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Behaviour of High Performance Ternary Blended Concrete containing Fly Ash and Nano Silica

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Abstract: High Performance Concrete (HPC) is widely used around the world for the design of tall buildings, long-distance bridges, gigantic buildings, and for the repair and expansion of existing structures. Consequently, the increasing use of high-strength concrete increases the use of Portland cement. In addition, an increase in cement consumption in the concrete industry leads to an increase in CO2 emissions, which contributes to global warming. Therefore, a significant reduction in the use of cement by replacing part of the cement with mineral additives would be beneficial for the climate. The aim of this experimental study is to identify the effect of the combined use of nano-silica (NS) and fly ash (FA) on the strength properties of concrete. Fly ash and nano-silica are used as a partial replacement for cement. In this experimental study, cement is partially replaced by 30% fly ash and nano-silica 1%, 2%, 3% and 4% by weight. The effect of the combined use of fly ash and nano-silica on the compressive strength, split tensile strength, flexural strength, water absorption and acid resistance of concrete with high performance characteristics (grade M60) is investigated. The test results of HPC concrete prepared using a combination of different proportions of fly ash and nano-silica are compared with test results for controlled concrete.

***Index Terms* - Nano Silica, Fly ash, High Performance Concrete**

I. INTRODUCTION

Concrete can be considered as the most widely used product in the construction industry. Concrete has been commonly used in structures such as schools, highway bridges, and airport terminals. The mechanical and durability properties of concrete have a similar meaning in the modern construction experience. Cement is the most commonly found product in concrete. Therefore, the consumption of cement increases. This absorbs a significant amount of energy in the manufacture of cement, which produces carbon dioxide, which produces emissions into the atmosphere. Consequently, the solution to this problem is to reduce the use of cement and use Pozzalanic products for the preparation of concrete. Previous studies indicates that the use of Fly-Ash (FA), Micro Silica (MS) and Ground Granulated Blast Furnace Slag (GGBS) as partial replacement of cement that reduces the consumption of cement and also increases the strength and durability of concrete. For further improvement of concrete properties Nano materials are currently used as supplementary materials. Recent advances in nanotechnology and the use of nano silica have allowed the use of concrete materials. Any type of mineral admixtures in concrete can be used with combination of Nano silica. According to the American Institute of Concrete, high-strength concrete (HPC) is classified as concrete that meets certain criteria of consistency and uniformity, which usually cannot be achieved only with traditional materials and standard methods of mixing, laying and curing. HPC is currently used in airports and on road surfaces, in underwater buildings, concrete prestressed bridges, nuclear containers and vehicle frames. Over the past three decades, the popularity of HPC has increased. HPC power ranges from 60 to 99 MPa. The water / cement ratio required for standard strength concrete is between 0.30 and 0.50. With high-strength concrete, a ratio of 0.30 to 0.45 water / cement is required. Initially, high-strength concrete (HSC) was considered good performance, but later realized that quality is not the only significant parameter of HPC. High-strength concrete differs in strength from ordinary concrete. Improving the quality of concrete will reduce the cost of maintenance and repair, as well as environmental impact. The use of high-strength concrete can also reduce the volume of reinforced steel. Supplementary cementitious materials (SCM), such as fly ash, silica fume, granulated blast furnace slag, metakaoline, rice husk ash, etc., are applied to concrete to improve the strength and solid-state properties of HPC. One of the key areas of research in the field of concrete production is the use of supplementary cementitious materials for the production of high-strength concrete. The use of chemical admixtures is important to maintain the performance of the HPC in concrete containing mineral admixtures. The main aspect that affects the properties of concrete is the careful use of the ingredients and their application. Many of the studied mineral admixtures are micron in size and cover cement pores. The aim of this experimental study is to identify the effect of the combined use of nano-silica (NS) and fly ash (FA) on the strength properties of concrete. Fly ash and nano-silica are used as a partial replacement for cement. In this experimental study, cement is partially replaced by 30% fly ash and nano-silica 1%, 2%, 3% and 4% by weight.

I. MATERIALS

Cement used in this study is 53 grade ordinary Portland cement conforming to IS 12269:1987 with specific gravity of 3.14, Initial and final setting time of 45 min and 30 min, consistency of 30% and finess modulus of 6.5%. Locally available river sand with specific gravity of 2.61 with max size of 4.7 mm and locally available crushed stone with specific gravity of 2.9 with maximum size of 12.5 mm were used as fine and coarse aggregates in concrete. Fly ash, the waste material of fine particulate and is the product of the pulverized coal-based thermal power station, is an environmental pollutant, it has the potential to be a resource material. The class F fly ash was used in this project to replace cement in concrete and it is acquired from thermal power station near Vijayawada with specific gravity of 2.4. The nano silica use in the investigation is in collodial form. It is acquired form beechems pvt. Ltd, Kanpur with colour White, Specific gravity 1.40, Particle size 40nm, Purity 99.5%.Glenium SKY 8233 is a new generation admixture based on modified polycarboxylic ether was used as Superplastizer. Water available in our campus was used in the investigation.

II. MIXING AND CASTING OF SPECIMENS

Initially, the materials are to be keeping it ready to avoid setting of the concrete. The fine aggregate passing through 4.75mm is sieved and the coarse aggregate of the maximum size of 12.5 mm is sieved and taken in the required quantity. Thus, all the required materials are to be arranged to the required quantity according to the mix design. For mixing of the control concrete, Cement, Fine aggregate, Coarse aggregate are to be dry mixed with the hand for about 3 minutes. Half of the water mixed with half of volume super plasticizers are to be shinked in that mix. After a minute, the remaining super plasticizer and water were added and thoroughly mixed for about ten minutes to gain the uniform consistency. A Vibrating table was used for the consolidation process and after that the mix were placed in the moulds for casting. For blended concrete, initially cement, Fly Ash and Nano Silica are to be mixed well in order to mix it with cement evenly. Then, fine aggregate is to be added followed by the coarse aggregate are to be dry mixed with the hand for about 3 minutes. Then the half volume of the water is to be mingled with half volume super plasticizers are then added to the batch mixer. After a minute, remaining super plasticizer and water was added and thoroughly grinded for about ten minutes in the mixer to obtain uniform consistency. Before placing the concrete in the cubes, the mould plates must be removed cleaned properly and all bolts must be completely tightened. Then apply a thin layer of oil on all sides of the mould. It is important that the side faces of the cube are parallel. The concrete sample will be filled in cubic moulds in 3 layers, each layer about 5 cm deep. Each layer must be compacted by hand or by vibration. Each layer of concrete filled in the mould must be compacted with not less than 35 strokes with the tampered bar. The strokes should penetrate the underlying layer and the lower layer should be surrounded along its depth. Where voids are left by the tampered bar, the sides of the mould must be struck to close the empty spaces. For the consolidation process, a vibrating table was used and then the mixture was placed in the casting moulds. After casting of the specimen, it is allowed to leave for one day to set. Then, the specimens are demoulded and kept it in the curing tank for curing. They specimens must be immersed in clean water at a temperature 24^0C to 30^0C till 7, 28 and 90 days age of testing. The cubes must be tested in the condition of saturation and dryness of the surface and must be kept outside one day before the testing.

III. MIX DESIGN

M60 Grade of concrete mix design was arrived at according to IS 10262-2009. The mix proportion arrived at for the experiments are shown in Table 1.

Table 1: Mix Proportion

Materials	Cement kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	Water kg/m^3
Quantity	445.72	747.9999	1092.8865	156

Mix Proportion =1: 1.68: 2.45 with water cement ratio (w/c) of 0.3.

IV. RESULTS AND DISCUSSION

5.1 Workability

The workability of concrete is the flexibility, with which concrete is mixed, transported, laid and compacted with minimal loss of homogeneity, and is strongly influenced by the water requirement when the concrete is mixed. Concrete water requirements depend on the properties of the aggregates and additives used. Water demand decreases with decreasing aggregate size, which, in fact, is a key need for large grades of concrete. The physical properties of mineral additives that are applied to concrete significantly affect the water demand and process ability of the concrete mixture. Superplasticizer is usually applied to concrete, which contains admixtures to maintain the workability within the desirable range.

Comparative analysis of the amount of superplasticizer applied to a very low amount of nanosilica means that with the addition of nanosilica, the water demand for concrete becomes higher. This is due to the fact that, due to the high specific surface area of nanosilica, an increase in the nanosilica content decreases the volume of water present in the mixture and its constancy. Therefore, an increase in the amount of mineral additives reduces the workability of concrete with a constant ratio of water to binder. Due to their high specific surface area and high reactivity, water molecules are easily attacked by silica particles. The volume of free water required to increase the fluidity of the mixture is greatly reduced. Thus, it has been observed that the viscosity of the mixture improves as concrete containing nanosilica reduces its workability.

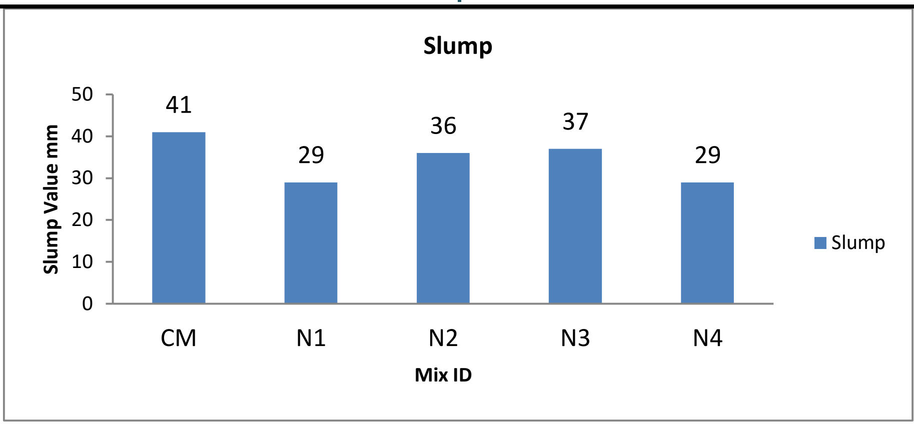

Figure 1: Graphical representation of Slump Cone

5.2 Compressive strength

At 7, 28 and 90 days strength of the 150 x150 x150 mm concrete specimen of each mixture at respective curing age are tested in the Compressive Testing Machine. For each mixture, three specimens are casted and the average value of the Compressive Strength is plotted in the graph given below.

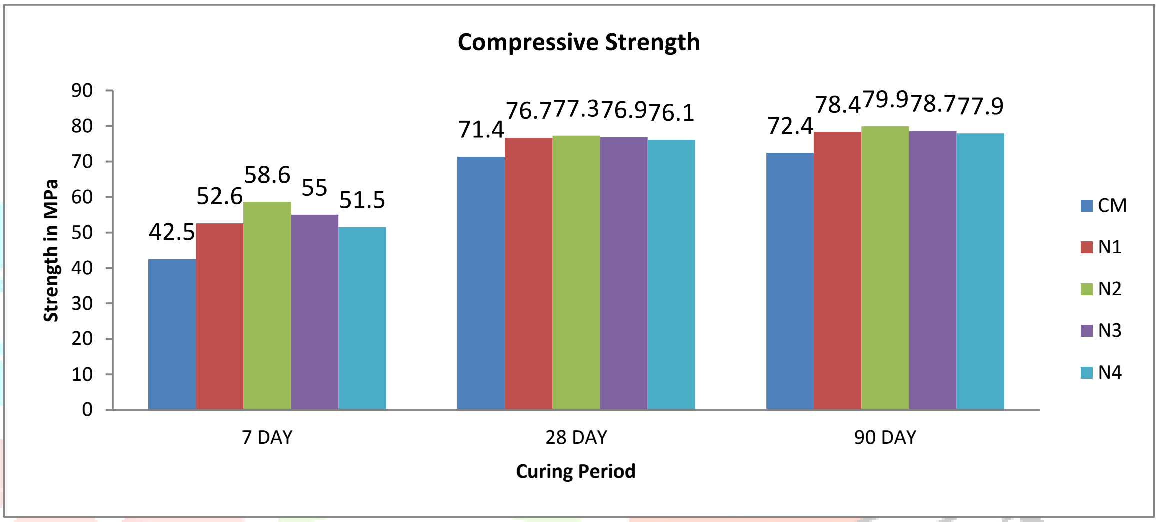

Figure 2: Graphical representation of compressive strength for 7, 28and 90 days.

The result shows that the HPC cubes are made of combination of Fly ash and nano silica achieves a compressive strength of 21.17% to 37.88% at the age of 7 days, a compressive strength of 6.58% to 8.26% at the age of 28 days, and a compressive strength of 7.59 to 10.35 % at the age of 90 days. The early age (7 days) compressive strength of mixes N1, N2, N3 and N4 was improved by 23.76%, 37.88%, 29.41%, and 21.47% respectively, in comparison to conventional concrete mix. Similar types of results were observed at the age of 28 and 90 days. The mixes with Fly Ash and Colloidal Nano Silica, i.e N1, N2, N3 and N4 showed an improvement in compressive strength by 7.42%, 8.26%, 7.70% and 6.58% respectively with respect to the conventional concrete mix at 28 days curing period. The later age compressive strength (90 days) showed a negligible change but a slight improvement in strength with respect to 28 days compressive strength. The improvement in compressive strength is 8.28%, 10.35%, 8.70% and 7.59% respectively with respect to the conventional concrete mix at 90 days curing period. The rapid formation of the CSH gel in the presence of ultra-high reactive nano sized silica with a high filler effect is the reason for the increase in strength. The intensity begins to decrease when the Nano Silica content becomes more than 2 percent, since an insufficient amount of nano-silica causes agglomeration of particles inside the concrete. This may also be due to the high degree of use of calcium hydroxide during additional pozzolanic silicon reactions at the early age. The test results show that the maximum compressive strength is obtained for a mixture with a combination of 2% nano-silica and 30% fly ash for all ages. Thus, the optimum replacement rate for nano-silica is 2% nano-silica and 30% fly ash, respectively, as cement replacement materials. The use of fly ash and nano-silica as a replacement for cement represents a significant increase in compressive strength. Improvement in the pozzolanic response and the effect of filler, nano-silica and fly ash are the main factors behind the increased intensity. During hydration, the interaction of nano-silica and fly ash with the excess calcium hydroxide creates an additional C-S-H gel. For HPC in general, the interfacial transition zone needs to be strong, homogenous and dense to improve efficiency. This is usually accomplished by the addition of mineral admixtures that act as filler and pozzolanic content. The effect of the introduction of nano-silica has a moderate effect on strength development associated with later age, since the role of nano-silica in increasing strength is achieved at an early age. The slight improvement in strength at 90 days is may be due to the pozzolanic effect of Fly ash, it can process pozzonalic till 90 days curing period. Sample failure template for the cube sample shown in fig. 6.3 it is shown that the fracture plane is along the aggregates. It can be seen that the interfacial transition zone is stronger due to the addition of nano-silica and Fly ash. The specimen fails when the unit reaches its ultimate load; otherwise the specimen is able to withstand more loads.

5.3 Split tensile strength

The split tensile strength of the concrete on 7, 28 and 90 days curing of the concrete are tested on the Compressive testing machine. The size of the samples is 300x150 mm. The cylinders were tested using the 2000kN capacity of Compression testing machine (CTM). For each mixture, three specimens are casted and the average value of the strength is plotted in the graph given below.

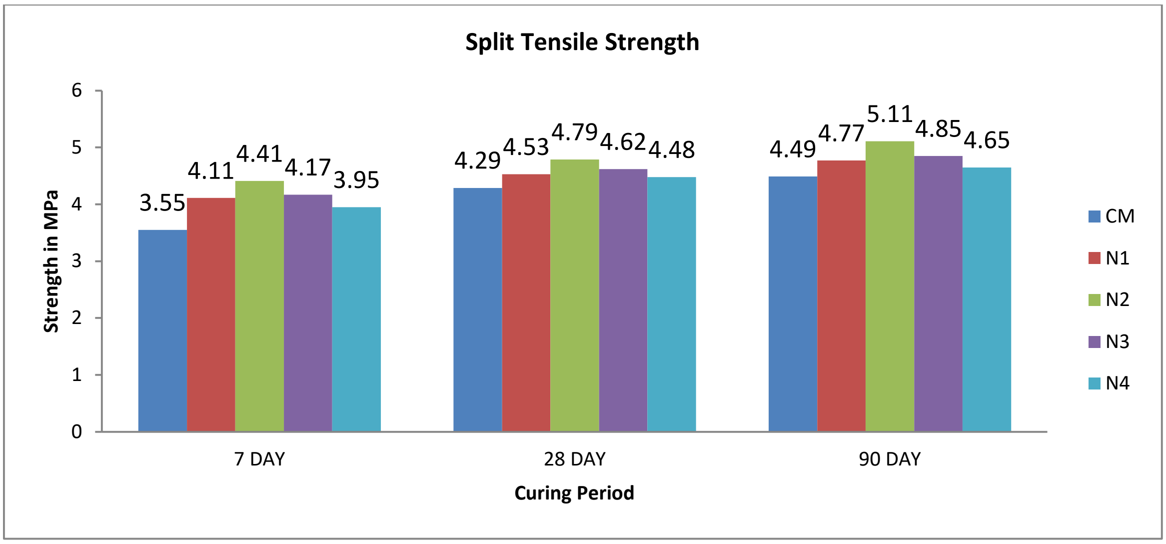

Figure 3: Graphical representation of split tensile strength for 7, 28and 90 days.

The result shows that the HPC cubes are made of combination of Fly ash and nano silica achieves a tensile strength of 11.26% to 24.22% at the age of 7 days, a tensile strength of 4.42% to11.65% at the age of 28 days, and a tensile strength of 3.56 to 13.8 % at the age of 90 days. The early age (7 days) tensile strength of mixes N1, N2, N3 and N4 was improved by 15.77%, 24.22%, 17.46%, and 11.26% respectively, in comparison to conventional concrete mix. Similar types of results were observed at the age of 28 and 90 days. The mixes with Fly Ash and Colloidal Nano Silica, i.e N1, N2, N3 and N4 showed an improvement in tensile strength 5.59%, 11.65%, 7.69% and 4.42% respectively with respect to the conventional concrete mix at 28 days curing period. The later age tensile strength (90 days) showed a negligible change but a slight improvement in strength with respect to 28 days tensile strength. The improvement in compressive strength is 6.23%, 13.80%, 8.01% and 3.56% respectively with respect to the conventional concrete mix at 90 days curing period. This improvement in tensile strength may be due to the improved properties of the concrete matrix and good interfacial bonding between binders (i.e., asphalt, fly ash and colloidal nano-silica) and the aggregates used. Interfacial zone (ITZ) plays an important role in improving tensile energy. ITZ is denser due to the use of nanoparticles, such as colloidal nano-silica, which leads to an increase in tensile strength. It was also noted that when the cement content was replaced with 2% colloidal nano-silica, the tensile strength of the ternary mixed concrete specimens improved and decreased slightly with increasing colloidal nano-silica content. The decrease in tensile strength by more than 2% of colloidal nano-silica is explained by the assumption that the volume of colloidal nanosilica particles is greater than the amount of lime formed as a result of hydration, which helps to wash out excess silica, which leads to a drop in force.

5.4 Flexural strength

The flexural strength of the concrete on 7, 28 and 90 days curing of the concrete. Flexural strength test was performed on beams with size 100x100x500mm by using the flexural testing machine of capacity 100kN. The beam is subjected to three point loading.

The result shows that the HPC cubes are made of combination of Fly ash and nano silica achieves a flexural strength of 16.58% to 33.84% at the age of 7 days, a compressive strength of 9.30% to 20.78% at the age of 28 days, and a flexural strength of 11.59 to 20.98 % at the age of 90 days. The early age (7 days) flexural strength of mixes N1, N2, N3 and N4 was improved by 19.96%, 33.84%, 25.88%, and 16.58% respectively, in comparison to conventional concrete mix. Similar types of results were observed at the age of 28 and 90 days. The mixes with Fly Ash and Colloidal Nano Silica, i.e N1, N2, N3 and N4 showed an improvement in flexural strength by 12.64%, 20.78%, 15.26% and 9.30% respectively with respect to the conventional concrete mix at 28 days curing period. The later age flexural strength (90 days) showed a negligible change but a slight improvement in strength with respect to 28 days flexural strength. The improvement in flexural strength is 13.52%, 20.98%, 16.19% and 11.54% respectively with respect to the conventional concrete mix at 90 days curing period. It was also noted that when the cement content was replaced by 2% Colloidal Nano Silica, the flexural intensity of the ternary concrete specimens improved and then decreased slightly with increasing colloidal nano-silica content. The use of fly ash and colloidal nano-silica improved strength compared to conventional concrete based on the above results. Compressive strength, tensile strength and flexural strength, however, were equal to each other.

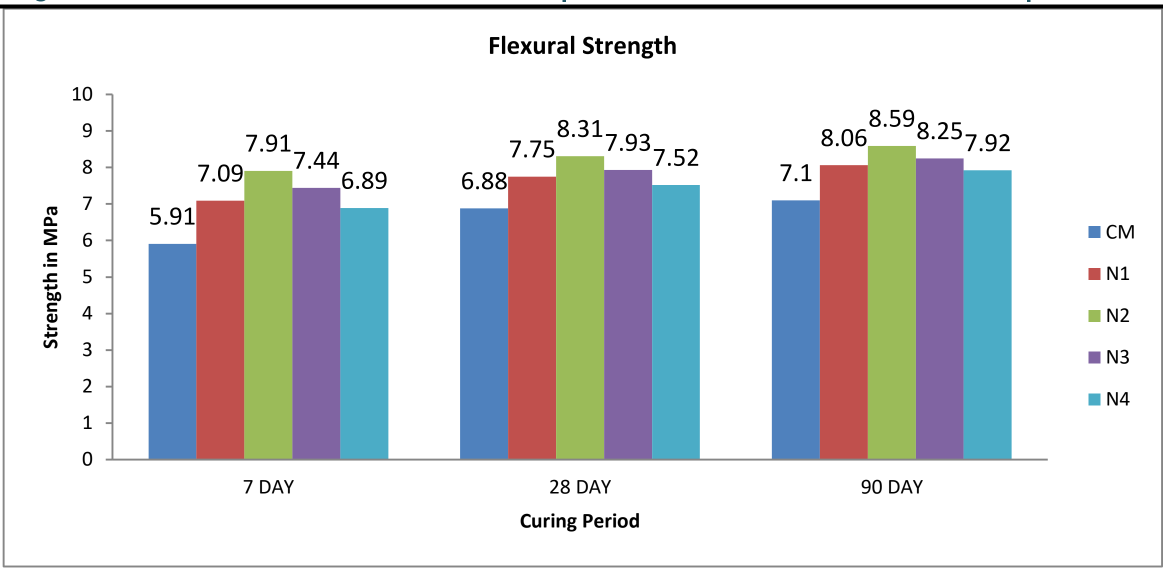

Figure 4: Graphical representation of flexural strength for 7, 28and 90 days.

5.5 Water Absorption Test

Water absorption test was done on 150x150x150 mm size cube for the ages 7, 28 and 90 days. The average amount of water penetrated into the voids is calculated.

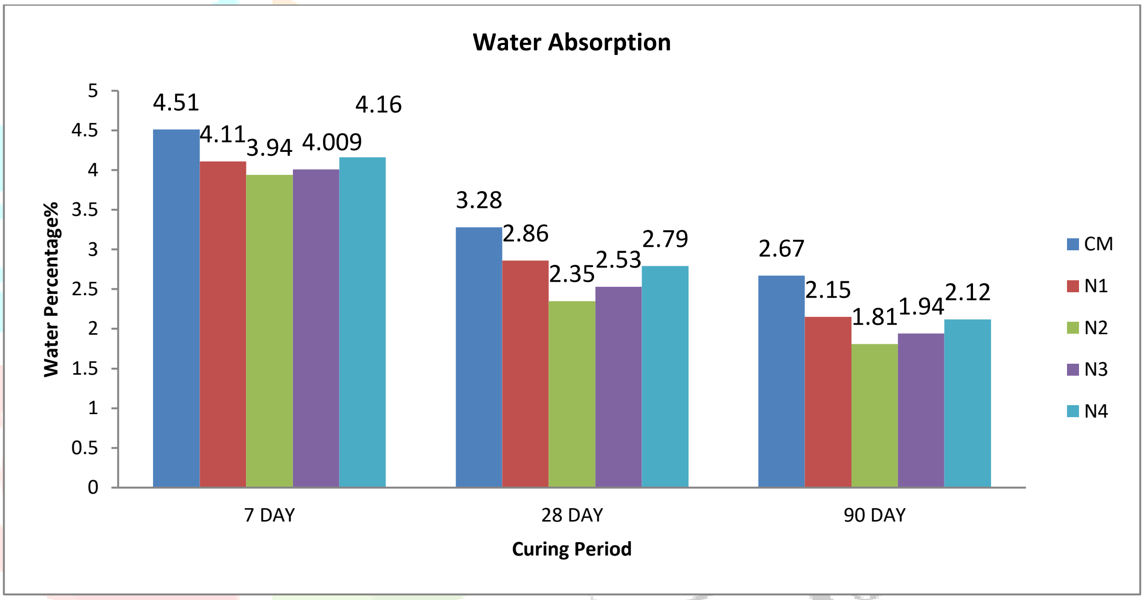

Figure 5: Graphical representation of Water Absorption Test for 7, 28 and 90 days.

It is clear from the results that ternary concrete mixes made with colloidal nano-silica exhibited a lower percentage of water absorption than conventional concrete mixes. The percentage of water absorption at an early age (7 day) was 4.11%, 3.94%, 4.009% and 4.16%, respectively, for mixtures N1, N2, N3 and N4 where as for conventional concrete it was 4.51%. Similar types of results were observed at the age of 28 and 90 days. Mixtures with nano-silica and fly ash, i.e., N1, N2, and N3, showed the percentage of water absorption by 2.86%, 2.35%, 2.53%, and 2.79%, respectively, within 28 days where as for conventional concrete it was 3.28% and 90 days of water absorption showed a percentage of 2.15%, 1.81%, 1.94% and 2.12%, respectively, for mixtures N1, N2, N3 and N4, where as for conventional concrete it was 2.67%. The low percentage of water absorption has led to the fact that fly ash and colloidal nano-silica can have a stronger pozzolanic effect due to their micro- and nano-sized particles in ternary concrete mixtures, making concrete denser, denser and, thus, increasing the concrete porous structure. Which helped to reduce the percentage of water absorption? The decrease in the percentage of water absorption when replacing colloidal nano-silica by more than 2% is explained by the fact that the amount of colloidal nano-silica particles is higher than the amount of lime released during hydration, which leads to excessive washing of silicon dioxide, which has an effect on the structure of concrete pores, which leads to a slightly higher water content.

5.6 Acid Attack Test

Acid attack test was done on 150x150x150 mm size cube for the ages 7, 28 and 90 days. The average amount of acid resistance was calculated.

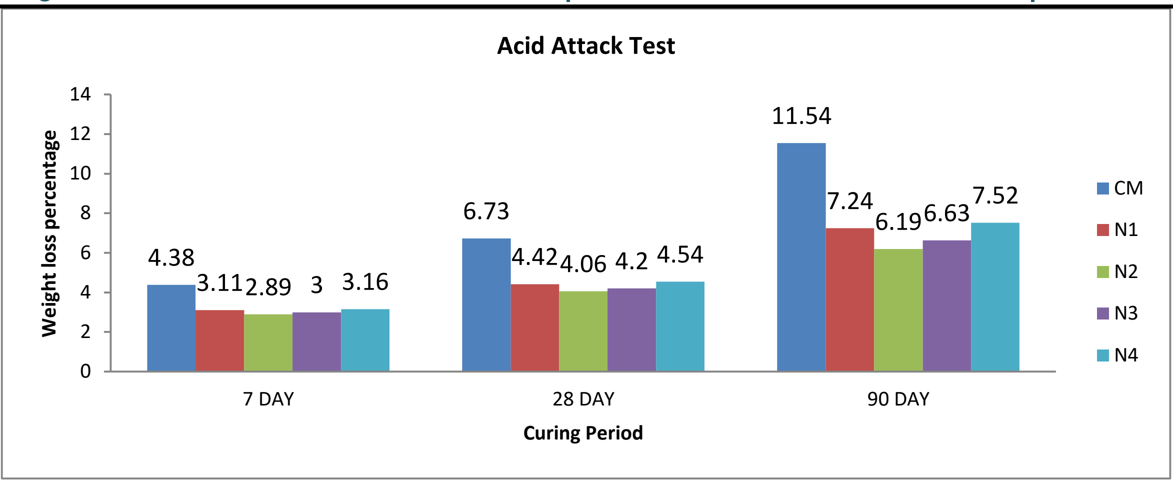

Figure 7: Graphical representation of acid attack test for 7, 28 and 90 days.

It is clear from the results that ternary concrete mixes made with colloidal nano-silica exhibited a low weight percentage than conventional concrete mix. The percentage of weight loss at an early age (7 day) was 3.11%, 2.89%, 3% and 3.16%, respectively, for mixtures N1, N2, N3 and N4 where as for conventional concrete it was 4.38%. Similar types of results were observed at the age of 28 and 90 days. Mixtures with nano-silica and fly ash, i.e., N1, N2, and N3, showed the weight loss percentage was 4.42%, 4.06%, 4.2%, and 4.54%, respectively, within 28 days where as for conventional concrete it was 6.73% and 90 days of Acid attack showed a weight loss percentage of 7.24%, 6.19%, 6.63% and 7.52%, respectively, for mixtures N1, N2, N3 and N4, where as for conventional concrete it was 11.54%. It was also noted that when the cement content was replaced by 2% Colloidal Nano Silica, the acid resistance of the ternary concrete specimens improved and then decreased slightly with increasing colloidal nano-silica content. The use of fly ash and colloidal nano-silica improved the acid resistance compared to conventional concrete based on the above results.

V. Conclusion

Experimental tests show that a mixture of fly ash and nano-silica can be used as a replacement for concrete in Portland cement.

1. Using the test results, we can conclude that the strength and durability properties of concrete improve with combination of 30% fly ash and 2% nano-silica and the further growth of strength and durability tends to decrease with an increase in the percentage of nano-silica.
2. It is also interesting to note that the improvement in compressive strength, tensile strength, flexural strength, water absorption and acid resistance of concrete with fly ash of the M60 grade with various percentages of nano-silica indicates the similar trend.
3. An increase in the percentage of nano silica content till 2%, the strength and durability properties tends to increase may be due to the presence of an additional binder in the presence of nano-silica. Nano-silica and fly ash combine with calcium hydroxide to create an additional binder. The use of an additional binder leads to an increase in the adhesion of the paste to the mortar, which leads to an improvement in the properties of concrete made from a mixture of nano-silica and fly ash.
4. The test results show that the maximum strength and maximum resistance to durability is obtained for a mixture with a combination of 2% nano-silica and 30% fly ash for all ages. Thus, the optimum replacement rate for nano-silica is 2% nano-silica and 30% fly ash, respectively, as cement replacement materials.
5. The use of fly ash and nano-silica as a replacement for cement represents a significant increase in compressive strength. Improvement in the pozzolanic response and the effect of filler, nano-silica and fly ash are the main factors behind the increased intensity.
6. The decrease in mechanical and durability properties by more than 2% of colloidal nano-silica is explained by the assumption that the volume of colloidal nano-silica particles is greater than the amount of lime formed as a result of hydration, which helps to wash out excess silica, which leads to a drop in force
7. The various properties of concrete can be improved by mixing 2% nano-silica and 30% fly ash. It can also be concluded that by using a mixture of fly ash and nano-silica, the cement content can be reduced without compromising about the strength and resistance to durability of the concrete.

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