Effect of nano-silica on strength and durability of geo-polymer concrete

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***ABSTRACT*-With the growing infrastructure development all around the world demand of Portland cement are increases day by day. The huge production of cement is associated with releases of CO_2 causing global warming issues. Therefore several efforts are in progress to reduce the use of Portland cement in concrete. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag,,rice-husk ash and metakaolin etc.**

The concept of sustainability of structures is touching new heights and many green building materials are tried and tested as partial or complete replacement for the cement. In this respect, the geo-polymer technology shows considerable prospect for application in concrete industry as an alternative binder to the Portland cement. Development of geo-polymer concrete using class F flyash brings many advantages like; enhancing workability, durability, better strength as well as lowering the price.

Nowadays, Nano Technology is also gaining prominence in the field of construction industries. In this study an attempt is made to find the effect for addition of Nano silica in geo-polymer concrete .The geo-ploymer concrete specimens were prepared using different percentage of nano silica. After finalizing the mixed design, the compressive strength was determined. The experimental study also carried out for durability aspects under different aggressive environment. The results obtained shows that geo-polymer concrete with nano silica addition exhibit good strength and excellent durability performance in aggressive environment. The beneficial effects of nano-silica in improving the workability, microstructure and strength qualities have also been established experimentally.

Keyword- Nano silica, Durability, Geo-polymer

I. INTRODUCTION

Production of Portland cement is highly energy intensive and is also an obvious contributor to the emission of carbon dioxide in environment. To produce 1 ton of Portland cement approximately 2.5 tons of raw materials including fuel is needed and this process produces approximately 1 ton of green-house gases which primarily consists of carbon dioxide. To increase the sustainability of concrete and a step towards clean environment, replacement of cement with by-product materials is most important. There are a vast amount of researches done regarding the partial replacement of cement by supplementary materials. Among the supplementary materials, fly ash plays a dominant role due to its high performance in enhancing the properties of concrete in addition to its low price as compared to other supplementary materials.

Fly ash is defined as 'the **finely** divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal system'. Fly ash particles are generally spherical in shape and ranges between 0.5 µm to 100 µm in size. Based upon composition there are two types of fly ashes- Class C and Class F. Using class F flyash as a supplementary material in concrete brings many advantages like; enhancing workability, durability and strength as well as lowering the price.
Davidovits (1988) discovered that the concrete used in ancient structures is alkali-activated alumino-silicate binders and named it as geopolymer concrete because of polymerization reaction;This led to the idea of cement replacement and the subsequent creation of 'Geopolymer Concrete'. In the past few decades, it has emerged as one of the possible alternative to Portland cement binders due to their reported high early strength and resistance against acid and sulphate attack apart from its environmental friendliness.

As the concrete technology develops, Nanotechnology has been applied to concrete production and has the potential of improving the performance of concrete In the last 10 years, a number of attempts were made in using nanomaterials in concrete. However most of these attempts remained in the research field, the only nanomaterial used in concrete as a construction purpose was nanosilica.

Nanosilica which is produced from silica sand has shown to be more effective in enhancing the strength of concrete. Although one of the basic materials for producing high strength concrete is silica fume, as it enhances the concrete's strength, researchers have reported that nanosilica has superior performance to silica fume in enhancing the compressive strength of concrete.

Nanosilica particles enhanced the microstructure by increasing the process of hydration and because of their high surface area; they increase pozzolanic activity more readily. They also acted as a void fillers which produces matrices with higher densities. The porosity and water absorption of geopolymer matrices have been reduced due to the addition of nanosilica to geopolymer paste. The beneficial effects of nanosilica in improving the workability, microstructure and strength qualities it to be one of the most widely used nanomaterials in the construction sector.
In this study the efforts are made in developing the fly ash based geopolymer concrete using nano-silica and study its effect on the performance of geopolymer concrete under aggressive chemical environment.

II. MATERIALS AND MIX PROPORTION

1. **Fly ash: -** Low Calcium (ASTM Class F) dry fly ash obtained from N.T.P.C Thermal Power plant (Rasulpur) Dadri, distirct- G.B Nagar, U P. has been used as the base material.
2. **Aggregates:-** Locally available aggregates, comprising 10 mm coarse aggregates in saturated surface dry condition, were used. The coarse aggregates were crushed to granite-type aggregates.
3. **Alkaline liquid:-** The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution.
4. **Nano silica:-CemSyn®-XTX,** is a series of silica based binders /fillers obtained from Bee-chem Chemicals Ltd., Kanpur.
   State - Dispersed in water
   Active nano Content (%W/W) - 30.0-32.0%
   pH (20°c) - 9.0-10.0
   Specific gravity – 1.20-1.22
   Particle size - 10 nm
5. **Mix proportions and curing**:- From the various different trial mixes, this mix proportion has been adopted for study.

- Total aggregates percent taken as 70%
- Alkaline to flyash ratio taken as 0.45
- Sodium hydroxide (NaOH) molar concentration 12M
- Sodium hydroxide solution(NaOH) to sodium silicate solution (Na_2SiO_3)ratio taken as 2.5
- Heat curing in oven, at 60˚C
- nano silica with 2%, 4%, 6% and 8% of fly ash by weight.

III. EXPERIMENTAL

1. Preparation of Test Specimens

1.1 Preparation of alkaline liquids

The sodium hydroxide (NaOH) solids in form of pellets were dissolved in water to make the 12 M .The sodium silicate solution and the sodium hydroxide solution were mixed together at least 24 hrs prior to use to prepare the alkaline liquid. On the day of casting of the specimens, the alkaline liquid was mixed together with the super plasticizer and the extra water (if any) to prepare the liquid component of the mixture.

1.2 Casting of fresh geopolymer concrete

First step is that the fly ash and the aggregates were first mixed together in the 10-litre capacity laboratory concrete pan mixer for about 4-5 minutes. Then secondly, the liquid component(alkaline liquids) of the mixture was then added to the dry materials and the mixing continued for further about 6-8 minutes to manufacture the fresh concrete .Before the fresh concrete was cast into the moulds, the slump value of the fresh concrete was measured as 92mm.
Then the fresh concrete was cast into the moulds. For compaction of the specimens, each layer was given 60 to 80 manual strokes using a rod bar, and then vibrated for 40-50 seconds on a vibrating table.

Figure 1: Casting on vibrater

Figure 2: Casted cube

2. Curing of test specimens

After casting, the specimens were covered with aluminum foil film to minimize the water evaporation during curing at an elevated temperature. The specimens of geopolymer concrete with or without nano silica were heat-cured at 60°C for 24 hours. After the required curing period, the test specimens were left in the moulds for at least 4-6 hours in order to avoid a drastic change in the environmental conditions. After demoulding, the specimens were further heat-cured at 60°C for 72 hours to gain their desired strength.

3. **Compressive strength test:-** The cubes are of 70.6mmX70.6mm dimensions. All The specimens were tested at 3days after casting to determine the compressive strength at different ages in accordance with the test procedures given in the Indian Standard Codes.

Figure 3: CTM

4. Durability tests:

4.1 Chloride resistance test:-

The chloride resistance of geopolymer concrete with the addition of nano silica was determined by measuring the residual compressive strength, change in mass, and visual appearance after chloride exposure.

Sodium chloride (Nacl) solution with 10% concentration was used as the standard exposure solution for all tests. The specimens were immersed in the chloride solution in a tub. Change in mass of specimens and compressive strength was measured in certain selected periods of exposure up to 4-8 weeks.

Figure 4: Specimens immersed in NaCl solution

4.2 Sulphate resistance test:-

The sulphate resistance of geopolymer concrete with the addition of nano silica will be determined by measuring the residual compressive strength, change in mass, and visual appearance after sulphate exposure.

Sodium sulphate (Na_2SO_4) solution with 10% concentration was used as the standard exposure solution for all tests. The specimens were immersed in the sulphate solution in a tub

Figure 5: Specimens immersed in Na_2SO_4 solution

The change in mass and compressive strength after 4-8 weeks of sulphate exposure was determined by testing the after (4-8weeks) period of exposure.

4.3 Acid resistance test:-

Acid resistance test is conducted on geopolymer concrete incorporates with nano silica to evaluate its resistance in terms of change in compressive strength, change in mass and visual appearance. Sulfuric acid and hydrochloric acid is the types of acid solution that is frequently used to simulate the acid attack in sewer pipe systems and many more situations.

To evaluate the acid resistance of fly ash-based geopolymer concrete, the specimens will be soaked in sulfuric acid and hydrochloric acid solution with selected concentrations ranging 3% -5% with the measured pH ranges 2-4.

Figure 6: Specimens immersed in acid solution

IV. RESULTS AND DISCUSSIONS

1. Compressive strength

The 70.6 x 70.6 mm cube specimens were prepared for each mix proportions of geo-polymer concrete with nano-silica. At least three of the specimens were tested for compressive strength at an age of 72 hours after casting for getting mean results. The specimens made from 6 trial Mix designs and final mix designs were cured at 80^{o}C for 72 hours, the mean results are presented in Table 1 & fig 7.

Table 1: Compressive strength

No. of Mix designs	Compressive strength in (MPa)					
	Nano silica 0%	Nano silica 2%	Nano silica 4%	Nano silica 6%	Nano silica 8%	Nano silica 10%
Trial mix design-1	17.9	22.0	25.5	27.2	30.7	28.1
Trial mix design-2	19.0	22.0	27.0	28.9	33.0	29.0
Trial mix design-3	21.4	23.4	26.0	29.1	32.0	31.5
Trial mix design-4	18.0	20.0	24.0	26.3	28.5	26.3
Trial mix design-5	22.0	24.2	27.6	28.0	31.5	29.0
Trial mix design-6	22.4	25.0	29.0	31.7	33.1	32.0
Final mix design	24.0	26.7	29.8	32.0	35	31.7

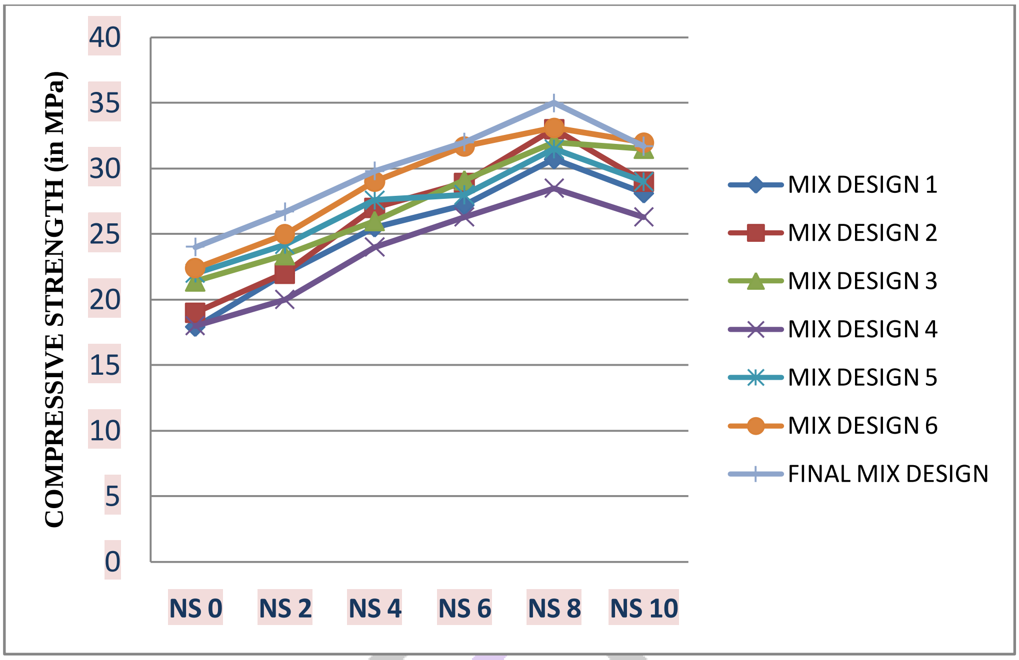

Fig 7: Compressive strength of GPC-N specimens

1.1 Discussions

From the Table 1 and fig 7, it s clearly seen that the compressive strength is increases with the percentage of nano silica up to 8%. Beyond this there were no further increase in compressive strength was observed rather the values seems to be start decreasing or constant for nano silica addition up to 10%.

2. Durability tests results

2.1 Chloride resistance

In order to study the chloride resistance properties of GPC-N specimens, a series of tests were performed. The test specimens of GPC-N were immersed in 10% sodium chloride (NaCl) solution. The performance of GPC-N cubes after exposures of 4-8 weeks were evaluate on the basis of following tests/observations.

- Change in Compressive strength
- Change in mass
- Visual appearance

2.1.1 Change in compressive strength

The compressive strength of these test specimens without any exposure of chloride solution was taken as the initial (reference) compressive strength.
The test specimens immersed in sodium chloride solution were removed from the tub, wiped clean with cloth or tissues, and tested after 5-10 hours period in saturated-surface-dry (SSD) and some of the specimens was tested in dry condition. But the trend of these test data is similar for the specimens tested in SSD and dry condition. The test results for 4-8 weeks exposure periods are presented in Table 2 & fig 8.

Table 2: Change in compressive strength for chloride samples of GPC-N

Sample Name	Strength (Initial)	Strength (after exposure for 4 weeks)	Strength (after exposure for 8 weeks)
NS-0	24.0MPa	22.1MPa	21.2MPa
NS-2	26.7MPa	24.0MPa	22.0Mpa
NS-4	29.8MPa	27.3MPa	26.0MPa
NS-6	32.0MPa	29.0MPa	29.9MPa

NS-8	35MPa	33.0MPa	32.1MPa

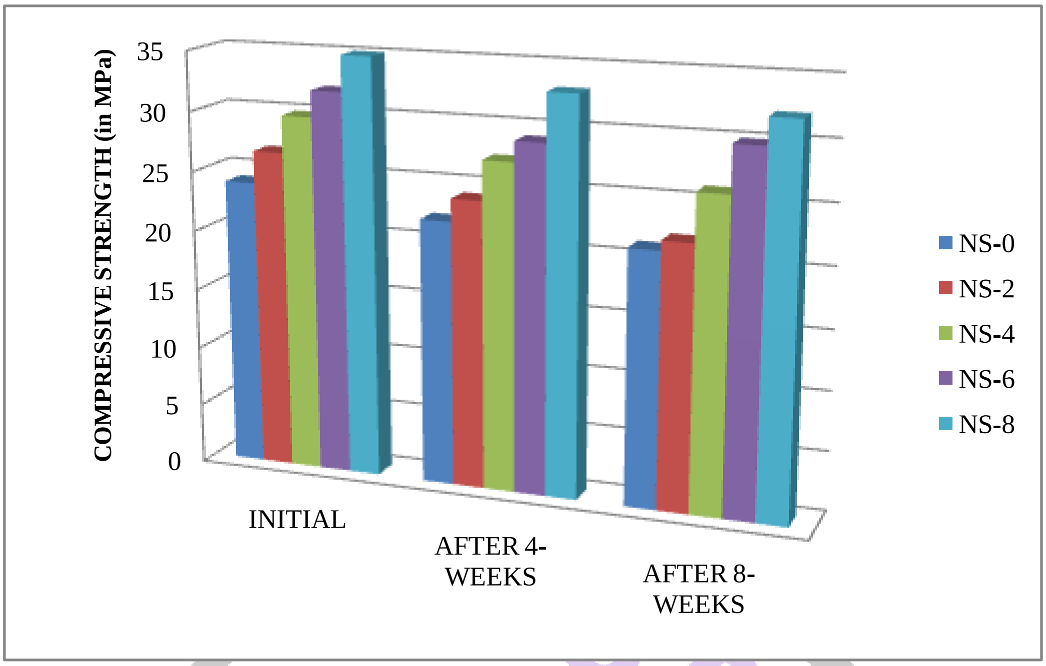

Figure 8: Change in Compressive strength of GPC-N Specimens immersed in sodium chloride solution

Hence, these test results of chloride resistance show that the exposure of geo-polymer concrete with or without nano-silica to 10% sodium chloride solution for 4-8weeks period caused very little change in the compressive strength.

2.1.2 Change in mass

The test results on the change in mass of GPC-N specimens are presented in Table 3 & fig 9. For comparison, Table 4 also presents the change in mass of specimens immersed in tap water for the given corresponding period. It can be seen that there was no reduction in the mass of the test specimens, as also confirmed by the visual appearance of the test specimens in fig: 10. However, there was a slight increase in the mass of specimens due to the absorption of the exposed chloride solution. The increase in mass of specimens indicates that the lesser solution absorption taken place as the addition percentage of nano-silica increase in geo-polymer concrete compared to geo-polymer concrete without nano-silica. The increase in mass of test specimens was approximately about 0.4% - 0.9% after 4-8 weeks period of exposure. In the case of test specimens soaked in tap water, this increase in mass was about 0.5% - 1.0%.

Table 3: Change in mass for chloride samples of GPC-N

Sample Name	Initial Weight	Weight (after exposure for 4 weeks)	Weight (after exposure for 8 weeks)
NS-0	757 gms	764 gms	771 gms
NS-2	765 gms	770 gms	776 gms
NS-4	762 gms	767 gms	772 gms
NS-6	743 gms	747 gms	751 gms
NS-8	737 gms	740 gms	743gms

Table 4: Change in mass for water samples of GPC-N

Sample Name	Initial Weight	Weight (after exposure for 4 weeks)	Weight (after exposure for 8 weeks)
NS-0	752 gms	761 gms	768 gms
NS-2	764 gms	770 gms	774gms
NS-4	766 gms	772 gms	776gms
NS-6	770 gms	775 gms	778 gms
NS-8	760 gms	764 gms	767gms

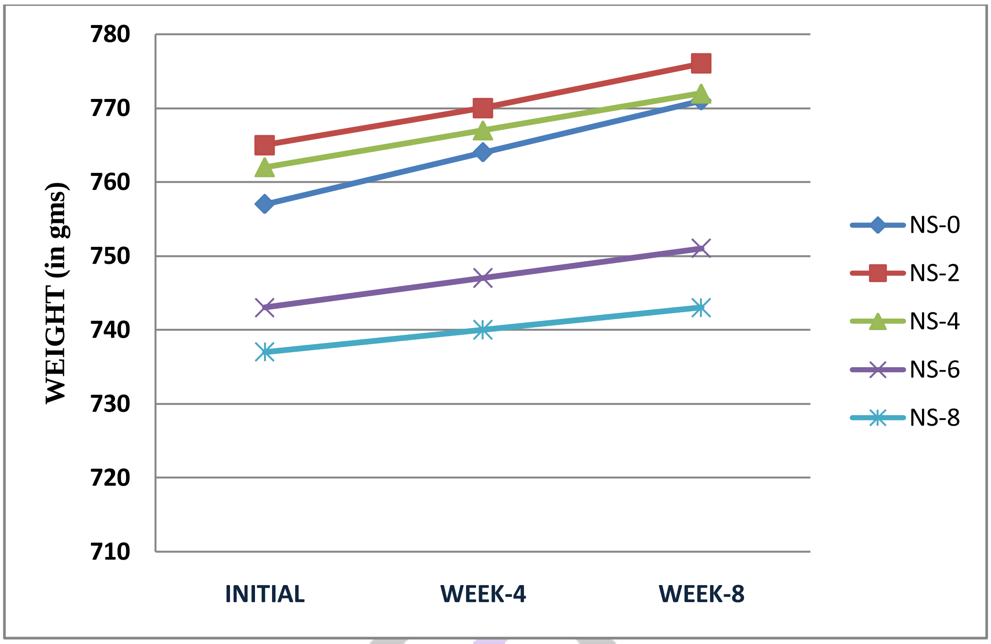

Figure 9: Change in Mass of GPC-N Specimens immersed in Sodium chloride solution

2.1.3 Visual appearance

The visual appearances of test specimens of GPC-N are shown in figure 10. It can be seen that the visual appearance of the test specimens after 4-8weeks of sodium chloride solution exposure revealed that there was a little efflorescence of chloride on the outer surface of GPC-N specimens as compared to the condition before they were exposed. The specimens immersed in tap water showed no change in the visual appearance. There was no sign of cracking, spalling or surface erosion on the test specimens.

Fig 10: Visual appearance of GPC-N samples

2.1.4 Discussion

In the present study, low-calcium fly ash of class F was used as the source material. The test results show that the excellent resistance of GPC-N specimens to chloride attack. Some important factors which contribute to better resistance to chloride attack are the low content of calcium oxide in fly ash used and the fine and discontinuous pore structure that results in low permeability due to addition of nano-silica.

2.2 Sulphate resistance

In order to study the sulphate resistance properties of GPC-N specimens, a series of tests were performed. The test specimens were immersed in 10% Sodium sulphate (Na_2SO_4) solution. The performance of GPC-N specimens after exposure of 4-8 weeks evaluate on the basis of following tests/observations:

- Change in Compressive strength
- Change in mass
- Visual appearance

2.2.1 Change in compressive strength

The compressive strength of GPC-N test specimens without any exposure of sulphate solution was taken as the initial (reference) compressive strength.

The test specimens immersed in sodium sulphate solution were removed from the tub, wiped clean with cloth or tissues, and tested after 5-10 hours period in saturated-surface-dry (SSD) and some of the specimens was tested in dry condition. But the trend of these test data is similar for the specimens tested in SSD and dry condition. The test results for 4-8 weeks exposure periods are presented in Table 5 & figure 11.

Table 5: Change in compressive strength for sodium sulphate samples of GPC-N

Sample Name	Strength (Initial)	Strength (after exposure for 4 weeks)	Strength (after exposure for 8 weeks)
NS-0	24.0MPa	22.8MPa	20.0MPa
NS-2	26.7MPa	25.2MPa	23.0Mpa
NS-4	29.8MPa	28.3MPa	26.1MPa
NS-6	32.0MPa	30.2MPa	28.3MPa
NS-8	35MPa	33.1MPa	30.7MPa

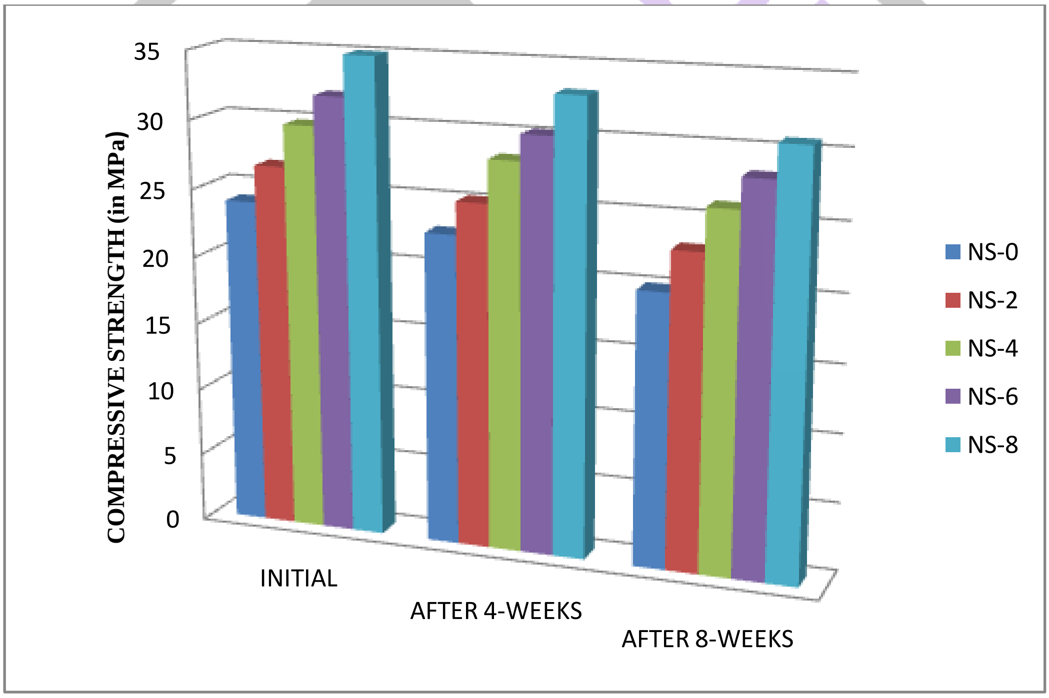

Figure 11: Change in compressive strength of GPC-N Specimens immersed in sodium sulphate solution

Hence, these test results of sulphate resistance show that the exposure of GPC-N specimens to 10% sodium sulphate (Na_2SO_4) solution for 4-8weeks period caused very little change in the compressive strength.

2.2.2 Change in mass

The test results on the change in mass of GPC-N specimens immersed in the solution of sodium sulphate (Na_2SO_4) for 4-8 weeks exposure period are presented in Table 6 & fig: 12. For comparison, Table 7 also presents the change in mass of specimens immersed in tap water for the given corresponding period. It can be seen that there was no reduction in the mass of the test specimens, as also confirmed by the visual appearance of the test specimens in fig: 13. However, there was a slight increase in the mass of specimens due to the absorption of the exposed sulphate solution. The increase in mass of specimens indicates that the lesser solution absorption taken place as the addition percentage of nano-silica increase in geo-polymer concrete compared to geo-polymer concrete without nano-silica. The increase in mass of test specimens due to absorption of solution was approximately about 0.4% - 0.9% after 4-8 weeks period of exposure.

Table 6: Change in mass for sodium sulphate samples of GPC-N

Sample name	Initial weight	Weight (after exposure for 4 weeks)	Weight (after exposure for 8 weeks)
NS-0	763 gms	770 gms	777 gms
NS-2	755 gms	761 gms	767 gms
NS-4	773 gms	778 gms	783 gms
NS-6	767 gms	770 gms	773 gms
NS-8	737 gms	739 gms	741gms

Table 7: Change in mass for water samples of GPC-N

Sample name	Initial weight	Weight (after exposure for 4 weeks)	Weight (after exposure for 8 weeks)
NS-0	752 gms	761 gms	768 gms
NS-2	764 gms	770 gms	774gms
NS-4	766 gms	772 gms	776gms
NS-6	770 gms	775 gms	778 gms
NS-8	760 gms	764 gms	767gms

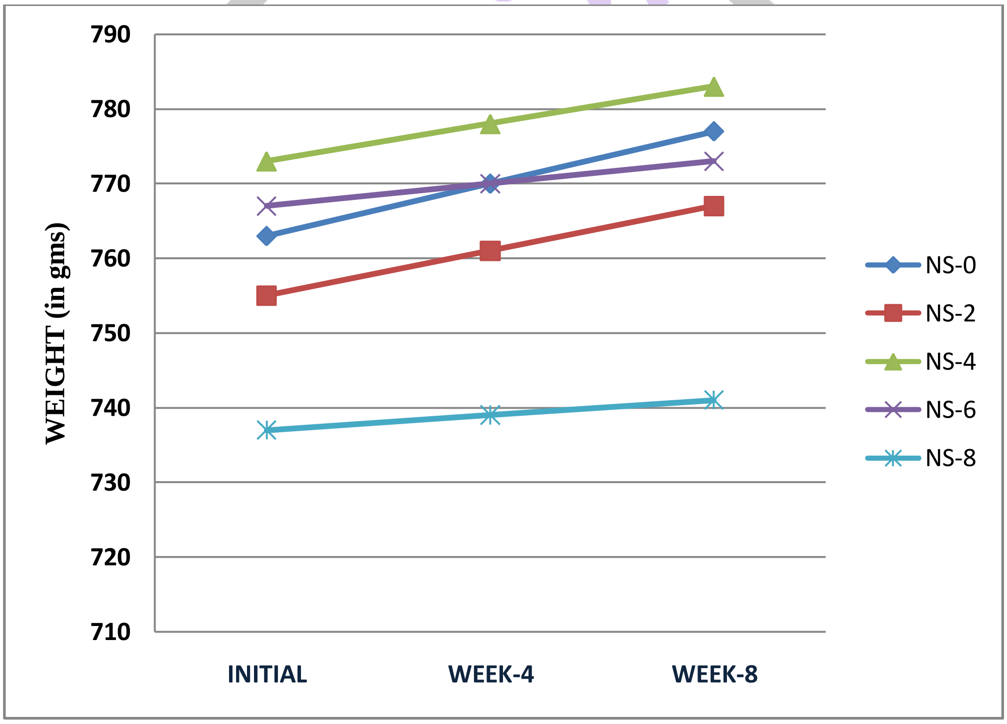

Figure 12: Change in Mass of Specimens immersed in Sodium sulphate Solution.

2.2.3 Visual appearance

The visual appearances of test specimens of GPC-N are shown in fig 13. It can be seen that the visual appearance of the test specimens after 4-8weeks of sodium sulphate solution exposure revealed that efflorescence and white patches of sulphate on the outer surface of GPC-N specimens as compared to the condition before they were exposed. There was no sign of cracking, spalling or surface erosion on the test specimens.

Figure 13: Visual appearance of GPC-N samples

2.2.4 Discussion

In the present study, low-calcium fly ash of class F was used as the source material. The test results show that the excellent resistance of heat cured GPC-N specimens to sulfate attack. Some important factors which contribute to better resistance to sulfate attack are the low content of calcium oxide in fly ash used and the fine and discontinuous pore structure that results in low permeability due to addition of nano-silica.

4.3. Acid resistance

In order to study the Acid resistance properties of GPC-N specimens, a series of test were performed. The test specimens of GPC-N were immersed in 3% - 5% concentrations of sulfuric and hydrochloric acid solution for 4-8 weeks exposure. The performance of GPC-N specimens after exposure of 4-8 weeks evaluate on the basis of following tests/observations:

- Change in compressive strength
- Change in mass
- Visual appearance

4.3.1 Change in compressive strength

The change in compressive strength of GPC-N test specimens without any exposure of sulphuric and hydrochloric acid solution was taken as the initial (reference) compressive strength. The test results are presented in Table 8-9 & fig: 14-17.

Table 8: Change in compressive strength for sulphuric acid samples

Sample name	Compressive strength of Sulphuric acid (3%)			Compressive strength of Sulphuric acid (5%)		
	Initial strength	Strength (after exposure for 4 weeks)	Strength (after exposure for 8 weeks)	Initial strength	Strength (after exposure for 4 weeks)	Strength (after exposure for 8 weeks)
NS-0	24MPa	22.1MPa	19MPa	24MPa	21.1MPa	18.3MPa
NS-2	27MPa	25MPa	23.5MPa	27MPa	24.7MPa	22.MPa
NS-4	30MPa	28MPa	25.1MPa	30MPa	27MPa	24.7MPa
NS-6	32MPa	29.3MPa	27.2MPa	32MPa	29.4MPa	26.5MPa
NS-8	35MPa	32.7MPa	29.4MPa	35MPa	33MPa	27.2MPa

Table 9: Change in compressive strength for Hydrochloric acid samples

Sample name	Compressive strength of Hydrochloric acid (3%)			Compressive strength of Hydrochloric acid (5%)		
	Initial **strength**	**Strength (after exposure**	**Strength (after exposure**	Initial **strength**	**Strength (after exposure**	**Strength (after exposure**

		for 4 weeks)	for 8 weeks)		for 4 weeks)	for 8 weeks)
NS-0	24MPa	21.9MPa	20.5MPa	24MPa	22.5MPa	19.2MPa
NS-2	27MPa	25.3MPa	23MPa	27MPa	25.3MPa	24.1MPa
NS-4	30MPa	28.0MPa	26.9MPa	30MPa	28MPa	26.7MPa
NS-6	32MPa	30MPa	28.7MPa	32MPa	31.2MPa	29.2MPa
NS-8	35MPa	32.2MPa	30.3MPa	35MPa	33.1MPa	29.6MPa

High reduction in compressive strength observed in plain geo-polymer concrete specimen up to 20% whereas in geo-polymer concrete specimen with nano-silica shows 16% reduction has been observed which suggest that the effect of acid exposure on GPC-N is low.

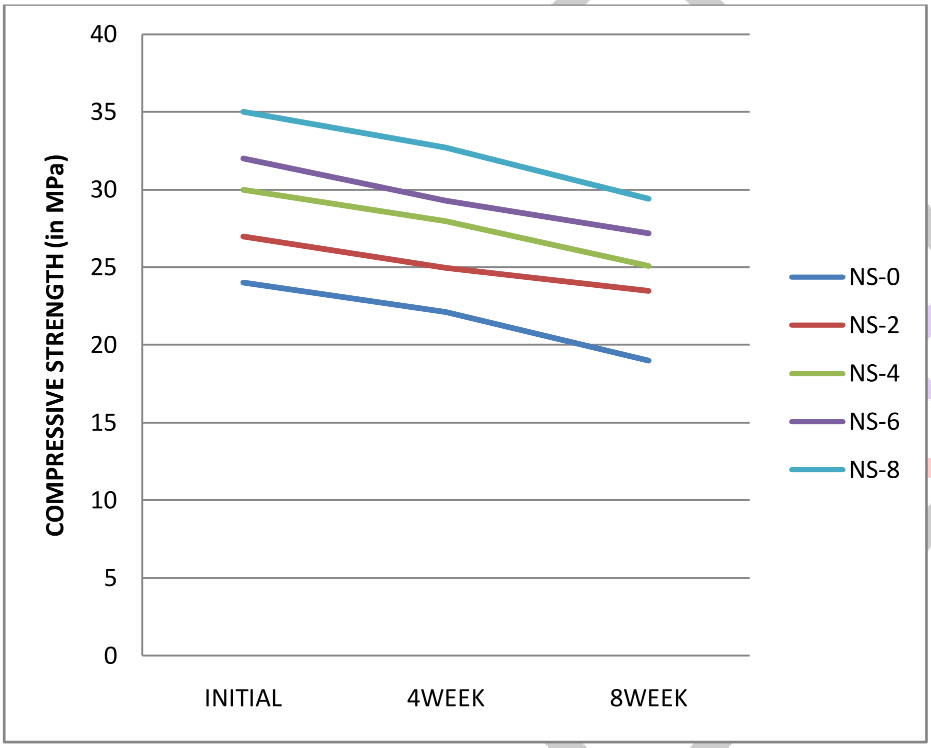

Figure 14: Change in compressive strength of GPC-N specimens exposed to 3% Sulfuric Acid Solution.

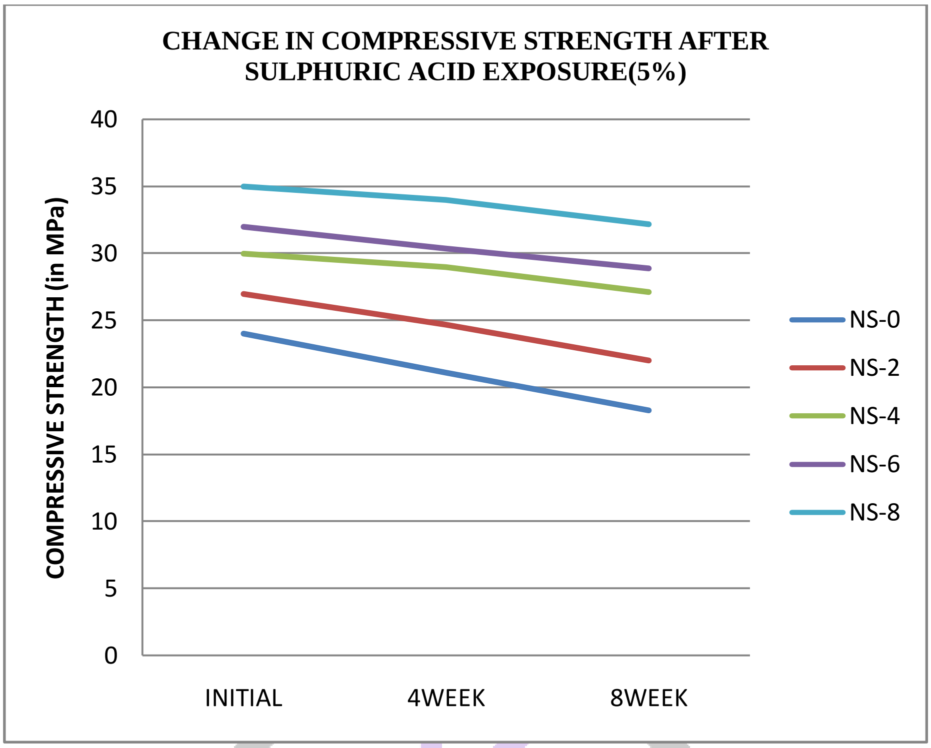

Figure 15: Change in compressive strength of GPC-N specimens exposed 5% Sulphuric acid

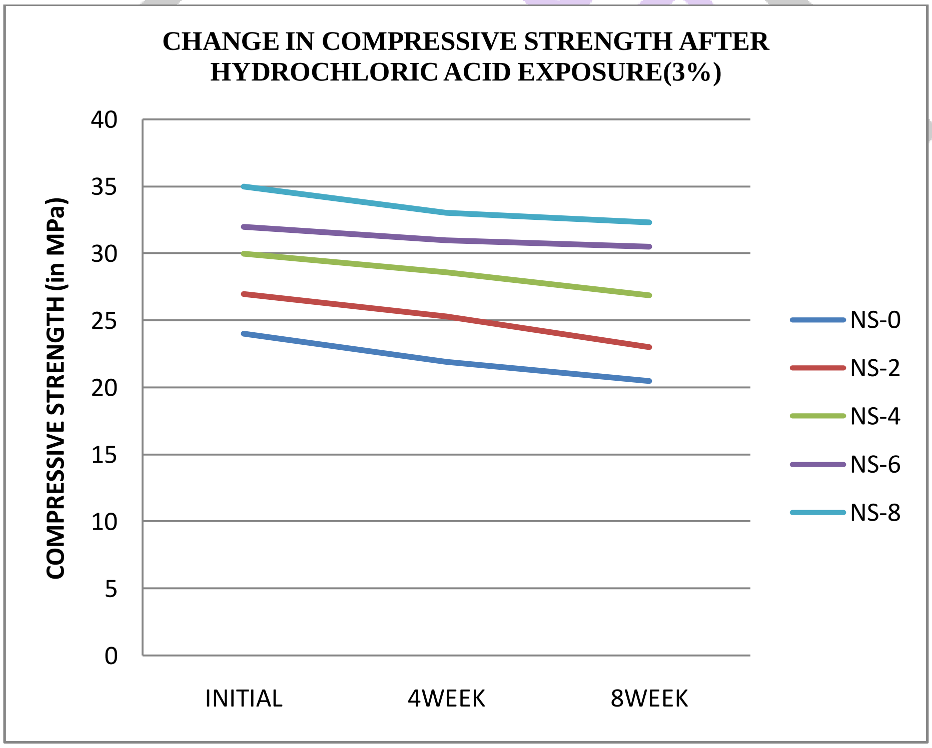

Figure 16: Change in compressive strength of GPC-N specimens exposed to 3% hydrochloric Acid Solution

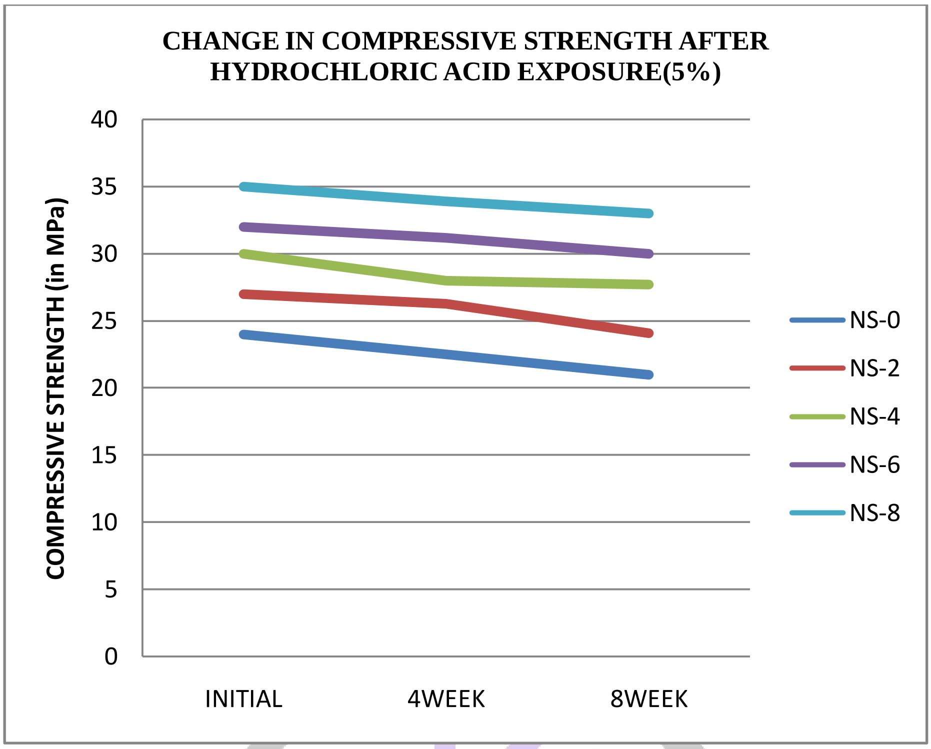

Figure 17: Change in compressive strength of GPC-N specimens exposed to 5% hydrochloric Acid Solution

It can be seen from figure 14-17 that the degradation in the compressive strength of GPC-N specimens due to sulphuric and hydrochloric acid exposure depends on the concentration of the acid solution and the period of exposure. The degradation in compressive strength increased as the concentration of the acid solution increased from 3% to 5% because pH value decrease and the exposure period increased.

For GPC-N specimens exposed to 5% sulfuric and hydrochloric solution, the rate of degradation was fast during the first 4weeks but after that the change was not significant till 8 week of exposure.

4.3.2 Change in mass

The test results on the change in mass of GPC-N specimens immersed in the solution of sulphuric and hydrochloric acid having 3% - 5% concentration for 4-8 weeks exposure period are presented in Table 10-11 & figure 18-21. It can be seen that there was no reduction in the mass of the test specimens upto 4 weeks of exposure, as also confirmed by the visual appearance of the test specimens in figure 22- 23. But, the mass loss taken place after 4week of exposure as the concentration of acids decreased. However, there was a slight increase in the mass of specimens due to the absorption of the exposed sulphuric and hydrochloric acid solution the increase in mass of specimens indicates that the lesser solution absorption taken place as the addition percentage of nano-silica increase in geo-polymer concrete compared to geo-polymer concrete without nano-silica. Very less mass loss recorded in higher percentage of nano-slica addition. The increase in mass of test specimens due to absorption of solution was approximately about 0.6% - 1.3% after 4-8 weeks period of exposure.

Table 10: Change in mass for sulphuric acid samples

Sample name	Sulphuric acid (3%)			Sulphuric acid (5%)		
	Initial weight	Weight (after exposure for 4 weeks)	Weight (after exposure for 8 weeks)	Initial weight	Weight (after exposure for 4 weeks)	Weight (after exposure for 8 weeks)
NS-0	750gms	759gms	753gms	775gms	782gms	769gms
NS-2	759gms	768gms	763gms	741gms	749gms	737gms
NS-4	756gms	764gms	760gms	762gms	769gms	760gms
NS-6	760gms	766gms	762gms	759gms	767gms	760gms
NS-8	754gms	760gms	757gms	755gms	761gms	754gms

Table 11: Change in mass for hydrochloric acid samples

Sample name	Hydrochloric acid (3%)			Hydrochloric acid (5%)		
	Initial weight	Weight (after exposure for 4 weeks)	Weight (after exposure for 8 weeks)	Initial weight	Weight (after exposure for 4 weeks)	Weight (after exposure for 8 weeks)
NS-0	769gms	778gms	767gms	779gms	787gms	778gms
NS-2	756gms	764gms	755gms	750gms	757gms	748gms
NS-4	756gms	762gms	753gms	759gms	765gms	755gms
NS-6	763gms	768gms	761gms	761gms	765gms	759gms
NS-8	728gms	732gms	725gms	764gms	769gms	762gms

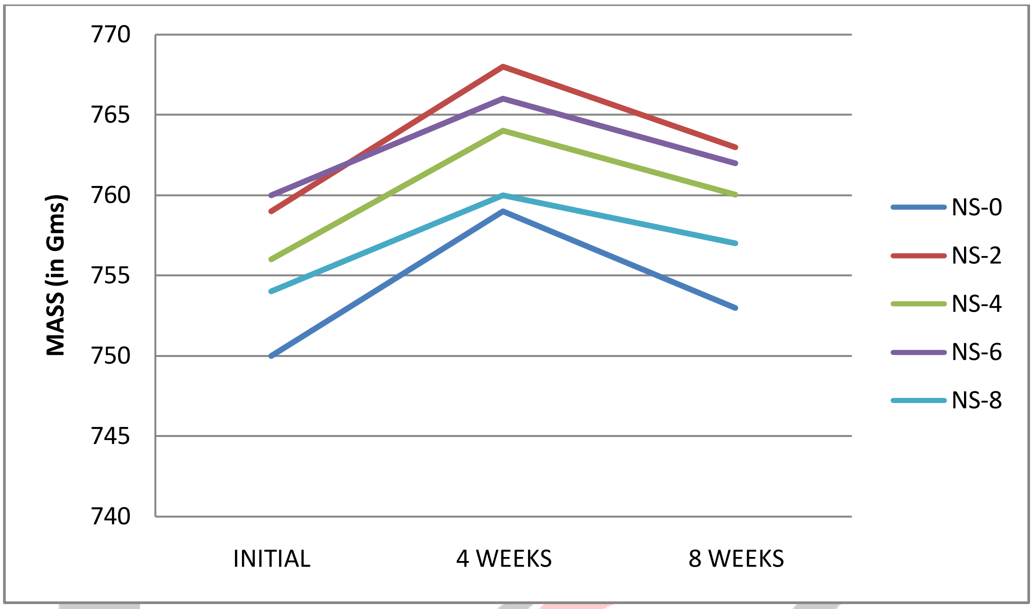

Figure 18: Change in mass of GPC-N specimens exposed to 3% sulfuric acid solution

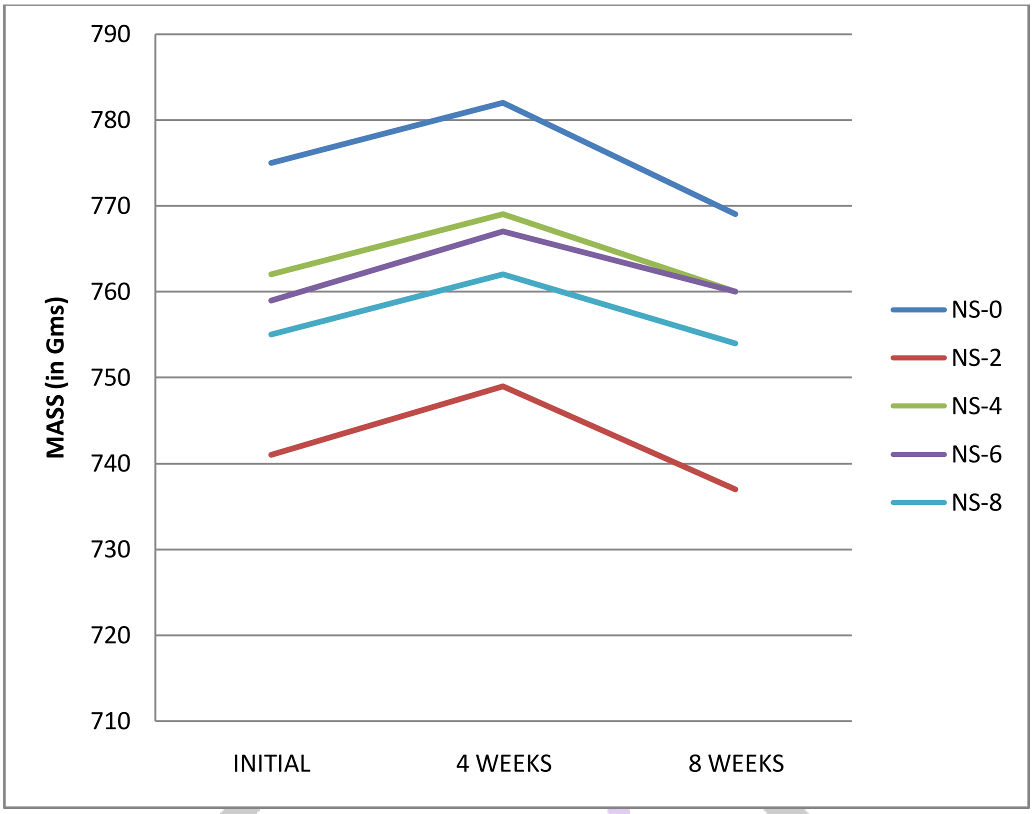

Figure 19: Change in mass of GPC-N specimens exposed to 5% sulfuric acid solution

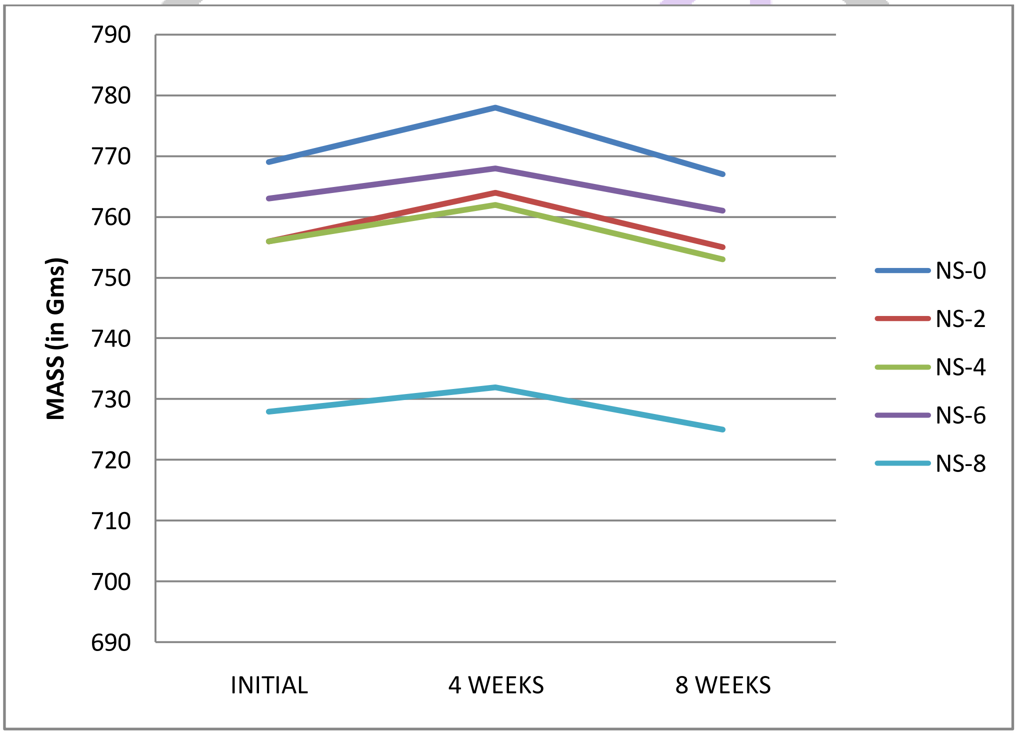

Figure 20: Change in mass of GPC-N specimens exposed to 3% hydrochloric acid solution

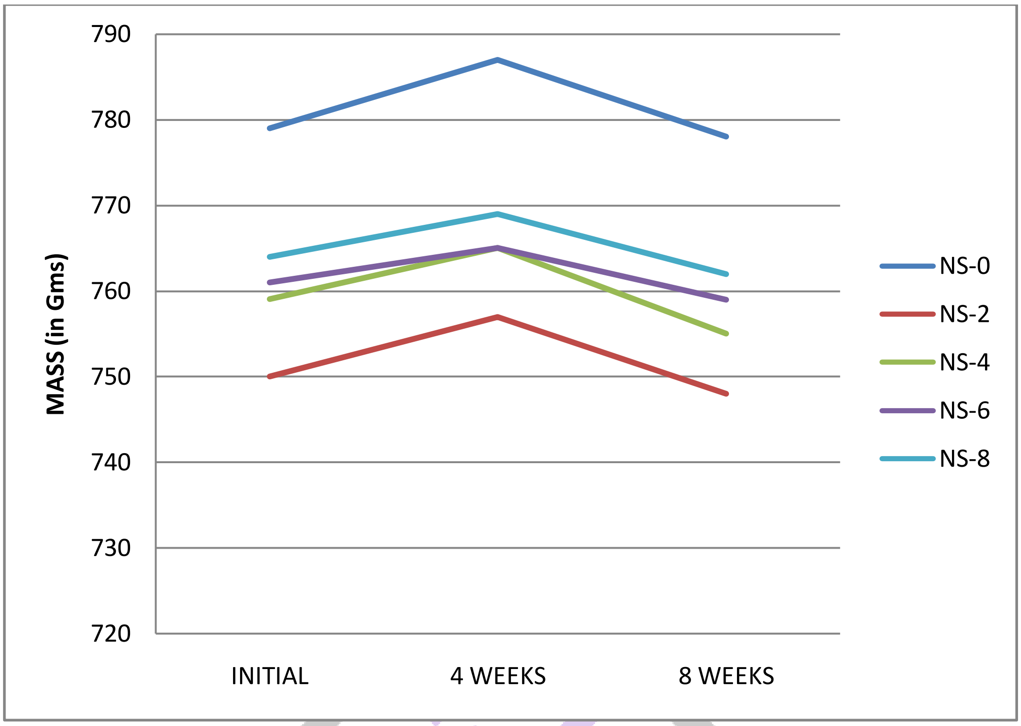

Figure 21: Change in mass of GPC-N specimens exposed to 5% hydrochloric acid solution

4.3.3. Visual appearance

The visual appearances of test specimens of GPC-N are shown in figure 22-23. It can be seen that the GPC-N specimens exposed to sulfuric and hydrochloric acid undergoes slight erosion and efflorescence of the respective acid solution on the outer surface. The damage to the outer surface of the GPC-N specimens increased as the concentration of the acids solution decreased. There was a sign of cracking, spalling or surface erosion on the test specimens of geo-polymer concrete.

Figure 22: Visual appearance of GPC-N specimens

Figure 23: Visual appearance of GPC-N specimens

4.3.4 Discussion

In the present study, low-calcium fly ash of class F was used as the source material. The test results show that the good resistance of heat cured GPC-N specimens to acid attack. Some important factors which contribute to better resistance to acid attack are the low content of calcium oxide in fly ash used and the fine and discontinuous pore structure that results in low permeability due to addition of nano-silica.

V. CONCLUSION

The following conclusions have been drawn from the study of effect of nano-silica on the strength and durability of flyash-based geopolymer concrete. The GPC-N cubes were casted with five different percentages of nano silica i.e. 0%, 2%, 4%, 6%, and 8% by weight of flyash respectively. The outcome of the different tests conducted on these GPC-N concrete cubes are summarized as follows:-

Testing of GPC-N specimens for strength and durability measurements:

1. Strength characteristics in terms of compressive strength:

- The compressive strength of GPC-N cubes were increases with increments of nano-silica up to 8%. . Beyond this there were no further increase in compressive strength was observed, however the values seems to be start decreasing or constant for nano silica addition up to 10%.
- The increase in compressive strength caused due to low permeability and dense geopolymer concrete matrix with addition of nano silica.
- Therefore it is concluded that Geopolymer with nao silica exhibits good compressive strength in comparison to Geopolymer without nano silica.
- The proper mixed design with controlled conditions of curing temperature and curing period are another significant factors which influence the strength charcterstics.

2. Durability Characteristics:

Chloride and Sulphate Resistance:

The test results demonstrate that GPC-N specimens have an excellent resistance to chloride and sulphate attack. There is no damage to the surface of test specimens as also confirmed by visual appearance after exposure to sodium chloride and sodium sulphate solution up to 4-8 weeks exposure.

- The chloride and sulphate intrusions were minimum in GPC-N cubes with 8% nano silica because of low permeability.
- The compressive strength of test specimens decreases after 4-8 weeks periods of exposure, however the rate of decrease in compressive strength is less as the percentage of nano silica addition increases.
- These test observations indicate that there is no mechanism to form gypsum or ettringite from the main products of polymerisation in heat-cured low-calcium fly ash-based geopolymer concrete with the addition of nano-silica.
- This shows that GPC-N concrete remains its strength even in aggressive chemical environment and therefore best solution for replacing OPC for concreting in aggressive environment.
- There were no major sign of surface deterioration, spalling, efflorescence and disintegration in GPC-N cubes.

Acid Resistance:

- The GPC-N cubes were exposed to different acid concentration for certain time period. The important observations and outcomes are as follows:
- The GPC-N cube with 8 % nano silica shows good resistance under acidic environment as the decrease in compressive strength was very marginal in comparisons to GPC without nano silica.
- As the concentration of sulphuric and hydrochloric acid increases the rate of surface erosion and decrease in compressive

strength were also increases. However, the sulphuric and hydrochloric acid resistance of geopolymer concrete with nano silica is significantly better than that of geopolymer concrete without nano silica.

- The GPC-N specimens indicated that the degradation in the compressive strength due to sulfuric acid and hydrochloric acid attack is mainly due to the degradation in the geopolymer matrix rather than the aggregates. Visual appearance shows that there was slight surface erosion and spalling of GPC-N specimens.
- The residual alkalinity test on GPC-N specimens showed that the alkalinities were seen to have almost lost in all the GPC-N specimens after the exposure of 4-8 weeks.

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