International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-12 Issue-4, April 2023

Impact of Substitution of Silica Nanoparticles on Compressive Strength of Concrete

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***Abstract:** In present work, we studied the effect of substitution of silica nanoparticles (SNPs), by replacement of cement on ultrasound pulse velocity and compressive strength of concrete specimens. We also obtained correlation between ultrasound pulse velocity (UPV) and the compressive strength. The mean particle size of silica nano-particle was 20nm. The quality of concrete specimen was assessed by measuring ultrasound pulse velocity (UPV) in m/s and compressive strength (N/mm²). The average value of UPV on 7th day of curing turned out to become 3200 ± 36, 3215 ± 42, 3290 ± 41, 3349 ± 24, 3450±17 and 3456 ± 12 for 0%, 0.5%, 1.0%, 1.5%, 2.0% and 2.5% content of SNPs in the specimens respectively. Similarly, the average value of UPV on 28th day was 3540 ± 36, 3580 ± 38, 3696 ± 42, 3820 ± 39, 4160 ± 40, 4163 ± 41 for same amount of substitution of SNPs respectively. It had been observed that the UPV was higher in the specimens replaced by silica nano-particles (by weight of cement) and it achieved maximum strength at nearly 2% (that is in between 2.0-2.5%). The average compressive strength on 7th day was 25, 25, 27.6, 30, 32.4 and 32 N/mm², but, on 28th day the it increased up to 38, 38.5, 40, 42, 48.5 and 48.8 N/mm² for the same content of silica nanoparticles (0%, 0.5%, 1.0%, 1.5%, 2.0% and 2.5%) respectively. As UPV increased so did the compressive strength. We observed strong correlation (correlation coefficient 0.997) between USV and compressive strength and variance (R^2 = 0.87), which meant 87% of variation of compressive strength could be explained by variation of USV for the specimens (which acquired its compressive strength) on 28th day. Compressive strength and USV increased due to hydration reaction leading to C-S-H (Calcium-Silicate-hydrate) gel formation which filled the pores in the concrete matrix. The compressive strength of concrete significantly increased with content of silica nano-particles within the selected range of content (1.5-2.5%), but there is limitation probably due to agglomeration of nanoparticles, which destroyed the salient features nano-particles.*

***Keywords:** Agglomeration, Compressive Strength, Ultrasound Pulse Velocity, Concrete Mix.*

I. INTRODUCTION

In this paper our aim is to study the impact of partial replacement of cement with silica nanoparticles (by weight of cement) on ultrasound pulse velocity and compressive strength of concrete to obtain good-performing concrete structure.

Manuscript received on 02 February 2023 | Revised Manuscript received on 21 February 2023 | Manuscript Accepted on 15 April 2023 | Manuscript published on 30 April 2023.

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Amorphous silica nano-particles exhibit pozzolanic reaction, on account of small size and pozzolanic reaction, the SNPs are very effective in enhancing the performance [1], strength and durability of concrete [1,2] by accelerating the hydration reaction and filling the micropores in the cement paste structure. Due to decreased porosity within concrete the strength of concrete will obviously increase. Thus nanoparticles can reduce porocity and provide denser microstructure [1]. Further, addition of silica nanoparticles also reduce setting time [3, 4]. In addition, SNPs is supportive to reduce the setting time of concrete [3,4], this is because the addition of nano-materials accelerates the hydration of tri-calcium silicate (C_3S) and dicalcium silicate (C_2S), which accelerates the formation of C-S-H gel, thereby shortening the setting time of the sediment [5,6]. Mohammed et al., (2016) have shown that nano-silica has the ability to improve the compressive strength and durability of concrete through chemical and physical action [7]. Nano-silica acts an activator to Pozzolanic reaction, this leads to produce more C-S-H gel, in addition to this, it also has ability of refine the pores of the system and densification of the interfacial transition zone (ITZ) [7]. Several investigators observed that on addition of SNPs to the cementing system hydration of concrete is increased which enhanced the early strength of concrete [8]. It could reduce the penetration of chloride ions and help prevent the corrosion of steel bars in concrete [9]. Nano-silica particles are also valuable in enhancing the strength of mortar, because they can fill the pores in the matrix and also act as an activator to promote pozzolan reaction [10]. The weakest area in concrete is the interface between the cement matrix and the aggregate. Adding an appropriate amount of nano-SiO_2 to the concrete can enhance the interface strength and refine the pores, which can effectively reduce the water permeability of concrete [11]. It has been pointed out that the incorporation of silica nanoparticles (SNPs) increases the non-evaporable water and degree of hydration of cement paste [12]. The degree of hydration had been observed to boost up in SNPs modified cement [12] and there was reduction in capillary porosity due to SNPs added in cement paste. In certain studies the SNPs refined the pore structure of the cement paste led to denser microstructure as a result of more polymerized C-S-H gel formation, desirable for high strength and durability [12]. Ultrasound pulse velocity can be used to predict compressive strength [13, 14]. However, there exists no definite rule to describe how does the relationship between UPV and the compressive strength of concrete change with its mix proportion. Of course, the regression models to some extent predict the relationship between USV andcompressive strength [13,14].

In certain cases with a particular mix proportion, there existed good correlation between UPV and the compressive strength. This indicates that the compressive strength and USV correspond with mixture proportion. UPV is influenced by mixture proportions, aggregate type, age of concrete, moisture content etc [15].

The compressive strength increases with decrease of w/c ratio and w/c ratio can be reduced by mixing superlpasticizer (SP) in concrete mix. Superplasticizers are referred to as high range water reducers as it reduces w/c (water-cement ratio) at the same workability. SP, would have accelerating and significant effects on properties of concrete due to reduction in water content of concrete [16]. It has been reported further that the compressive strength improved due to addition of superplasticizer after 28 days of curing [17] The investigator showed that, the optimum amount of admixture must be 1.0 %, however, over dosage of SP would deteriorate the properties of concrete with indication of lower compressive strength [16].

The concrete block made of same grade, age, quality under same condition after 28th day of curing can predict relationship relationship between UPV and compressive strength [17-19].

II. METHODOLOGY

A. Sample Preparation of Concrete Specimens

For measurement of UPV or compressive strength, we needed casting of concrete cubes of size 150mm and measuring ultrasound pulse velocity (UPV) and compressive strength of the specimens. Mix ingredients were cement, water, fine aggregates, coarse aggregates super plasticizer in proportions as, Cement = 350kg/m^3 , Water = 140 kg/m^3 , Chemical Admixture (Superplasticiser) = 7 kg/m^3 , Fine aggregates = 830.56 kg/m^3, Coarse aggregate = 1215.43 kg/m^3, W/c = 0.4 and the average size of silica nanopartcles (SNPs) 20 nm**.**

We preferred the ‘‘dry mixing” procedure and the mixing duration was set at 55 minutes which we assumed to prevent agglomeration of particles. The ingredients were mixed in a high-speed blender to get uniform distribution of the nanoparticles in the mix and also to prevent agglomeration of these particles due to Van der Waals forces.

All the ingredients of concrete were mixed to prepare concrete mixture. For the mixes containing silica nanoparticles in concrete, the nanosilica powder were added to one liter of water with superplasticizer (i.e. 2% of cement by weight). Silica nanoparticles were added in small fraction to the concrete mix by replacement of cement (expressed in percentage). An experimental test had been carried out on the 150mm cube size specimens in which content of silca nanoparticles was 0%, 0.5%, 1.0% and 1.5%, 2.0 and 2.5% by weight of cement (b.w.c).

After the completion of mixing, the concrete paste was poured in the cubical mold (dimensions 150mm × 150mm × 150mm) with precautions against formation of voids, we strictly followed the provisions laid down by the Bureau of Indian Standards. All constituents and their respective quantity (water content, cement, superplasticizer, fine and coarse aggregate) remained the same in all cubical specimens, except the content of silica nanoparticles, which varied in the range 0-2.5% by partial replacement of cement.

This, way we prepared six samples for each set of nano-silica mix sample with its content varying from 0% (sample without nanoparticles), 0.5%, 1.0%, 1.5% 2.0, and 2.5% respectively. The samples without (0% SNPs) silica nanoparticles were used as control.

Curing: On successful casting, the cubes of the specimens were taken out from the specimen holders (moulds) after 24 hours and submerged in dirt-free water at room temperature (nearly 28^{0}C) untill the testing day (i.e. on 7th or 28th days). The surface of specimens was dry but saturated when tested. The samples were divided into two groups (i) Control Group and (ii) Experimental Group of specimens in which cement was partially replaced by 0.5%, 1.0% and 1.5%, 2.0% and 2.5% silica nanoparticles by weight of cement respectively.

B. Ultrasound Pulse Velocity: Measurement Technique

Ultrasound Pulse Velocity (UPV) technique is a non-destructive (NDT) method of determining health of concrete structure. UPV depends on the properties of the medium. The UPV have been used for assessing quality of concrete, elastic modulus, cracks, voids and several defects inside the structure. For determining UPV and hence quality of concrete, measurement (of UPV) were carried out on 07th day and 28th day, the tests were performed on the specimens (control as well as experimental). UPV provides information on strength of material and hence relationship between compressive strength and UPV can be determined and correlation could be established [18-19].

Apparatus: The UPV measurement equipment consisted of two identical transducers having central frequency 54 kHz and diameter 5.0 cm, out of which one transmitted the ultrasonic pulse, and the other received it. The transducer convert electrical pulse into mechanical vibration having frequency in between 40 kHz to 50 kHz.

Pulser-Receiver setup is used to excite the transducers for generation of ultrasonic pulses. This unit consisted of electronic circuit for generating pulses and the receiver unit received the signal. The third component is a CRO which is a data acquisition system employed to display and analyze the receive output. We used 100 MHz oscilloscope (Iwatsu SS-5711C with Universal counter). Transit time or Time Delay (in μs-microseconds) was directly displayed on the counter of CRO could be recorded. Block diagram for measurement of Ultrasound Pulse Velocity is shown in Fig.1. In this set up the two transducers T (Transmitter) and R (Receiver) are indicated and cubical test specimen (dimension 150mm × 150mm × 150mm) is placed between the transmitting transducer left and the receiving transducer on right. The transmitting transducer was excited by electrical pulse to produce ultrasonic pulse, it passed through concrete block and the received by the receiver, signal on passing through the specimen was fed to CRO (cathode ray oscilloscope CRO-5511C, sampling rate 100 MHz with A/D data acquisition board). We can adjust pulse repetition rate (PRR) between 20 Hz - 2 KHz, because of inbuilt facility in the pulser-receiver set up which gives output 1.0V.

Retrieval Number:100.1/ijeat.D40330412423
DOI: 10.35940/ijeat.D4033.0412423
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ASTM recommended, transducers frequency in the range 20-100 kHz for measurements of ultrasound pulse velocity. We, therefore, used 54k Hz transducers for UPV test. An input square wave pulse of frequency 50 kHz fed to the transmitter was amplified to nearly 100V (peak to peak).
For measurement of UPV in a sample, the cube samples (block of 150mm × 150mm × 150mm) was placed in between the transmitting transducer and receiving transducer and gel (petroleum jelly) was applied at the contact face between the transducer and the sample in order to enable easy propagation of ultrasound pulse (by matching acoustic impedance between air gap and concrete medium), otherwise the air pocket between the transducer and concrete may give error in measurement of transit time.
Time of travel (transit time) in sample of precisely known thickness or length was recorded in microseconds (μs) from universal display unit of CRO. Distance travelled in sample divided by Transit time would give ultrasound pulse velocity. In 1951 Whitehurst reported soniscope tests on concrete structure (Proceedings ACI Vol. 47, pp 433 (1951).

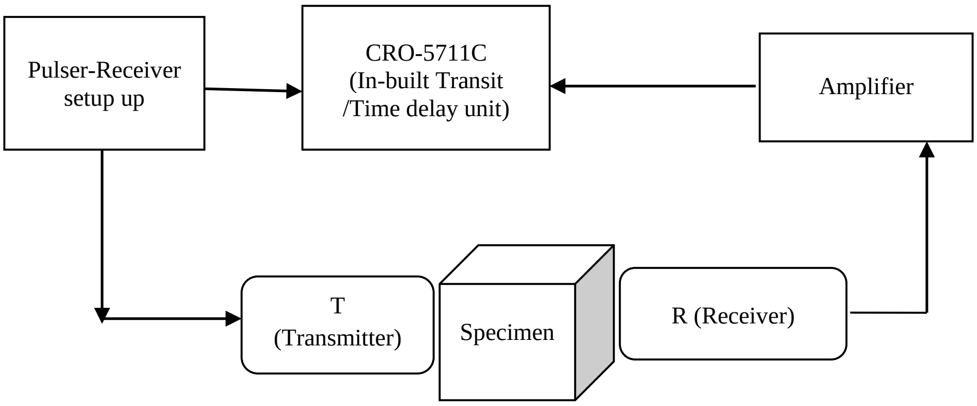

Fig. 1. Block diagram of Ultrasound Pulse Velocity Test, T and R are the Transmitting and Receiving Transducers. The test specimen is placed between Transmitting Transducer left and the receiving transducer on right.

The criteria for grading of concrete quality on the basis of ultrasound pulse velocity (IS 13311 part 1: 1992) has been presented (Table 1).

Table-1: Criteria for Grading of Concrete Quality on the Basis of Ultrasound Pulse Velocity (IS 13311 part 1: 1992).

Number	Ultrasound pulse velocity (UPV) in concrete	Quality grading of concrete
1	> 4570 m/s	Excellent
2	3660-4570	Very good
3	3050-3660	Questionable/Satisfactory
4	2130-3050	Generally poor

Table 1, shows guidelines of quality classification of concrete based on UPV. Higher velocity would suggest better quality and continuity inside the material, while decreased velocity imply poor quality, cracks, bubbles or voids within the structure of concrete. Thus, in defective domain of concrete, the compression wave velocity becomes slower than the normal (un-defective) region and the signal amplitude is also attenuated. If the structure contains large gap, intense voids, signal may totally be attenuated. In addition to this, the signal may become distorted due to a honeycomb defect. UPV depends on modulus of elasticity and density of the medium through which it propagates, consequently, it gives information about internal defects or imperfection, location of defect, compactness and homogeneous or heterogeneous regions within the concrete. Ultrasound pulse velocity for six samples of each group with variation of content of silica nanoparticles for 07 days and 28 days were calculated.

C. Measurement of Compressive Strength

Compressive strength test is a destructive test, measured by crushing the concrete specimen in compressive testing machine. The test determines characteristics of concrete. It is calculated by formula as given;

Compressive Strength = Load / Cross-sectional Area.

Compressive strength is expressed in pounds per square inch or Mega Pascals (MPa) in SI units or N/mm^2 (Newton per cubic millimeter).
The surface of the specimens was investigated under dried condition according to Indian Standard IS: 516-1959 norms. The compressive strength tests were accomplished on compressive test machine. The cubes of specimens (size 150mm) were allowed to dry up. They were tested on their sides and the gauging time was strictly observed. A cube was positioned appropriately in the testing machine and load was applied gradually at the rate of 140 kg/ cm^2 (13.7293 N/mm^2) till the specimen break. For example, on a cubical sample of 15 cm ×15 cm ×15cm, the break-load were 56, 57, 58 tons the compressive strength turned out to become 24.42, 24.85 ans 25.29 N/mm^2 respectively then the average compressive strength was 24.85 ≈ 25 N/mm^2. There were six cubes of specimens in each group in which cement content were partially replaced by 0%, 0.5%, 1.0%, 1.5%,2.0% and 2.5% silica nanoparticles. For each group six specimens were tested using the same procedure for calculating average compressive strength.

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DOI: 10.35940/ijeat.D4033.0412423
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III. RESULT AND DISCUSSION

Variation of average ultrasound velocity with concentration Silica nanoparticles on 07th and 28th days are shown Fig. 2 & 3 respectively. The comparison of average value of ultrasound pulse velocity for 0%, 0.5%,10%, 1.5%, 2.0% and 2.5% respectively on 7th and 28th day are also indicated in Fig 4. Ultrasound pulse velocity increases with content of silica nanoparticles after seven days (Fig. 2) and the same happens after twenty eight days also (Fig 3). Overall, the 28-days quality of concrete was found far better than those of 07-day quality in terms assessment using UPV.

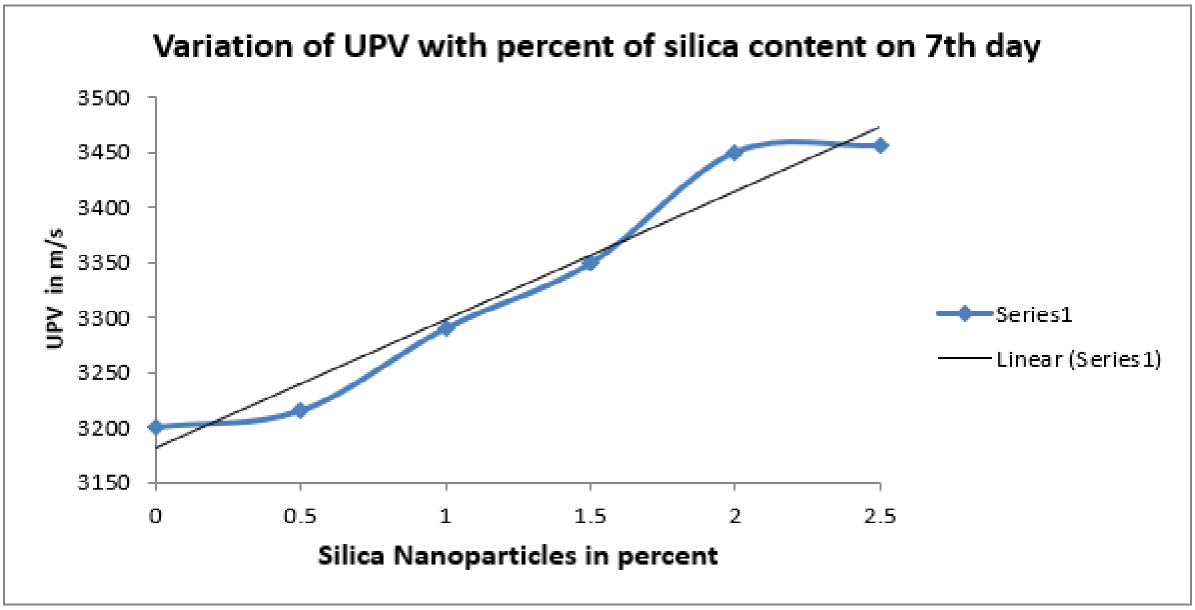

Fig. 2. Variation of Ultrasound Pulse Velocity with Content of Silica Nanoparticles After 07 days.

It had been observed that the ultrasound velocity in the samples increased with content of silica nanoparticles on 07th day (Fig.2). Further, the change in USV was not found significant for the samples containing 0.5% SNPs content with respect to the control samples and nearly the same result was observed for those samples which contained silica nanoparticles below 1.0%. The average value of UPV was found to be 3200 ± 36, 3215 ± 42, 3290 ± 41, 3349 ± 24, 3450±17 and 3456 ± 12 for 0%, 0.5%, 1.0%, 1.5%, 2.0% and 2.5% SNPs content respectively (Fig. 2). But, the significant increase in UPV for content between the range 1.5-2.5% was observed. Overall, the trend for rise of UPV could be linear as shown in Fig. 2.

Similarly, the variation of Ultrasound Pulse Velocity with Silica nanoparticles expressed in percentage on 28th days are shown in Fig 3. The UPV increased on 28th days of curing when compared with 7th day data in all cases, because the samples were getting stronger with time.

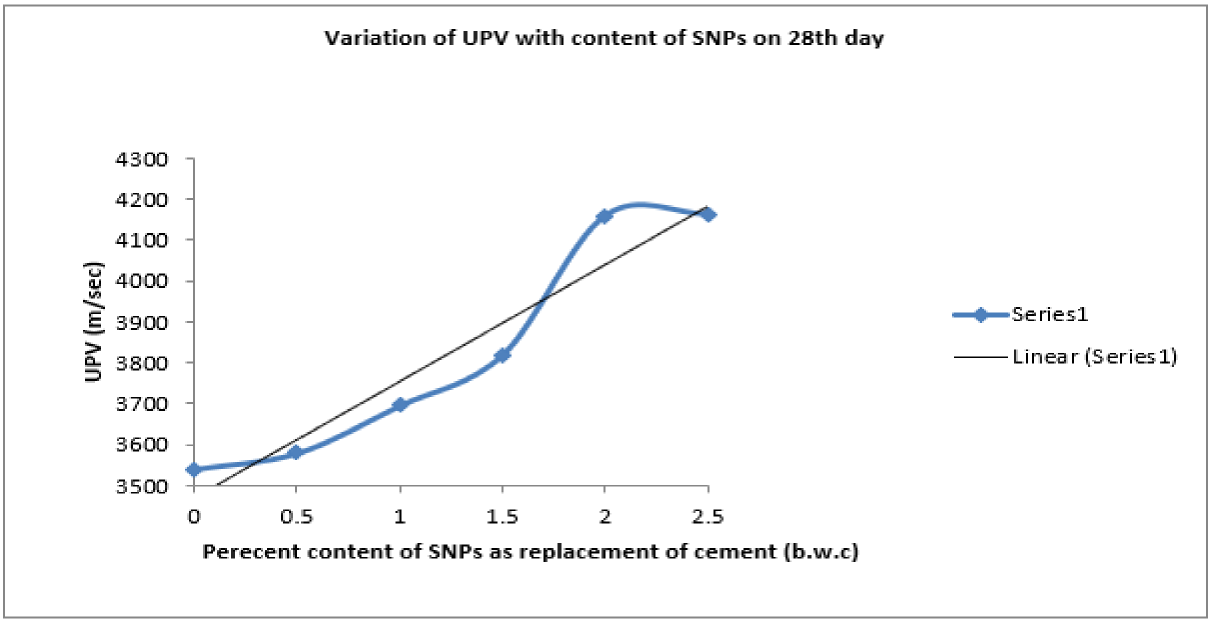

Fig. 3. Variation of Ultrasound Pulse Velocity with Concentration Silica Nanoparticles After 28 days.

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The ultrasound pulse velocity (UPV) for control sample was 3540 m/s on 28th days. UPV increases with content of nanoparticles up to 2.0%, but remained nearly the same for content 2.5% (not decreased). Further, there was no significant change in USV for sample content between 0-0.5% change in silica nano-particles. The average value of UPV on 28 day was 3540 ± 36, 3580 ± 38, 3696 ± 42, 3820 ± 39, 4160 ± 40, 4163 ± 41 for content of silica-nanoparticles 0%, 0.5%, 1.0%, 1.5%, 2.0%,and 2.5 % respectively (Fig.3). The results indicate that the quality of concrete was influenced with increased UPV due to addition of SNPs . Overall, the linear trend for rise of UPV was observed as shown in Fig. 3. A comparison of result on UPV on 7th and 28th days are shown in (Fig. 4), it was observed that the overall quality of concrete was very good in terms of ultrasonic velocity on 28 days (Fig. 4) as it went on increasing with content of silica nanoparticles. Further, the maximum value of UPV was observed for those specimens which contained SNPs between 2.0-2.5% replaced by the weight of cement. This would mean that there is limitation on addition of amount of silica nanoparticles to the concrete mix. As ultrasound pulse velocity went on increasing with time, because, concrete blocks were getting stronger with time, so does the compressive strength of the specimen. A comparison of UPV with content of SNPs are (shown in Fig. 4) UPV was consistently higher on 28th day than that of 7th day data.

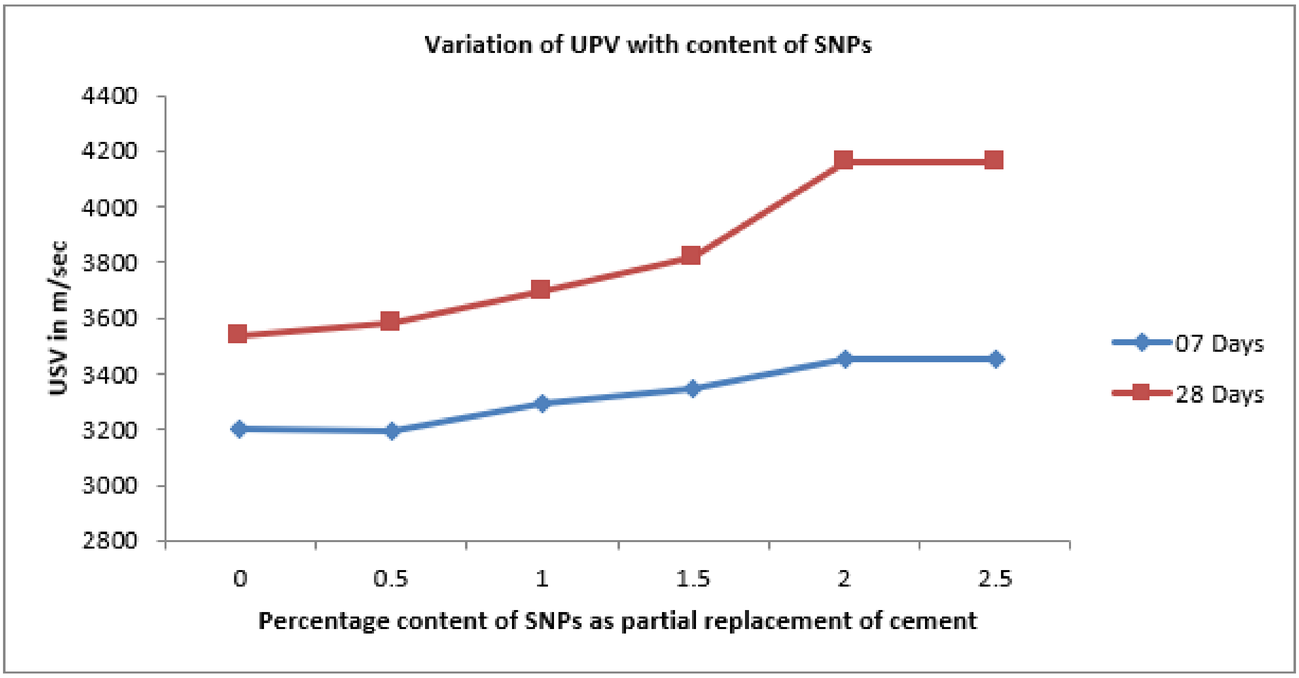

Fig. 4. Comparison of Variation of Ultrasound Pulse Velocity with Content of Silica-Nano Particles on 07th day and 28th day.

UPV results indicated rise in compressive strength because of higher pulse velocity due to substitution of SNPs.

The compressive strength test result shows variation of compressive strength on 07th days (Fig. 5.). The results indicate that the compressive strength increased with content of silica nanoparticles between 1.0 to 2.0 percent, it was maximum for the specimens which had nearly 2.0% content. Further, there was no significant change in strength at 2.5% in comparison with that of 2.0%. Further, there was no significant change in compressive strength for the control samples (samples without silica nano-particles) and 0.5% nano-silica substitution in the specimens. From the compressive strength results, it has been observed that increase in compressive strength of concrete is due to addition of a certain minimum quantity of nano-SiO_2. The increase in strength was found maximum for 2.0% substitution of SNPs.

A comparison of results on 7th day and 28th day compressive strength has been shown in Fig 5. It had been observed that there was significant increase in compressive on 07th day and the average compressive strength of concrete varied between 25-32 MPa (Fig 5). The compressive strength increased with content of SNPS, it was significantly higher for the samples which had 2.0-2.5 % substitution of silica nanoparticles (SNPs) by weight of cement. It also appears that there was a limit on optimum quantity of SNPs content and that quantity turns out to become nearly 2%.

Variation of compressive strength on 28th days are also shown in Fig 5. The compressive strength of control specimen was 38 MPa (in comparison to 25MPa on 7th day). Higher compressive strength was observed for higher substitution of silica nanoparticles, the compressive strength went up to 48.8 MPa under the impact of substitution of silica nanoparticles on 28th day. This might be due to higher hydration rate initiated by pozzolanic activity and filling up of the pores / voids with the particles of smaller dimensions. It appears that the pozzolanic impact had been started during initial days and remained continued till 28th day (duration of experimentation) of curing.

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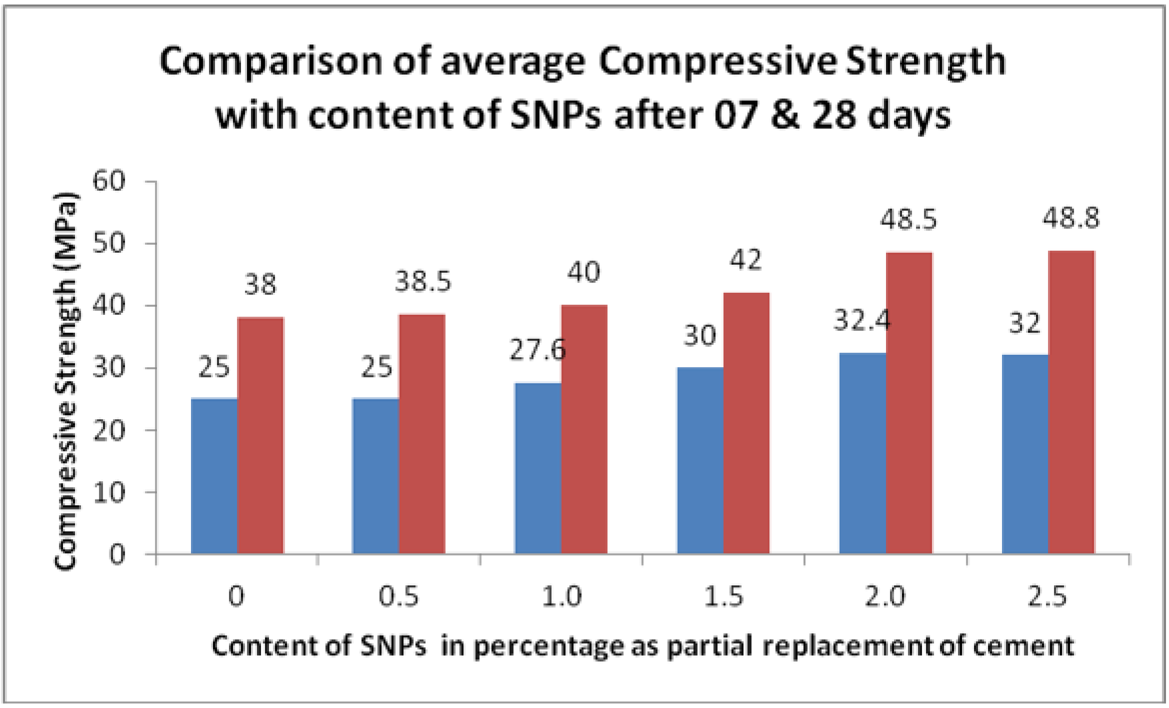

Fig. 5. Variation of Compressive Strength with Concent of SNPs Expressed in Percent. Nanoparticles Were Added as Partial Replacement of Cement (b.w.c.).

The comparison of average compressive strength on 07th day and 28th day are shown in Fig 5. The results indicate that compressive strength on 28th day increased nearly 1.5 times higher than that of 7th day. Further, the effect of nanoparticles was significant and that due to partial replacement of cement compressive strength increased significantly. We also observed that the compressive strength increased considerably during the early-age, it increased with content of SNPs in the specimens between the range 1.5-2.5%, however, for content below 1.0% there was no significant change in early-stage compressive strength. The compressive strength of the experimental samples (containing nano-SiO_2) was observed to increase with increased nano-SiO_2 content till the threshold value. The highest compressive strength was observed between 2.0-2.5%. It appears that the optimum value of SNPs was probably at 2.0% or in between 2.0-2.5%. Above this threshold value, the compressive strength decreased even after adding higher amount of nano-SiO_2 as reported by some investigators. This could be probably due to agglomeration of nanoparticles. It appears that within specified range from 1.5 to 2.5 % content of silica-nanoparticles in the samples, ultrasound velocity was higher which indicated increased strength of concrete due to partial replacement of cement by nanoparticles. This might be on account of enhanced hydration processes and pores filling effects of silica nanoparticles. In concrete mix replacement of cement by amorphous nano-silica particles accelerated hydration process. Due to small size and pozzolanic reaction, the SNPs effectively appears to enhance the performance [1], strength and durability of concrete [1, 2] by accelerated hydration reaction plus filling up the micropores within the cement paste structure, as a result the pores volume either completely or partially filled, this resulted into higher strength of concrete structure. Added further, the nanoparticles reduced setting time [3, 4], porocity and provided denser microstructure [1]. The strength of concrete material increases with addition of silica nanoparticles have also been supported by several investigators. Some investigators pointed out that substitution of SNPs enhanced early stage compressive strength i.e. on 7th day of curing the specimens due to faster hydration rate [8]. Further, it could prevent corrosion of iron in concrete structure by bringing down penetration of chloride ions [8]. Added further, an appropriate amount of SNPs substituted to the cement in concrete mixture can increase the interface strength (interface between cement matrix and aggregates), refine the pores, and bring down the water permeability of concrete effectively [12].

In nut shell, the increased compressive strength is attributed primarily to the two important factors (i) Hydration of cement and (ii) Pore filling effect (or activities). In cement, addition of nanoparticles accelerates the hydration process. On account of small size, large surface area and the pozzolanic nature SNPs can in enhance the strength [1], durability [2] and performance of concrete [1]. The SNPs can reduce the porosity and tighten the interfacial transition zone (ITZ) between the aggregate particle and the cement paste [1,12]. Further, substitution of nanoparticles appeared to provide denser microstructure, shortened setting time of concrete [3,4] due to accelerated hydration of tri-calcium silicate (C_3S) and dicalcium silicate (C_2S), as a result C-S-H gel formation turned faster and setting time of the sediment was shortened [5, 6]. Silica nanoparticles possessed ability to improve the compressive strength and durability of concrete through chemical and physical action [7] by increased non-evaporable water content and hence degree of hydration of cement paste [13].

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In present study, silica nanoparticle size was 20 nm, obviously, it had considerable filler effect due to its tiny sizes. It appears that nano-silica initiated formation of hydrated products at a good rate which led to high early strength 28MPa on 7th days and it was higher than that of normal concrete (i.e. concrete without SNPs). At the same-time it had been observed that overall effect of nano-silica on compressive strength was also higher after 28 days than of control specimens.

A. Correlation Between Compressive Strength and Ultrasonic Pulse Velocity

There is correlation between compressive strength and ultrasonic pulse velocity. In present study, we have chosen the mixture proportion on the basis of various regression models, we observed that all the models exhibited nearly the similar trend above 300 kg/m^3 for M30 grade concrete mix.
The variation of average compressive strength as a function of ultrasound pulse velocity on 28th day has been shown in Fig 6.

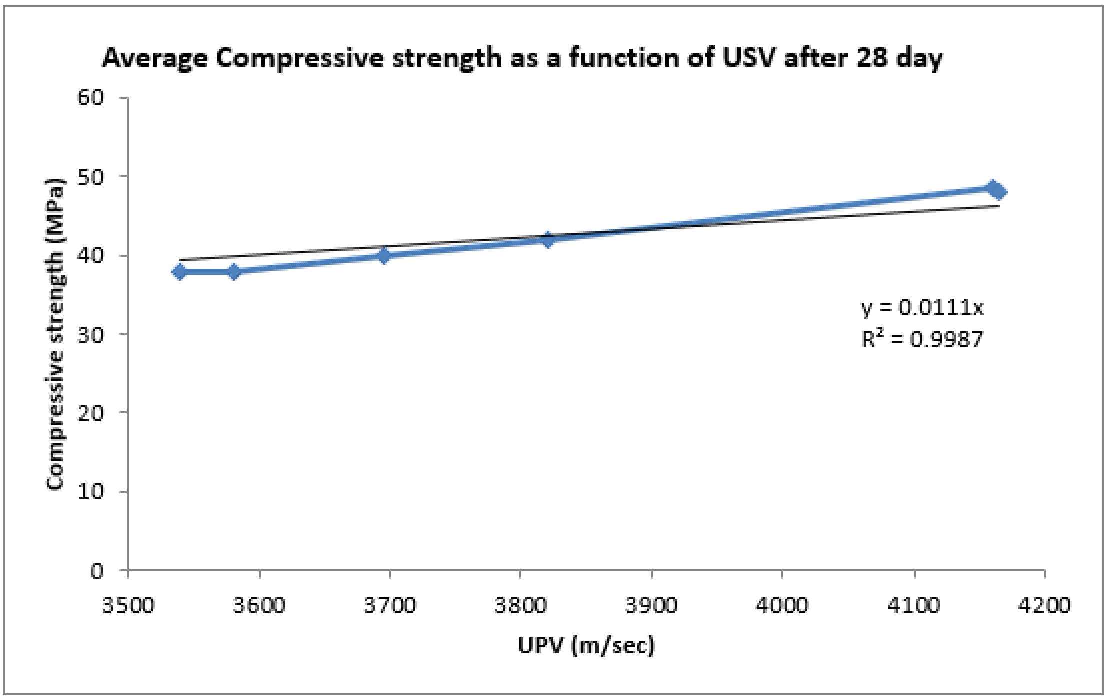

Fig. 6. Variation of Average Compressive Strength as A Function of Ultrasound Pulse Velocity on 28th day.

Here, R^2 = 0.87, this implies that 87% of variation of compressive strength can be explained by variation of ultrasonic pulse velocity for the specimens which acquired its compressive strength on 28th days as show in Fig 6.
There is strong correlation between compressive strength and ultrasonic pulse velocity for the concrete cubical specimen after 28 days as correlation coefficient turns out to become 0.997. Further, the intercept = -22.97347412 and slope = 0.0170873, hence the regression line is represented by Y=0.303 X – 72.28.

IV. CONCLUSION

Ultrasound pulse velocity as well as compressive strength increased with partial substitution of silica-nanoparticles (by weight of cement) in the concrete specimens.
The average value of UPV on 7th day of curing turned out to become 3200 ± 36, 3215 ± 42, 3290 ± 41, 3349 ± 24, 3450±17 and 3456 ± 12 for 0%, 0.5%, 1.0%, 1.5%, 2.0% and 2.5% content of SNPs in the specimens respectively. Similarly, the average value of UPV on 28th day was 3540 ± 36, 3580 ± 38, 3696 ± 42, 3820 ± 39, 4160 ± 40, 4163 ± 41 for same amount of substitution of SNPs respectively.
Further, the UPV was higher in the specimens in which cement was replaced by silica nano-particles (SNPs). However, there was no significant change in UPV for replacement of cement with silica nanoparticles at 0. 5%. It appears from that the UPV increased with content of silica nanoparticles above 1.0 % and it was maximum in between 2.0 to 2.5%.
Similarly, the average compressive strength on 7th day was 25, 25, 27.6, 30, 32.4 and 32 N/mm^2, however, but, on 28th day the average compressive strength turned out to become, 38, 38.5, 40, 42, 48.5 and 48.8 N/mm^2 for the same content of silica nanoparticles i.e. 0%, 1.0%, 1.5%, 2.0%, 2.5% respectively.
As UPV increased so did the compressive strength. We observed strong correlation (correlation coefficient 0.997) between USV and compressive strength and variance (R^2 = 0.87), which meant 87% of variation of compressive strength could be explained by variation of USV for the specimens (which acquired its compressive strength) on 28th day.
Compressive strength and USV increased due to hydration reaction leading to C-S-H (Calcium-Silicate-hydrate) gel formation which filled the pores in the concrete matrix. The compressive strength of concrete significantly increased with content of silica nano-particles within the selected range of content (1.5-2.5%), but there is limitation probably due to agglomeration of nanoparticles, which destroyed the salient features nano-particles.

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DECLARATION

Funding/ Grants/ Financial Support	No, I did not receive.
Conflicts of Interest/ Competing Interests	There is no known competing financial interest and no potential conflict of interest.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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Retrieval Number:100.1/ijeat.D40330412423
DOI: 10.35940/ijeat.D4033.0412423
Journal Website: www.ijeat.org

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