, and combined nano-alumina and ceramic waste powder as cement substitutes. Nano-alumina was added in 0.5% and 1% proportions to the cement, while ceramic waste powder was employed in 15% and 20% quantities. From the study, the following findings may be made:

1. Especially in the first stages, specimen compressive strengths fall as ceramic waste powder content increases. These findings demonstrate that as people get older, the rate of compression strength loss slows.
2. Particularly in the early stages, the compressive strengths of specimens rise with increasing nano-alumina content.. These results show that the increase in compressive strength is reduced at an older age because most of the nano-alumina particles react with calcium hydrate at an early age so the early days are higher compared to an older age.
3. Concrete's ability to absorb water was reduced by the use of ceramic waste powder, nanoalumina, or a combination of the two. The samples with 20% ceramic waste powder and 1% nano-alumina showed the biggest decline. The capacity of concrete to absorb water was significantly reduced when both ceramic waste powder and nano-alumina were used, and concrete's compressive strength was boosted.
4. In order to achieve the best results, 15% ceramic waste powder and 1% nano-alumina should be used in concrete. This is because the compressive strength of C15N1 decreased only slightly while water absorption dramatically decreased.
5. The addition of ceramic waste material increase with increasing the acid resistance. The addition of nano-alumina also increases with increasing the acid resistance.
6. It would be a suitable material for incorporation into concrete due to the very little drop in compressive strength, rise in acid resistance, and decrease in water absorption

capacity with the utilisation of ceramic waste powder (especially up to 20%).

Conflict of interest

The authors declares no conflict of interest

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