ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

A Study on the Variation of Strength and Durability Properties of Concrete with Partial Replacement of Cement Using Nano-Silica (NS) and Fly Ash (FS)

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ABSTRACT

This paper studies the recent investigations and development of combined application of Pozzolanic additions - Nano-Silica (NS) and Fly Ash (FA) on the strength properties of concrete for sub sequential growth of concrete industry. This investigation not only saves the natural resources but also controls the environmental pollution by usage of wastes. The limited work is done on partial replacement of Fly Ash and Nano-Silica in cement paste, mortar and concrete. In the present study the cement is partially substituted by 20% and 30% of Fly Ash and Nano-Silica 1.0%,2.0%,3.0%, 4.0%,5.0% and 6.0% by weight. To understand the application of Fly Ash and Nano-Silica various literatures have been reviewed and their influence on Compressive Strength, Bending Strength (Flexural Strength), Elastic Modulus or Young's Modulus and Tensile Strength abd RCPT of M25 grade of concrete is investigated. The experimental investigation results of concrete are tabulated using the combination of various proportions of Fly Ash and Nano-Silica are collate with that of Controlled Concrete. The mechanical strength development and durability properties of concrete are greatly influenced because of this combined application of Nano-Silica and Fly Ash compared to the Controlled Concrete properties. The sustainable increase in the various strength characteristics of concrete prepared using Nano-Silica and Fly Ash can be accredited to the efficacious packing of colloidal particles and the need of additional mix in the application of Fly-Ash and Nano-Silica

INTRODUCTION

Concrete has been recommended as a construction material in wide range. At present in construction, prior to strength, the durability of concrete also has importance. The minimum cement content to satisfy the strength and durability requirements. The Indian standard code of IS 456:2000 for plain concrete design is used. This results in usage of cement in huge content. The cement production results in evolution of lots of carbon dioxide resulting in environment mortification [1]. By usage of additive Pozzolanic alternative materials [2] instead of cement upto certain proportion will be another solution for this problem. Earlier studies show that the usage of Fly-Ash (FA), Micro Silica (MS), Ground Granulated Blast Furnace Slag and Kaolinite as replaced materials [3] which results in increases in strength and durability. By introducing Nano sized materials as a partial replacement of cement which improves the performance of cement.

Because of many experimental researches on Nano particles, Nano-Silica is available as replacing material of cement in making concrete. Nano-Silica (NS) [4] is a Nano-sized, highly reactive nebulous silica. Because of Nano-Silica particle is as small as other particles and also having very large surface area as the substitute materials, its usage comparatively intensify the concrete performance upto extensive range. This amalgamation of

Cite this article as: S.Shakir Ali & Dr.K.Rajasekhar, "A Study on the Variation of Strength and Durability Properties of Concrete with Partial Replacement of Cement Using Nano-Silica (NS) and Fly Ash (FS)", International Journal & Magazine of Engineering, Technology, Management and Research, Volume 5 Issue 6, 2018, Page 231-239.

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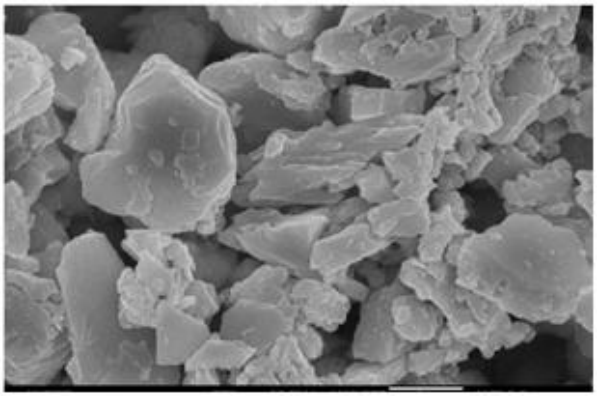
Nano-Silica and fly ash as a substitute material for cement has to be scrutinized. These particles are very tiny and generally allow forming a group of mass due to its large surface influence, consistent dispersion of these fine particles is a predominant thing to get results upto serviceable or advantageous results.

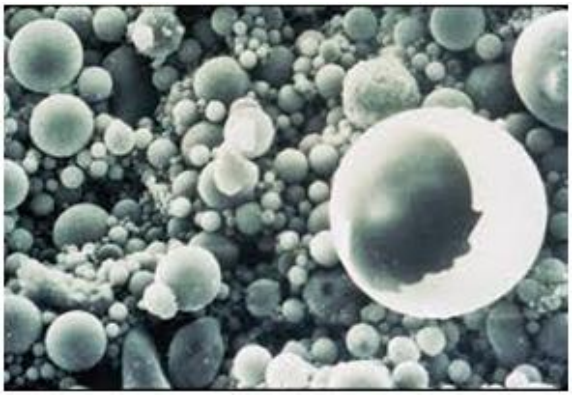
The substitutes of cement i.e., fly ash and Nano-silica which is highly prospective is to be understandable and used in rightful manner. Until last decade a squander material Nano-Silica is now emerged as an environmental protector with its less toxic nature when compared with cement. Now-a-days the CDM technology or Clean Development Mechanism [5] exceptionally encouraged by both cement industries and also government. Advanced counties like United States and Japan are responsible for 35%-40% of global discharges, besides this India accords upto 3.5% of the Green house emissions (GHS) when compared with normal average of 5.5%.

By the end of every year in India with predominant usage of substitute materials i.e., fly ash and Nano-silica the emission of Carbon dioxide are reduced by 30 million tons, coal powder by 20 million tons and lime powder by 35 million tons. The possible levels of this emission of green house gases are to be controlled upto the mark.

In most of the construction projects Class-F fly ash [6] is used. Due to ordinary temperature conditions heat produces while curing of concrete which results in a unique Cementitious material [7] in the mixes of High Strength and Mass Concrete also. So, the Class-F fly ash is a best suitable and recommendable Cementitious material in summer conditions. For the past 7 decades the investigations on the performance of fly ash has been carried out and by its application results itself shows its implementation as substitute. At preliminary phase, Pozzolonic procedure [8] is predominant. Most of Researchers involved for the development of the potential performance of fly ash and the hydration process of substitute materials with cement. Depending on the fly ash properties and their cognition it is seen that the particles Class-F fly ash includes morphology which is quite varying them from normal Pozzolonic particles as shown in Figure 1.



(a) Portland Cement



(b) Fly Ash

Figure1 SEM micrographs (8,000×)

Fly ash has the ideal character of reducing water when compared with other substitute Pozzolonic materials. Both structure of hardened cement and Rheological properties are influenced initially by using fly ash.

The Structural and Surface properties are formed in the mixture due to morphology effect because of crystalline nature of the minerals which are in powdered form. The particle size distribution also occurs because of morphological effect [9]. The three important phases like Filling, Lubricating and well distributing are carried in the concrete because of effect of using fly ash in cement as substitute material. These three phases of concrete depends on shape, size etc. This also impact on properties of concrete.

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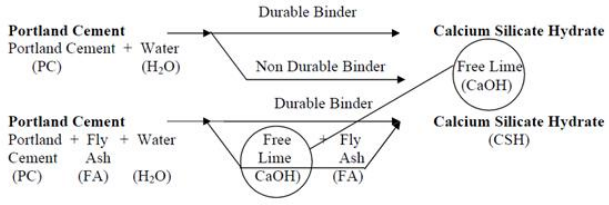
The further advancements lie in the following features,
1) Assimilating the Fly ash in Concrete which is most commonly used design method deliberately enhances the total quantity of binder in concrete mix and eases the compaction.
2) During the process of hydration of cement heat produces and which can be prodigiously decreased by replacing cement with Fly ash upto certain quantity in concrete mix.

As per ASTM(American Society for Testing and Materials) C125, is a Siliceous material and Aluminous material which is a non-Cementitious or a partial Cementitious valued one with a finely divided formed and also combines with Ca(OH)2¬ in the presence of moisture to form a Cementitious compound [10] at ambient temperature. Fly ash is basically used to improves the Strength and Workability and contribute to strength development and hence considered to be an effective ingredient of concrete. It also has been widely used as replacement of cement in both High Strength and normal concrete mix. The preliminary aim of using fly ash is due to its high fineness, which decreases the air gaps (pores) in the concrete mix and improves the compressive strength.

The following equation shows the difference in reaction when fly ash is introduced.



The unstable state of Al2O3 and SiO2 in fly ash are made active using the product Ca(OH)2 which liberated from the hydration of cement due to Pozzolanic effect of fly ash results in the formation of hydrated gel. The air gaps or pores present in the concrete are to be filled by this hydrated gel produced which results in the predominant increase in strength of concrete and also often leads to the generation of long-term strength to concrete. Dumping the waste mineral products of Thermal power plant to the environment can cause severe effects, so that the usage of waste material has been given special importance. The waste By-products are to be utilised to produce new products or used effectively as the natural admixtures for the environmental protection.

NANO SILICA:

In the present days the micro-level does not provide enough insight into the building materials. Therefore, all around the world, the research is being diverted into the nano level, which is claimed to have tremendous potential for the future. The fundamental processes that govern the properties of concrete are affected by the performance of the material on a nano scale. The main hydration product of cement-based materials, the C-S-H gel, is a natural nano-structured material [11].

For the creation of huge materials a technology based on the usage of minute particles which are nano sized are used by manipulating them. It is important to check whether the particle size usually in the order of ≤100nm because the particle size i.e., nano (10-9) may affects the properties of materials.

The technology of using nano sized particles is not a present-day technology, as we know it exists few decades ago by the continuation of technologies along with science which are rapidly developing on analysis of nano sized, micro sized and other smaller particles as shown below,

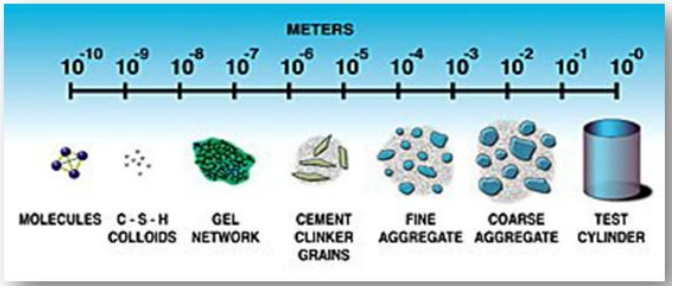


Fig.2 Particle Size variation

Behaviour of Nano-Silica (NS) in Concrete

Because of its nature the Nano-Silica (NS) tends to accelerate the Hydration process of cement [12]. Cement replacement with Nano-Silica will improve the strength

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International Journal & Magazine of Engineering, Technology, Management and Research
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properties also. The spherical shape of Nano-Silica (NS) fills the air gaps in the concrete specimen which results in the improved structure of concrete specimen with more durability and non-permeable nature. Because of the gaps filled with Nano-Silica (NS) the density of concrete specimen is increased and also the Compressive Strength of concrete improves. The two failures conditions of Segregation and Bleeding are controlled with increase in workability of concrete with usage of Nano-Silica (NS). The Early stage cracking occurs in concrete due to low workability is also lowered with the Nano-Silica application in Pavement Design [13].

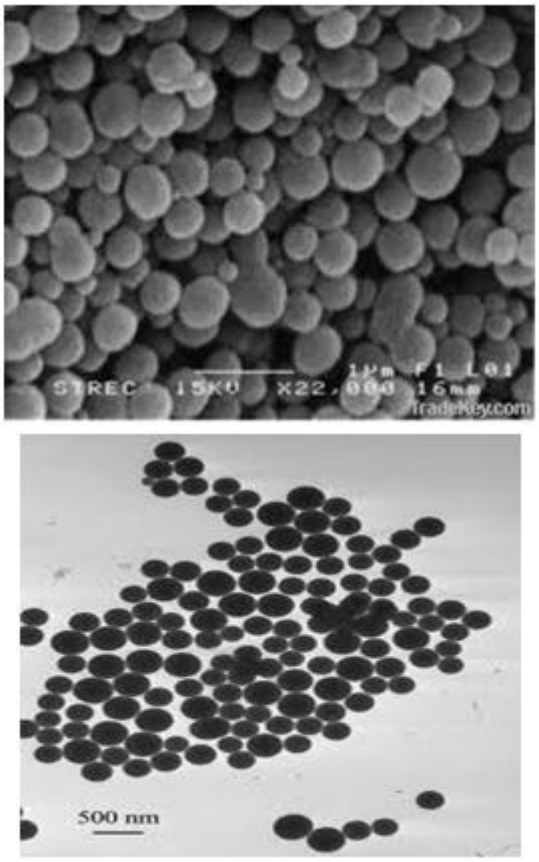

Fig: 1.3 Nano-Silica (NS) with Spherical Shape

MATERIAL PROPERTIES

In general concrete is widely used construction material which comprises of cement, Fine aggregates, coarse aggregates and water. Due to hydration of cement the stronger mass is formed with cement and water paste. The voids in the cement and water paste is filled by the both coarse and fine aggregates.

We know that the plastic nature of cement tends it to mould in any form easily. So, the moulded cement can be smoothened using a trowel. Major precautionary steps are to be followed to control the rapid loss in water content and also to avoid pores in concrete which results in decrement in strength. The two affects of Segregation and bleeding are controlled in concrete. The cement and water paste only defines the quality of the concrete specimen. The proportions which we use in mix design are also plays an important role in determining the characteristics of concrete. An air gaps retarding agent is to be mixed with this so that the pores in the concrete can be eradicated which results in density increment.

Due to the Tri-calcium Silicates present in the concrete may gradually increases the strength properties. Fine aggregates used to concrete preparation are advisably rough, angular and but now-a-days we are using only rounded grains. Because we are using stone which are angularly available which attains a density of 2,500 Kg/m3. A steel bar or Mesh are introduced in concrete because of its weaker strength characteristics in tension zone.

CEMENT

As per the specifications of code IS: 8112-1989 (ordinary Portland cement) of 43grade is used for the present investigation. The cement utilized should be free of lumps and fresh and various investigations carried out should be as per Indian Standard Code specifications.

FINE AGGREGATES

Available sand from Local River confirming to IS: 383-1970 was used as fine aggregates in concrete preparation. The fine aggregates passing through 4.75mm IS sieve is utilized.

COARSE AGGREGATES

Coarse aggregates of nominal sizes 20mm and 10mm locally accessible demolished stone acquired from the quarries confirming to IS383-1970 was utilized in the proportion of 1.5:1.0

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WATER

Water used for casting and curing of concrete specimens should be free from all types of contaminants like alkalis, salts, acids, organic matter, oils and other pollutants. The water with impurities can adversely influence the strength properties of concrete.

FLY ASH

For the present investigation Fly Ash of "Class-F" obtained from the Thermal Power plant is used. The Fly Ash proportions of 20% and 30% by weight of cement are used. The Physical properties of Fly Ash are as shown in table-5

Figure 5 Fly Ash Sample

Table 5: Properties of Fly Ash

S.No.	Properties	Values
1	Silica (SiO_2)	56.87 %
2	Aluminium trioxide (Al_2O_3)	27.65 %
3	Ferric oxide ($Fe_2O_3 + Fe_3O_4$)	6.28 %
4	Titanium dioxide (TiO_2)	0.31 %
5	Magnesium oxide(MgO)	0.34 %
6	Loss of ignition (LOI)	4.46 %
7	Specific gravity of Fly Ash	2.12

NANO-SILICA

Nano-Silica utilised in this investigation is a Pozzolanic colloidal silica emulsion. It is a better Pozzolanic material because of its high content of Amorphous Silica (>99%) and also their reduced spherical size of order 15 nano meters-50 nano meters.

In our present investigation we used the Nano-Silica contents as 2%, 4% and 6%. The properties of Nano-Silica is shown in table-6

Table 6: Properties of Nano-Silica

S.NO.	Properties	Actual results
1	Nano solids	39.5-41%
2	Ph	9-10.0
3	Specific Gravity of the sample	1.29-1.31
4	Sample Texture	White Liquid (Milky liquid)
5	Dispersion	Water

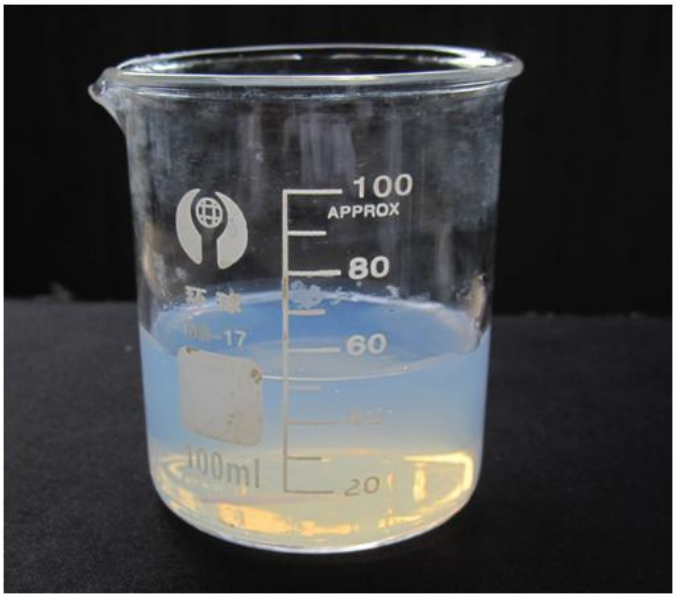

Fig 6 Nano-silica sample

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TESTS ON NANO-SILICA (NS) AND FLY ASH (FA) CONCRETE

COMPRESSION STRENGTH TEST

The strength property test in which the very important test is compressive strength of cube or cylinder specimens are ease to performed and also relates it to the controlled concrete confirming to the IS: 516-1959 and these specimens are underwent compression test by using CTM machine as shown below:

Compression Strength Testing Machine

The casted Concrete cubes of size 150mm × 150mm × 150mm were prepared for the CTM machine test and it is to be done at rate of 140kgs/Sq.cm/minutes until the cracking occurs or failure occurs and it is to be done at 7, 28 and 56 days of curing period.

SPLIT TENSILE STRENGTH TEST

At 28days of curing age the concrete specimens are prepared for Split Tensile Strength by using codal provisions of IS 5816-1999 and its specifications. The test carried on cylinder specimens of 300mm height and 150mm diameter. The load on the sample is carried out until the specimen fails with gradually applied load. The extreme load that is applied on the specimen is noted down. The splitting tensile strength (Ft) is given by the relation,

$$F_t = 2P/\pi DL$$

Where, P = Compressive load
L = Length of the cylinder
D = Diameter of the cylinder

Split Tensile Testing Machine

RESULTS

COMPRESSIVE STRENGTH

By the combined application of Fly Ash and Nano-Silica the compressive strength of cube specimens varies with Age of concrete in days as shown in fig-6 and the strength attained is the average of three test results.

It is noticed that the compressive strength attained by the combined application exhibits more than that of Controlled concrete as shown in table 7

Table 9: Cube Compressive Strengths of M35 Grade Concrete

Concrete Mix	Fly Ash (%)	Colloidal Nano Silica (%)	Compressive Strength (MPa)				
			3 Days	7 Days	28 Days	56 Days	90days
Control Concrete	0	0	18.17	28.55	43.25	45.50	46.20
FA 20 % + NS 0 %	20	0	19.53	30.90	45.42	48.35	49.12
FA 20 % + NS 1.0%	20	1.0	21.03	34.22	48.92	50.78	49.98
FA 20 % + NS 2.0%	20	2.0	24.25	39.70	55.13	57.14	57.65
FA 20 % + NS 3.0 %	20	3.0	20.26	31.85	48.25	50.30	53.21
FA 20 % + NS 4.0 %	20	4.0	19.98	30.54	45.32	48.12	50.17
FA 20 % + NS 5.0 %	20	5.0	17.31	27.55	40.12	40.78	42.22
FA 30% + NS 0 %	30	0	19.22	33.14	44.19	47.66	49.77
FA 30 % + NS 1.0 %	30	1.0	21.23	34.02	47.25	50.32	52.09
FA 30 % + NS 2.0 %	30	2.0	21.54	34.26	48.94	51.85	52.10
FA 30 % + NS 3.0%	30	3.0	20.39	31.72	45.32	47.62	49.86
FA 30 % + NS 4.0%	30	4.0	19.10	32.12	43.15	46.55	47.45
FA 30 % + NS 5.0%	30	5.0	17.97	29.86	41.32	44.69	46.59

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International Journal & Magazine of Engineering, Technology, Management and Research
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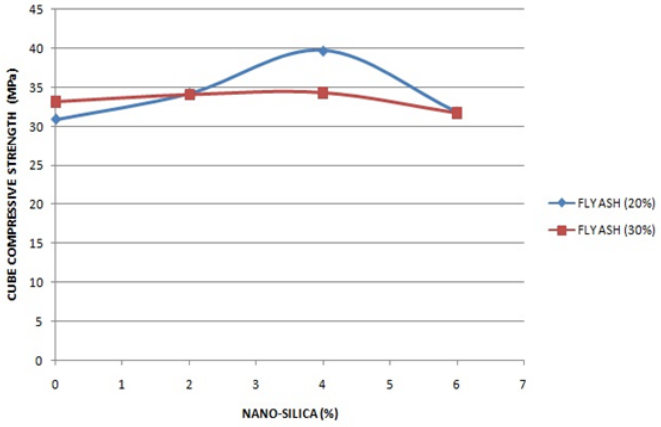
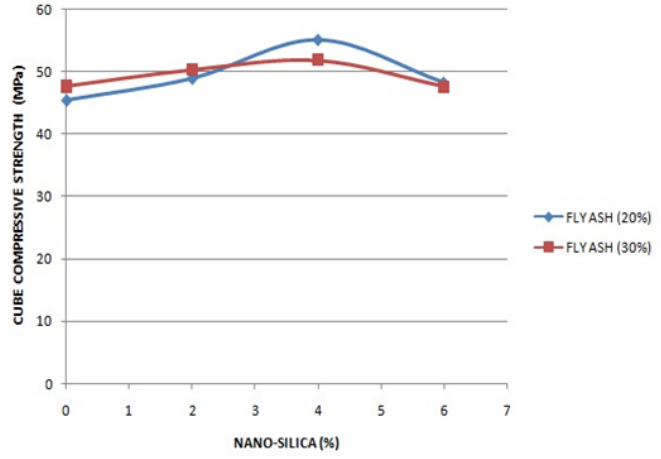
It is noticed that, the cube compressive strength increases upto the combination Fly Ash (20%) and Nano-Silica (4%) at 7 days and 28 days as 39.70MPa and 55.13MPa. It is observed that a sudden decrement in cube compressive strength occur when Nano-Silica content is above 4%. When Fly ash (30%) content is changed and Nano-Silica (4%) then the compressive strength is less than the compressive strength of controlled concrete. The cube compressive strength increases upto 11.22% and 12.10% by the combined application of Fly Ash (20%) and Nano-Silica (4%) as shown in fig-7



(a) 7 days cube compressive strength (MPa)



(b) 28 days cube compressive strength (MPa)

Fig: 8 show the variation of cube compressive strength (MPa) at 7days and 28days with Nano-Silica (%) with various proportions of Fly Ash (%).

Differentiating the compressive strength between cube specimen and cylinder specimen at 28days of curing of concrete specimen for various Fly Ash and Nano-Silica proportions is mentioned in table-8. The compressive strength varies between cube and cylinder around a ratio of 0.88.

Table: 10 Shows the Differentiation of compressive strengths of Cube and Cylinder at 28days curing with various Fly Ash and Nano-Silica content

S.No.	Concrete	Cube Compressive Strength (MPa) σ_{Cube}	Cylinder Compressive Strength (MPa) $\sigma_{Cylinder}$	$\sigma_{Cylinder}/\sigma_{Cube}$
1	Control Concrete	43.25	37.25	0.86
2	FA 20 % + NS 0 %	45.42	39.97	0.88
3	FA 20 % + NS 1.0 %	48.92	43.04	0.88
4	FA 20 % + NS 2.0 %	55.13	49.62	0.90
5	FA 20 % + NS 3.0 %	48.25	42.46	0.88
6	FA 20 % + NS 4.0 %	45.32	38.65	0.85
7	FA 20 % + NS 5.0 %	40.12	36.71	0.91
8	FA 30% + NS 0 %	44.19	37.56	0.85
9	FA 30 % + NS 1.0 %	47.25	40.64	0.86
10	FA 30% + NS 2.0%	48.94	43.56	0.89
11	FA 30% + NS 3.0 %	45.32	40.79	0.90
12	FA 30% + NS 4.0 %	43.15	39.10	0.90
13	FA 30% + NS 5.0 %	41.32	36.21	0.87

SPLIT TENSILE STRENGTH

For M35 Grade of concrete mix the Split Tensile Test variance is investigated for the concerned proportions of Pozzolanic substituent Fly ash and Nano-Silica and is mentioned in table-9. The investigated Split Tensile Strength for controlled concrete is 4.14 N/mm2. This strength varies gradually with the increase in Nano-Silica content upto 4% and then a sudden decrement in strength occurs with increase in Nano-Silica as shown in fig-8. It seems that the combined application of Fly ash and Nano-Silica with 20% and 4% gives extreme strength improvements and if the Nano-Silica content changes to 6% with same fly ash obtains the tensile strength as 4.39 N/mm2.

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Table: 11 Shows the percentage variation of split tensile strength for M35 grade concrete mix for various proportions of Fly Ash and Nano-Silica

Concrete Mix	FA (%)	Nano Silica (%)	Split Tensile Strength (N/mm^2) for 28 Days
Control Concrete	0	0	4.14
FA 20 % + NS 0 %	20	0	4.26
FA 20 % + NS 1.0 %	20	2	4.34
FA 20 % + NS 2.0%	20	4	4.70
FA 20 % + NS 3.0%	20	6	4.30
FA 20 % + NS 4.0%	20	4	4.10
FA 20 % + NS 5.0%	20	5	4.6
FA 30% + NS 0 %	30	0	4.15
FA 30 % + NS 1.0%	30	2	4.33
FA 30% + NS 2.0%	30	4	4.43
FA 30% + NS 3 .0%	30	6	4.20
FA 30% + NS 4 .0%	30	4	4.13
FA 30% + NS 5 .0%	30	5	4.8

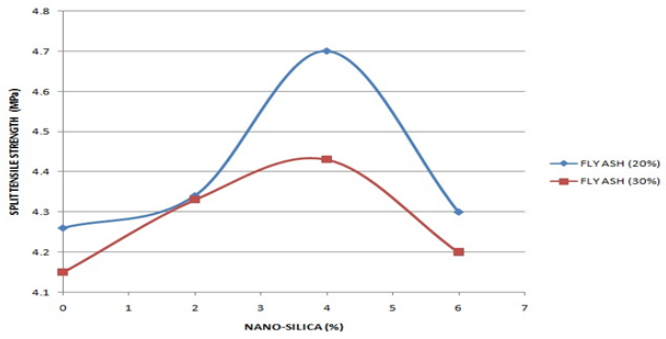

Fig:9 Graphical variation of split tensile strength of M35grade concrete for various mix proportions of Fly ash and Nano-Silica.

CONCLUSION

- From the investigation results i.e., a partial replacement of cement with Fly Ash and Nano-Silica it is studied that various strength properties of concrete mix increases upto 4% application of Nano-Silica content and decreases with further increment.
- It is quite enthusiastic observation that the changes occurred in the strength properties like compressive strength, tensile strength and flexural strength with change in cement proportion.
- Due to the presence of additional binder which is formed by the combination of Fly ash and Nano-Silica with Calcium hydroxide substantially increases the strength properties of concrete.
- Because of additional binder formed in concrete due to the Pozzolanic additives tends to form a paste-aggregate bond which leads to increment in the strength properties of concrete.
- The partial replacement of Fly ash and Nano-Silica tends to give maximum increment in strength properties at Fly ash content 20% and Nano-Silica content 4%.
- But the decrement in the strength properties with increase in Nano-Silica content is due to the formation of poor quality binder.

SCOPE OF FUTURE WORK:

The influence of Fly Ash (FA) and Nano-Silica (NS) are investigated on strength properties of concrete and also durability. This study also helps further to investigate the Resistance impact on concrete using Fly Ash (FA) and Nano-Silica (NS).

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