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Research Article

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The Impact of Combination of Al_2O_3 Nanoparticles with Fly Ash and Glass Powder in Concrete

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Abstract

The manufacture of cement is another source of carbon dioxide emissions. The possibility of using glass in concrete to reduce waste disposal costs is fascinating. Glass is a material that can be recycled and used continuously without changing its chemical makeup. The current study examines the impact of nano alumina (Al_2O_3) and fly ash replacing cement and glass powder replacing sand mixed and examined mechanical characteristics, microscopic examination, and non-destructive test. Nano alumina is applied in concentrations of 0.5%, 1%, 1.5%, and 2% as a part replacement for ordinary Portland cement (OPC). Fly ash replaced cement at a constant amount of 15% and glass powder at a fixed proportion of 15% for sand. The findings showed that it achieves its maximum strength at a nano alumina substitution rate of 1.5%.

Keywords

Mechanical properties, Fresh state test, Scanning electron microscope, Glass powder, Nano alumina, Fly ash

Introduction

Cement production is a root cause of CO_2 emissions. CO_2 and other greenhouse gases harm the ecosystem and increase global warming. To avoid the negative consequences of concrete assembly on the environment, new concrete binders must be developed. Significant research is being conducted to replace cement using various waste items and manufacturing leftovers [1]. Because of this, nanoparticles are now well known and used in many different architectural applications, particularly those that call for cement-based materials [2]. Concrete may encounter an alkali-silica reaction when using coarse glass or glass fiber since glass is alkali-sensitive, which could have negative effects. The stability of concrete can be significantly harmed by silicate reaction if appropriate steps are not applied to reduce its effects. Alkali silica reaction can be avoided by incorporating mineral admixtures into the concrete mixture [1]. Mineral admixtures like silica fume, pulverized fuel ash and metakaolin are routinely used to achieve this. Numerous studies have shown that these materials can lessen the alkali silica response. Concrete can weigh less, as is widely known, if the aggregate contains a significant amount of broken glass [1].

Fly ash and other nanoparticles are among the modifications used in recent years. Fly ash, a leftover of manufacturing operations, raises questions about sustainability when utilized in significant amounts in concrete. The pozzolanic activity of fly ash is caused because of containing of alumina and silica. Calcium silicate hydrate (CSH) is the end product of these blends' reactions with calcium hydroxide during hydration. These components efficiently boost the concrete's resistance to dangerous processes like alkali silica reaction and sulphate assault by creating a structure that is stronger, denser and less permeable. In practice, fly ash can only replace 15% (roughly) of the overall weight of cement [2].

The effects of nano alumina on the non-destructive tests, mechanical properties and microscopic structure of ternary mixed concrete have been studied. The main ingredient of a pozzolan is alumina, which can be amorphous or glassy. Hydrated calcium aluminates produce calcium hydroxide, which reacts with this substance. The rate of the pozzolanic reaction is directly correlated with the responsive surface area [3, 4].

In the concrete business, attempts have been made to partly replace cement with other waste material [5, 6]. In this investigation, some of the sand and cement were replaced with nano alumina, fly ash and waste glass powder in fuse with regular concrete. And its mechanical, microscopic, fresh condition, and non-destructive test properties were examined.

Materials and Method

Concrete composition

The mix ratio (i.e., 1:1.24:2.20) was created using IS: 10262-2019 to create a mix design (M30). In this experiment, six different mixes were created, as indicated in table 1. The main outcome of this inquiry is to ascertain how the physical properties and microscopic structure of concrete would change when cement and sand are replaced with fly ash, glass powder and nano alumina. Replacing sand at a constant of 15% by glass powder and fly ash replaces cement to a constant extent of 15%, and nano alumina substitutes cement to constant extents of 0.5%, 1%, 1.5%, and 2%. Numerous practical tests and material studies are conducted to assess the quality of concrete. The substance shouldn't be hazardous or present in concentrations that would affect the strength or caliber of the concrete.

Cement

The cement utilized in the current experiment is OPC grade 43 (Table 2), which was purchased from a nearby retailer and tested in accordance with IS:18112.

Fly ash

To be able to boost resistance to alkali-aggregate expansion, heat cracking and sulphate attack and to enable minimization in cement, mineral admixtures like fly ash are frequently used in increasing quantities to concrete. The current experiment used class F-fly ash. The specific gravity is 2.135.

Glass powder

Glass powder was imported from a bazaar in Kolkata for use in this study. Without losing any of its quality, glass can be recycled, making it a technically recyclable material. The size of the waste glass powder used is 100 microns.

Nano alumina

Properties in table 3.

Coarse aggregate

The proportion of coarse particles in the total volume of concrete ranges from 70 to 80 percent. Because of this, it is true that our concrete's actual shape is provided by the coarse aggregates. Strong muscles are largely developed by coarse particles. Many tests were conducted. According to IS 383-1970, the values obtained for specific gravity and fineness modulus were 2.71 and 5.89, respectively.

Fine aggregate

Sand continues to hold a special relevance in the formulation of concrete mix. It was determined that the sand used in this project is zone II sand because it was completed in Punjab, which is in zone II. Sieve evaluation also supported this. Tests were performed on the fine aggregate in line with IS 383-1970. Outcomes in table 4.

Methodology

Physical property test

For its strong compression strength and low-tension fragility, concrete is well known. As a result, according to IS: 516-2021. As defined by the ISI, the compression strength is the amount of the force necessary to cause a standard sample to break in uniaxial compression at a particular rate of force, such as a 150 mm cube. The specimen size for the compression strength test is 150 mm x 150 mm x 150 mm.

Flexural testing in accordance with ASTM D790 is utilized to estimate how much force is necessary to break a beam

Table 1: Types of mix.

Sample	Cement (%)	Fine aggregate (%)
NA0FA0GP0	100	100
NA0FA15GP15	15 FA + 85 OPC	15 GP + 85 Sand
NA0.5FA15GP15	0.5 NA+ 15 FA + 84.5 OPC	15 GP + 85 Sand
NA1FA15GP15	1 NA + 15 FA + 84 OPC	15 GP + 85 Sand
NA1.5FA15GP15	1.5 NA + 15 FA + 83.5 OPC	15 GP + 85 Sand
NA2FA15GP15	2 NA + 15 FA + 83 OPC	15 GP + 85 Sand

Table 2: Properties of cement.

Specific gravity	3.2
Standard consistency	28.5%
Initial setting time	30 min
Final setting time	9 h

Table 3: Properties of nano alumina.

Average size	20 - 400 nm
purity	99.5%
SSA	120 - 140 m^2/g
Morphology	Spherical
Color	White
Density	3.98 g/cm
Thermal conductivity	40 (W/mK)

Table 4: Outcomes.

Physical properties	Values obtained	IS acceptance IS 383-1970
Fineness modulus	2.62	Ok
Water absorption	0.87	Ok
Specific gravity	2.46	Ok

under three-point loading conditions. The flexural modulus of a material gauges its rigidity when bent. The force from the loading nose is applied to the core of the 10 x 10 x 50 cm hardened concrete sample, forcing the three points to deform till failure at a predetermined rate. Two spans that are 40 cm distant support the specimen.

Testing for splitting tensile is done on specimens that are 300 mm in height and 150 mm in diameter. The specimen was spread out horizontally after it had finished curing and dried before a load was given radially over its surface, which causes the sample to break along its diameter. When the highest applied force is divided by the relevant geometrical elements, the strength is achieved. ASTM C496 served as the basis for the creation of this method [7].

Microstructure

Scanning electron microscope (SEM), is used to view the concrete at a microscopic level [8].

Water absorption

Firstly, for the water absorption test, the samples are dried at a specific duration and temperature and then they are cooled. As soon as the specimens have cooled, they are weighed. After that, the chemical is placed in the water until equilibrium is reached at the chosen temperature, typically 23 °C [9].

UPV test

UPV (Ultrasonic pulse velocity) testing, a non-destructive *in-situ* technique, is used to evaluate the state of natural and concrete materials. This test gauges the strength of concrete by measuring the speed of an ultrasonic pulse as it travels through a concrete building. An ultrasonic pulse is delivered to the concrete under test, and the time it takes for the pulse to exit the building is then recorded [10].

Workability

According to IS: 1199-1959, the slump test is done to determine the state of fresh concrete. The qualities of the component materials, water-cement ratio, mixing technique, dose, usage of admixtures, and other factors all have an impact on the concrete slump value [11].

Fly ash and glass powder fixing

Compressive tests were performed using glass powder in place of sand and fly ash in place of cement. Figure 1 demonstrates that for both fly ash and glass powder, the greatest strength was attained at a dosage of 15%. It begins to gain strength up to 15%, which is 39 MPa at 56 days, and then starts to lose strength after 20% substitution when glass powder and fly ash are added at an equal percentage. As a result, it is set at 15% for both fly ash and glass powder [12].

Results and Discussion

Compressive strength

Mixed with nano Al_2O_3 displayed much higher compression strengths than normal mix (Figure 2). The mix containing only glass powder and fly ash is 39.4 MPa, whereas the mix including 1.5% nano Al_2O_3 rose to 46.3 MPa, in contrast to the typical mix's compression strength of 38.2 MPa after 56 days. Numerous investigations that indicated adding nanoparticles to concrete strengthened it validated the results, which were congruent with those of compression strength. However, after 2% of the nanoparticle addition, the mix's strength began to deteriorate. At 56 days, the compressive strengths of 2% nano Al_2O_3 dropped to 43.22 MPa.

Flexural strength

The flexural strength of mix incorporating nano Al_2O_3 was significantly higher than that of regular mix (Figure 3). The mix containing only glass powder and fly ash is 4.9

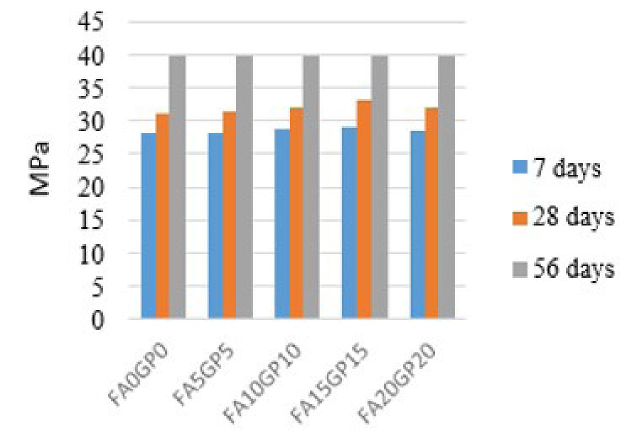

Figure 1: Compressive strength of combination of glass powder and fly ash.

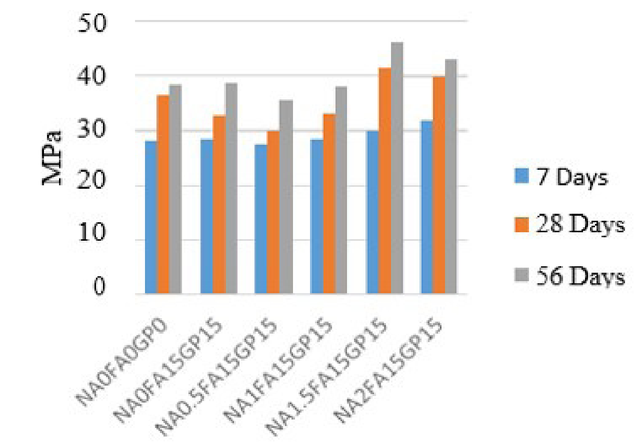

Figure 2: Compressive strength.

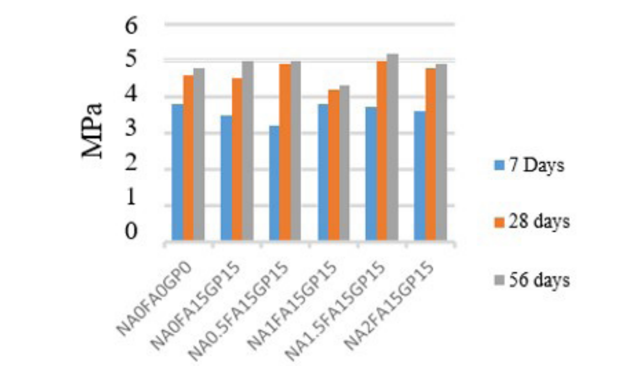

Figure 3: Flexural strength.

MPa, whereas the mix with 1.5% nano Al_2O_3 increased to 5.2 MPa from the usual mix's strength of 4.81 MPa after 56 days. The results were in line with those of the strength and were corroborated by other investigations that discovered that inserting nanoparticles into concrete made it stronger. However, after 2% of the nanoparticle addition, the mix's strength began to deteriorate. Flexural strengths of 2% nano Al_2O_3 fell to 4.9 MPa after 56 days.

Splitting tensile strength

The splitting tensile strengths of mix having nano Al_2O_3 were significantly higher than those of regular mix (Figure 4). After 56 days, the strength of the glass powder and fly ash-only mix was 3.93 MPa, while the mix including 1.5% nano Al_2O_3 increased to 4.33 MPa, in contrast to the regular mix's 4.06 MPa strength. The results were in line with those of the strength and were corroborated by numerous investigations that discovered strengthening concrete by adding nanoparticles. However, after 2% of the nanoparticle addition, the mix's strength began to deteriorate. The splitting tensile strengths of 2% nano Al_2O_3 dropped to 4.13 MPa after 56 days.

UPV test

UPV test with different nano alumina concentrations is shown in figure 5. It is clear that the inclusion of nano alumina elevates the ultrasonic pulse velocity rating from good to exceptional in accordance with IS 13311 part 1:1992. These tests are widely used to make quality predictions about specimens without actually damaging them. This study found that the addition of nano alumina significantly increased UPV, indicating an improvement in the concrete's quality. Additionally, the compressive strength increases in comparison to other mixes as we get greater velocity at 1.5% nano alumina substitution. Higher velocities signify greater continuity and quality, whereas slower velocity may suggest concrete with numerous voids and fractures.

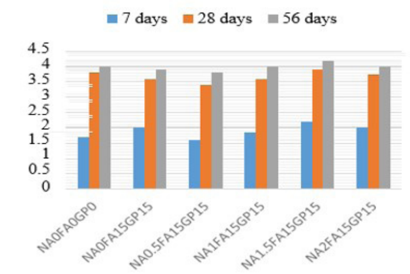

Figure 4: Splitting tensile strength.

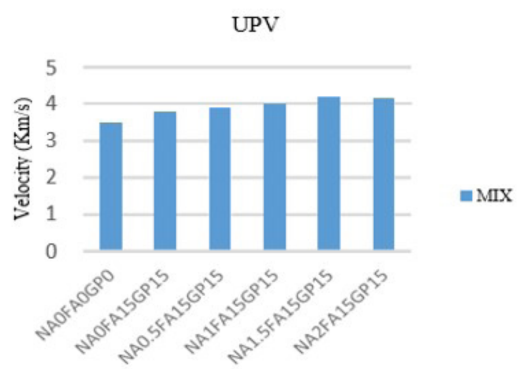

Figure 5: UPV.

Water absorption

The amount of water absorbed changes depending on the concentration of nano alumina, as seen in figure 6. It was discovered that inserting nano alumina reduces water absorption. Water absorption decreases as nano alumina concentration increases. The absorption of water is reduced by the existence of nano alumina. Both the quantity of holes in concrete and the size of mixtures to suck water are reduced. This indicates, adding nano alumina makes the mixture denser than it would be without it.

Workability

The results of slump testing for various combinations are shown in figure 7. The slump test findings for concrete with various concentrations of nano alumina reveal that the nano alumina (%) is what caused the mixes' slump values to decrease. As nano alumina concentrations have increased, workability has decreased because some of the mixing water is pulled to nano alumina. Nano alumina has a large surface area and unsaturated bonds, which cause it to attract water to its surface. As a result, the amount of water needed to increase the mixture's fluidity is significantly reduced.

SEM analysis

Samples were kept from hydrating before SEM. A sample is collected from a crushed cube that has nano-sized fly ash, glass powder, and Al_2O_3 that has cured for 56 days. To create a clearer impression, it is once more crushed into a powder and covered with gold. The photos above were magnified at x1100, x2300, and x3700 after being scanned under a SEM testing machine. The particles are tightly packed and have some fissures, as seen in figure 8a. CH and CSH formation are depicted in figure 8b as a binding component, CSH increases

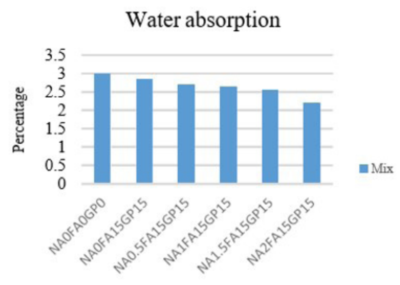

Figure 6: Water absorption.

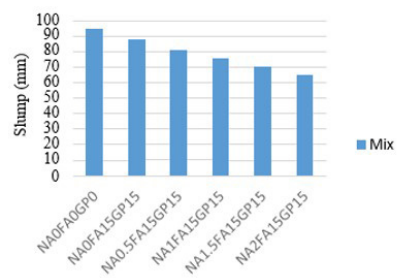

Figure 7: Slump test.

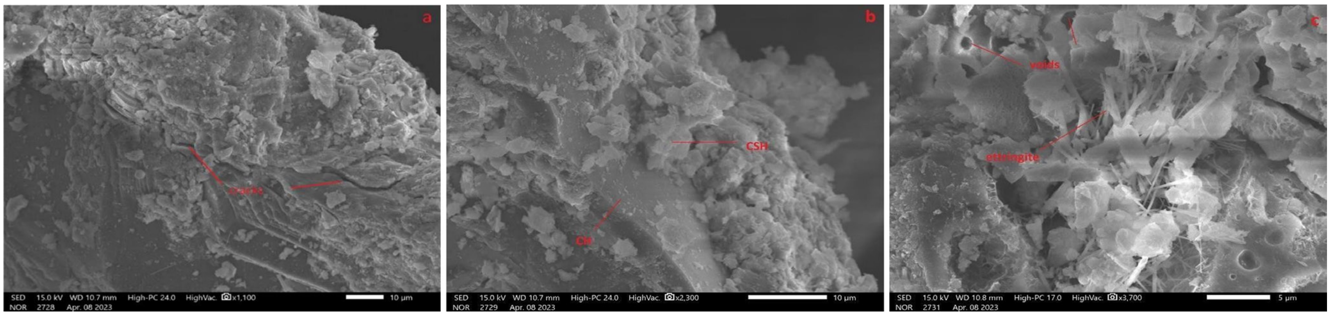

Figure 8: SEM showing **(a)** cracks, **(b)** CH and CSH, and **(c)** Voids and ettringite.

the concrete's strength. Ettringite and voids are visible in figure 8c. The AFt phase ettringite occurs quickly in cement that contains fly ash or natural pozzolanas. Ettringite has been detected in cement having natural pozzolana for up to a year and cement having fly ash for 6 h to 28 days. Ettringite can disappear after three days by converting to monosulfate. Fly ashes with low SO_3 levels demonstrated conversion, however fly ashes with high SO_3 levels did not. It aids with environmental control.

Conclusions

These conclusions could be drawn from the study's results:

- According to the results, concrete's strengths were somewhat boosted when 15% fly ash and 15% glass powder were added as partly replacements for sand and OPC, respectively.
- The trials' findings strengths rise when a maximum of 1.5% nano alumina is added.
- However, after 2% of the nanoparticle addition, the paste's strength began to deteriorate.
- The addition of nano alumina significantly increased UPV, indicating that the concrete's quality had improved.
- Nano alumina is added to reduce water absorption.
- The rise in nano alumina causes a decrease in workability. Superplasticizer must be applied as a result.
- A denser matrix and more reaction product, as seen by the SEM, improved the microstructures of mix containing 1.5% nano alumina.

Acknowledgements

None.

Conflict of Interest

None.

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