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Experimental study on mechanical performance of Rice Husk Ash derived Nano silica with the addition of S-Glass Fibres in Concrete

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Abstract - *One of the major consumer of material and energy sources of India is the construction industry. Among every one of the materials used in construction, concrete has a critical effect. In the meantime, nanotechnology is a standout amongst the most powerful advancements in this century and it has essentially pulled in the development part. Better understanding and engineering cementitious material at nanometer scale can bring about novel development materials which are more solid and sturdy than conventional materials. The fundamental idea driving the use of Nano material having large surface area is to enhance compressive and flexural quality at early ages, decreased porosity and enhanced hydration attributes when compared with conventional cementitious materials. Nano materials can likewise clear the way to diminish the cement content in concrete than the conventional mixes while keeping up same quality attributes, which will lead into the production of 'greener' concrete. This paper surveys the efforts, current status, and impact of Nano-Silica on properties of cement mortar for better understanding of the materials and their uses. This paper likewise displays the impact of S-Glass fibers on the mechanical properties of concrete.*

Key Words: **Nano Silica (NS), S-Glass Fibres (GF), Compressive Strength, Split Tensile Strength, Rice Husk Ash, etc ...**

1. INTRODUCTION

One of the most widely used construction materials is concrete. The main ingredient of concrete is Ordinary Portland Cement (OPC) which is preferred because of its low cost and good durability. It is a fact that about one ton of carbon dioxide is released to the atmosphere during the production of one ton of OPC. Extensive research is being made in concrete industry to reduce the carbon footprint of concrete by completely or partially replacing the bulk portion of cement in the concrete with supplementary cementitious materials (SCMs). During the past decade, there have been many revolutionary developments in the field of nanotechnology to promote their use in cement based material. The potential of nanotechnology in improving the performance of concrete should go along with the availability of local materials. Nano silica (NS), an advanced pozzolanic material is found to improve the microstructure and stability of cement by consuming free lime during cement hydration. As a result calcium silicate hydrate (CSH) gel is formed. In addition to its high fineness, the NS is particularly beneficial in acting as a nucleus and making the cement hydrate dense and thereby the interfacial transition zone between hardened cement pastes and aggregate is improved. Past research on concrete using Nano silica has called attention to that Nano-silica improves the workability and quality of concrete or mortar. The utilization of Nano silica as halfway substitution of bond has some invaluable impacts on concrete performance. This study intends to tentatively research the impact of including Nano silica alongside the mix of S-Glass Fibres on mechanical properties compressive strength and tensile strength of concrete.

Gladwin Alex et al [1] investigated using micro level materials such as marble powder and rice husk ash as a replacement of cement. **Kalpana Kumari et al [2]** conducted a study to understand the effect of Nano TiO_2 (NT), Nano $CaCO_3$ (NC) particles and a combination of NT and NC particles (NTC) on various properties like compressive strength, workability and durability of fly ash concrete by partial replacement of cement. **Ehsan Mohseni et al [3]** investigated the effects of RHA and Nano alumina in Polypropylene Fibre (PPF) reinforced cement mortars. Compressive strength, flexural strength, water absorption and drying shrinkage of the hardened composites were investigated. **S Chithra et al [4]** investigated the effect of colloidal Nano silica on the properties of High Performance Concrete with copper slag as fine aggregate. **Wengui Li et al [5]** investigated the effects of nano-SiO_2 (NS) and nano-$CaCO_3$ (NC) on the flow ability, strengths and microstructure of ultra-high-performance. **Mohamed Amin et al [6]** evaluated the effect of addition of Nano silica, $Cu0.5Zn0.5Fe_2O_4$ (Cu-Zn ferrite) and $NiFe_2O_4$ (Ni ferrite) on the compressive strength, splitting tensile strength, flexural strength and modulus of elasticity of concrete. **P Jai shankar et al [7]** investigated the influence of Nano particles such as Nano ZrO_2 (NZ), Nano Fe_3O_4 (NF), Nano TiO_2 (NT) and Nano SiO_2 (NS) on the mechanical and durable properties of concrete. **S Tanveer Hussain et al [8]** studied the strength properties such as Compressive strength, split tensile strength and flexural strength of M40 and M50 grades of concrete with the use of micro silica and Nano silica as partial replacement of cement. **Muna M Abdullah et al [9]** observed the effect of glass fibre content on the mechanical

properties of glass fibre reinforced concrete and mortar at 28 and 14 days respectively. Although other nanoparticles were studied, Nano silica has often been the first choice due to its high pozzolanic activity.

Several literatures were studies for the synthesis of Nano-Silica using an environmental friendly process. **Farshid Ghorbani et al [10]** proposed a study to optimize silica extraction procedure and improve its purity and eventually produce high quality SNPs from rice husk as agricultural waste. **A. F. Hassan et al [11]** obtained high purity nanosilica by thermal treatment of rice husk ash (RHA) employing the sol–gel method without using any surfactant. **Midhun Dominic C.D et al [12]** presented a work to replace commercial silica commonly used in natural rubber industries with high purity rice husk Nano silica through a sol-gel process. **Tzong-Horng Liou et al [13]** investigated the surface and pore characteristics of Nano silica formation via alkali extraction of rice husk. **W A P J Premaratne et al [14]** synthesized Nano silica by a chemical precipitation process from paddy husk ash (PHA) efficiently and effectively. **Nittaya Thuadaij et al [15]** prepared Nano silica by precipitation method and characterized by various analytical techniques. In this study mechanical performance of concrete is studied with the use of S-Glass Fibres and Nano silica in the range of 1-4% by weight of cement.

2. METHODOLOGY

2.1 Materials

Cementitious materials used were commercial available Ordinary Portland Cement (OPC), Nano Silica and S-Glass Fibres. The content of Nano Silica replacement varied between 1-4% of the weight of cementitious content and the fibres were varied between 0.1-0.4%. A polycarboxylic ether polymer based super plasticizer (Master Glenium SKY8233) was utilized.

a) Nano Silica (Nano SiO_2)

Nano Silica is efficiently and effectively synthesised from Rice Husk Ash (RHA) in the laboratory using an environmental friendly technique. Rice Husk Ash is one of the most abundant agricultural wastes which contain around 97% of silica. The method is simple, economical, conservative and reproducible.

i) Synthesis of Nano Silica

Rice Husk Ash (RHA) collected from Chennai Gate Rice Mill, Erode was used in this synthesis process. The collected RHA is washed with deionised water in order to remove the dirt and impurities. It is then dried in an oven at 60°C for 18hours to make it moisture free. 60gms of RHA is mechanically stirred in 1litre of 2.5M NaOH solution for about an hour. This solution is now placed in an auto clave at 120°C for 150minutes. The solution is then filtered and the residue is allowed to cool.

$$SiO_2\ (RHA) + NaOH \rightarrow Na_2SiO_3 + H_2O$$

The obtained sodium silicate solution is alkaline in nature and hence repeatedly washed with hot water in order to bring the pH to 7. The transparent filtrate of sodium silicate solution is slowly titrated with concentrated sulphuric acid (conc. H_2SO_4) under vigorous stirring. Sodium silicate has shown to be neutralized with diluted sulphuric acid to precipitate silica in the form of gel. The chemical reaction that takes place in the above process is

$$Na_2SiO_3 + H_2SO_4 \rightarrow SiO_2 + Na_2SO_4 + H_2O$$

The silica gel is filtered, fragmented and washed repeatedly with hot water in order to remove the sulphate salts. The clean silica gel is then placed at 200°C in a hot air oven for 30hours. The resultant silica sample is then pulverised using a ball mill to obtain Nano-silica. The obtained silica appeared as fine and white powder with purity of 96%

ii) Characterization of Sample

The prepared Nano Silica sample was subjected to PSA, EDAX, SEM, XRD analysis and the results are as follows. The structural morphology of the silica nanoparticles synthesized form RHA are examined by Scanning Electron Microscope (SEM) using VEGA 3 TESCAN and the results are shown in Fig. 1. The Nano silica particles don't demonstrate clear limits as they are in agglomerated and amorphous form. In this way, SEM information affirmed that the size of the silica particles incorporated from RHA is in the range of Nano-metres.

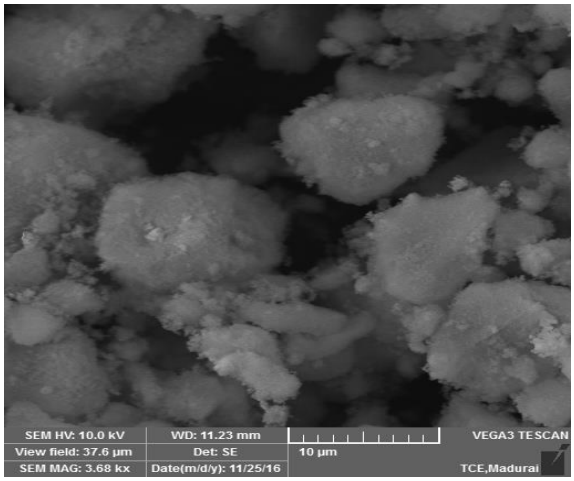

Fig. 1. SEM Images of Nano Silica

The chemical constituents of the Nano-Silica sample are confirmed by Electron Dispersive Analysis using X-Rays (EDAX) and the results are given in Fig. 2. Highest purity of 95.71% amorphous silica is obtained from the above method and this is confirmed using the EDAX results. The particle size of the sample is measured at 25°C and a scattering angle of 90° using the scattering light intensity principle. The Particle Size Analyser confirms the size of the sample to be 164.8nm. X-Ray Diffraction pattern of extracted silica sample is shown in Fig. 3. XRD diffractograms of Nano silica showed strong board peaks at $2\theta = 22.14°$ which indicated the absence of any ordered crystalline structure (amorphous structure)

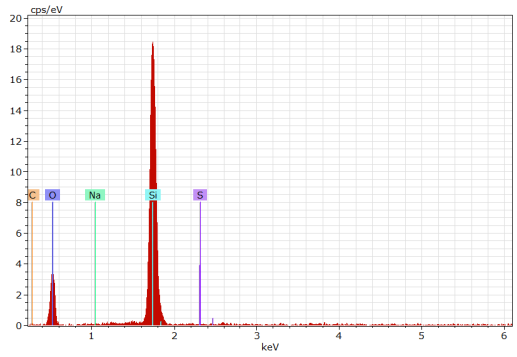

Fig. 2. EDAX Result showing the chemical composition of the silica sample

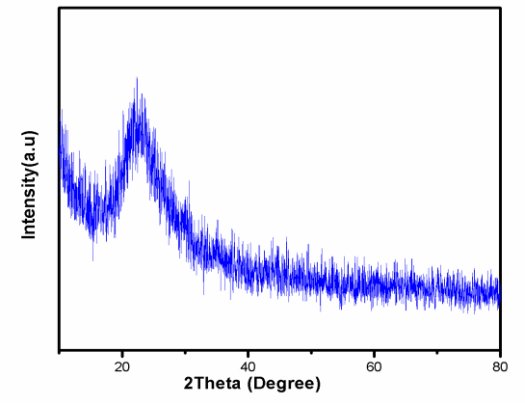

Fig. 3. X-Ray Diffraction pattern of extracted silica sample

High purity (96%) amorphous Nano silica, obtained from the agricultural waste is used as a partial replacement of cement in this study. The average particle size diameter of the Nano silica is 165nm.

b) S-Glass Fibres

S-Glass Fibres are Magnesium alumina silicate glasses used for reinforcement in composite structural applications which require high strength and stability under extreme temperature and corrosive environments. The properties of S-Glass Fibres are given in Table I.

Table I. Properties of S-Glass Fibres

Composition	64%SiO_2 - 24%Al_2O_3 - 10%MgO
Density	2.485 Mg/m^3
Fibre Diameter	10 microns
Bulk Modulus	51 GPa
Poisson's Ratio	0.23
Young's Modulus	86 GPa

c) Cement

Ultra-Tech cement of Ordinary Portland Cement (OPC) of 53 grade confirming to IS: 12269-1987 is used in this study. The specific gravity of the cement is 3.15

d) Fine Aggregate

Locally available river sand confirming to Zone II of IS 383:1970 of maximum size 2.36 mm and with a specific gravity of 2.65 was used.

e) Admixtures

A Poly-carboxylic ether based super plasticizer MasterGlenium SKY 8233 complying with ASTM C494 Type F standards is used. The properties of the super plasticizer are given in Table II.

Table II. Properties of Super Plasticizer

Material	Master Glenium SKY 8233
Colour	Light brown liquid
pH	≥6
Chloride Ion Content	<0.2%

2.2 Mix Design and Methodology

Twenty mortar mixes were used in this study and the mix proportions are given in Table III. The mortar mix consisted of one part of cement to three parts of Fine Aggregate. The water to binder ratio is maintained at 0.4. To improve the workability of the concrete, poly-carboxylic ether based super plasticizer is used at the rate of 1.5% by weight of binder. The experimental program is to study the 7, 28 days compressive and split tensile strength of mortar with different replacement levels of OPC with Nano silica (1%, 2%, 3% and 4% by weight of cement) and with the addition of S-Glass Fibres (0.1%, 0.2%, 0.3% and 0.4% by weight of mixture). The specimens of standard mortar cubes (70.6mm x 70.6mm x 70.6mm) and standard mortar cylinders of (100mm Diameter x 200mm Height) were cast with various percentage replacements of Nano silica and S-Glass Fibres.

All the mixes are hand mixed at room temperature. Firstly, the cement along with the fine aggregate are dry mixed for about two minutes. Secondly the specified amount of S-Glass Fibres are evenly distributed and mixed for about two minutes. In order to prevent agglomeration of Nano particles, the calculated amount of Nano silica is first dispersed in water containing super plasticizer and then slowly added to the dry mix. The mixing is continued for another four minutes until proper workability is achieved. The mortar is then poured into various moulds and is casted into mortar cubes and cylinders. The specimens are then mechanically vibrated using a vibrator.

Table III. Mix Proportions of experimental specimens

Mix Proportion	Cube				Cylinder			
	Cement	FA	GF	NS	Cement	FA	GF	NS
0.1GF	220gm	660gm	0.88gm	-	900gm	2700gm	3.6gm	-
0.2GF	220gm	660gm	1.76gm	-	900gm	2700gm	7.2gm	-
0.3GF	220gm	660gm	2.64gm	-	900gm	2700gm	10.8gm	-
0.4GF	220gm	660gm	3.52gm	-	900gm	2700gm	14.4gm	-
0.1GF-1NS	217.8gm	660gm	0.88gm	2.2gm	891gm	2700gm	3.6gm	9gm
0.1GF-2NS	215.6gm	660gm	0.88gm	4.4gm	882gm	2700gm	3.6gm	18gm
0.1GF-3NS	213.4gm	660gm	0.88gm	6.6gm	873gm	2700gm	3.6gm	27gm
0.1GF-4NS	211.2gm	660gm	0.88gm	8.8gm	864gm	2700gm	3.6gm	36gm
0.2GF-1NS	217.8gm	660gm	1.76gm	2.2gm	891gm	2700gm	7.2gm	9gm
0.2GF-2NS	215.6gm	660gm	1.76gm	4.4gm	882gm	2700gm	7.2gm	18gm
0.2GF-3NS	213.4gm	660gm	1.76gm	6.6gm	873gm	2700gm	7.2gm	27gm
0.2GF-4NS	211.2gm	660gm	1.76gm	8.8gm	864gm	2700gm	7.2gm	36gm
0.3GF-1NS	217.8gm	660gm	2.64gm	2.2gm	891gm	2700gm	10.8gm	9gm
0.3GF-2NS	215.6gm	660gm	2.64gm	4.4gm	882gm	2700gm	10.8gm	18gm
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0.3GF-4NS	211.2gm	660gm	2.64gm	8.8gm	864gm	2700gm	10.8gm	36gm
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0.4GF-3NS	213.4gm	660gm	3.52gm	6.6gm	873gm	2700gm	14.4gm	27gm
0.4GF-4NS	211.2gm	660gm	3.52gm	8.8gm	864gm	2700gm	14.4gm	36gm
W/B Ratio : 0.4				Super plasticizer : 1.5% of weight of binder				

After 24 hours, the specimens are demoulded and the mortar specimens are cured in a curing tank until the time of testing. Compressive strength and split tensile strength of the mortar specimens are determined after 7 and 28 days of curing.

The compressive strength of the mortar specimens were assessed based on ASTM C109 using a Compression Testing Machine (CTM) of capacity 2000kN. The Split tensile strength of mortar specimens were assessed based on ASTM C496-90 using a Compression Testing Machine (CTM) of capacity 2000kN. Both the tests were conducted at 7 and 28 days for all twenty mixes.

3. RESULTS AND DISCUSSION

3.1. Compressive Strength

The results for compressive strength after 7 and 28 days are given in Table IV. The variations of 7 days and 28 days compressive strength for various percentages of mortars with S-Glass Fibres are shown in Fig 4. Fig. 5 & 6 gives the variation of 7 & 28 days compressive strength of mortars with Nano Silica and S-Glass Fibres.

Mix Proportion	7 Days Strength	28 Days Strength
0.1GF	29.53	34.39
0.2GF	27.43	33.34
0.3GF	29.99	36.78
0.4GF	28.87	33.40
0.1GF-1NS	29.07	37.88
0.1GF-2NS	34.77	39.44
0.1GF-3NS	35.21	41.17
0.1GF-4NS	35.67	40.05
0.2GF-1NS	36.88	42.75
0.2GF-2NS	36.94	43.42
0.2GF-3NS	37.32	43.24
0.2GF-4NS	36.47	44.28
0.3GF-1NS	38.36	45.76
0.3GF-2NS	36.13	46.93
0.3GF-3NS	36.78	47.51
0.3GF-4NS	43.92	52.50
0.4GF-1NS	39.68	47.77
0.4GF-2NS	37.74	45.80
0.4GF-3NS	38.20	46.04
0.4GF-4NS	35.81	43.32

Table IV. Compressive Strength of Mortar at 7 & 28days

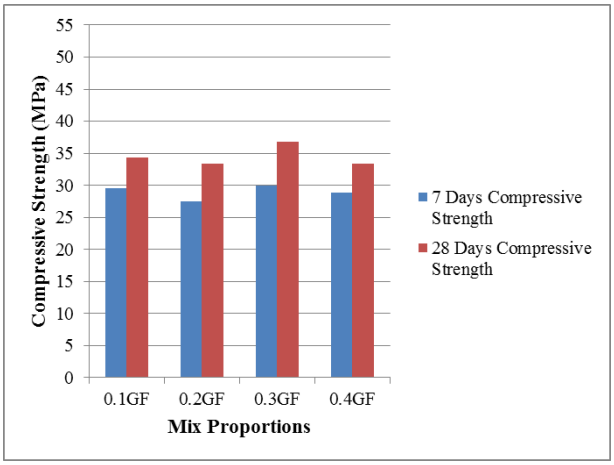

Fig. 4. Variation of Compressive Strength for mortars with S-Glass Fibres

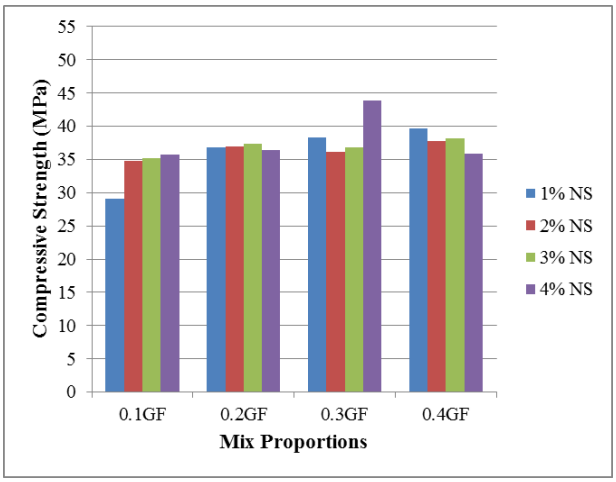

Fig. 5. Variation of 7 Days compressive strength of mortars with NS and S-Glass Fibres

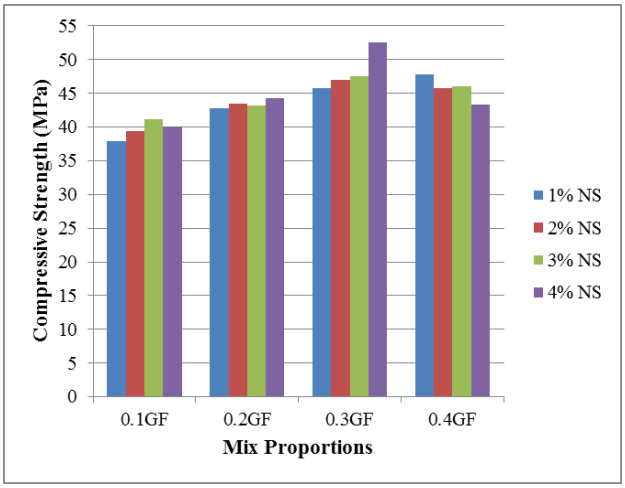

Fig. 6. Variation of 28 Days compressive strength of mortars with NS and S-Glass Fibres

3.2. Split Tensile Strength

The results for split tensile strength after 7 and 28 days are given in Table V. The variations of 7 days and 28 days split tensile strength for various percentages of mortars with S-Glass Fibres are shown in Fig 7. Fig 8 & 9 gives the variation of 7 & 28 days split tensile strength of mortars with Nano Silica and S-Glass Fibres.

Table V. Split Tensile Strength of mortar at 7 & 28 Days

Mix Proportion	7 Days Strength	28 Days Strength
0.1GF	2.26	2.98
0.2GF	2.48	3.24
0.3GF	3.31	3.37
0.4GF	2.83	3.26
0.1GF-1NS	2.73	3.39
0.1GF-2NS	3.45	3.67
0.1GF-3NS	3.38	3.79
0.1GF-4NS	3.55	3.80
0.2GF-1NS	3.49	3.99
0.2GF-2NS	3.37	4.02
0.2GF-3NS	3.41	4.06
0.2GF-4NS	3.34	4.14
0.3GF-1NS	3.52	4.29
0.3GF-2NS	3.77	4.27
0.3GF-3NS	3.73	4.32
0.3GF-4NS	3.88	4.66
0.4GF-1NS	3.41	4.40
0.4GF-2NS	3.29	4.38
0.4GF-3NS	3.07	4.20
0.4GF-4NS	2.81	4.13

From Fig 7, it is clear that the 7 days split tensile strength attains it peak for mortar with 0.3% S-Glass Fibres without the addition of Nano silica. The 28 days strength for the same mix shows a value of 3.37MPa. From Fig 8 & 9 it is seen that the split tensile strengths of the mortars with S-Glass Fibres were increased significantly with the incorporation of Nano silica. The tensile strength achieves its maximum for 4% replacement of Nano silica for mortar with 0.3% S-Glass Fibres.

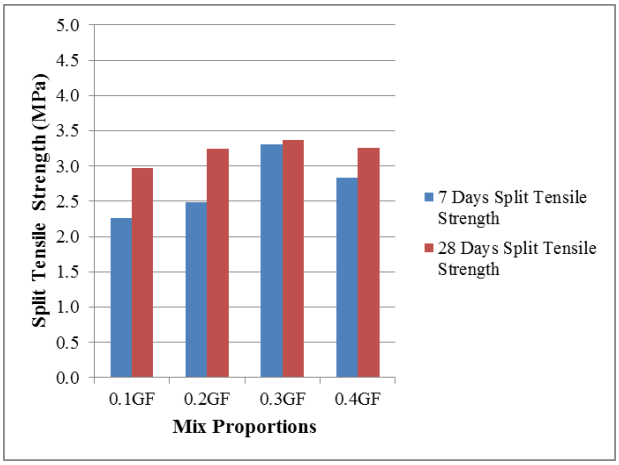

Fig. 7. Variation of 7 & 28 days Split Tensile Strength for mortar with S-Glass Fibres

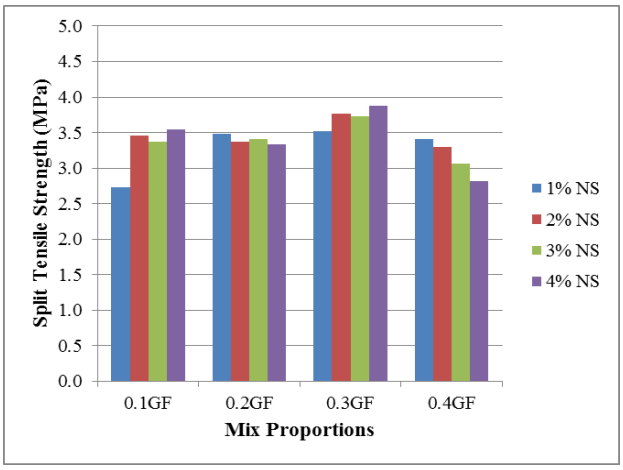

Fig. 8. Variation of 7 Days Split Tensile strength of mortar with NS and S-Glass Fibres

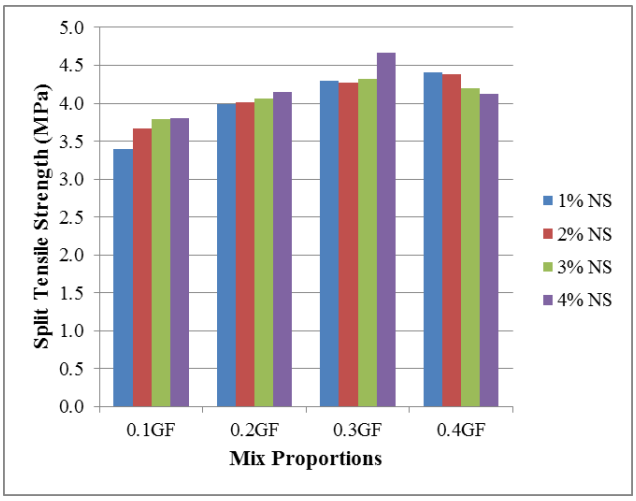

Fig. 9. Variation of 28 Days Split Tensile strength of mortar with NS and S-Glass Fibres

4. CONCLUSION

This paper presents the effect of Nano silica addition on the mechanical properties of mortars with S-Glass Fibres. Based on the experimental results, the following conclusion can be drawn.

- Amorphous silica of high purity (about 96%) is synthesised from Rice Husk Ash (RHA) using an environmental friendly technique in the laboratory. The average particle diameter of the Nano silica is about 165nm.
- Increase in addition of S-Glass Fibres improves the compressive and split tensile strength. However optimum level of S-Glass Fibres is found to be 0.3%. On further increase in S-Glass Fibres, there is a decrease in strength.
- Nano silica improves the compressive strength of mortar with S-Glass Fibres. Cement replacement up to 4% Nano silica has a noticeable influence on the compressive strength of mortar specimens with 0.3% S-Glass Fibres. Thus the optimum replacement level of Nano silica is 4%
- It is seen that the 7 days compressive strength of the specimen containing 4% replacement of Nano silica is 46.45% higher than the reference mix. Also, the 28 days compressive strength of the mortar specimens is 42.75% more than that of reference mix.
- The 7 and 28 days split tensile strength of the specimen with 4% replacement of Nano Silica is 17.22% and 38.27% higher than that of the reference mix.

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