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

Anil Kumar Singh, Chaitanya Chauhan

Abstract: *In the 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 a correlation between ultrasound pulse velocity (UPV) and the compressive strength. The mean particle size of silica nanoparticles was 20nm. The quality of the concrete specimen was assessed by measuring the ultrasound pulse velocity (UPV) in meters per second (m/s) and the 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 the 28th day was 3540 ± 36, 3580 ± 38, 3696 ± 42, 3820 ± 39, 4160 ± 40, and 4163 ± 41 for the same amount of substitution of SNPs, respectively. It had been observed that the UPV was higher in specimens replaced by silica nanoparticles (by weight of cement) and achieved maximum strength at nearly 2% (between 2.0% and 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 duplicate 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 a strong correlation (correlation coefficient 0.997) between USV and compressive strength and variance (R2 = 0.87), which meant 87% of the variation of compressive strength could be explained by the variation of USV for the specimens (which acquired their compressive strength) on the 28th day. Compressive strength and USV increased due to the hydration reaction, leading to the formation of C-S-H (Calcium-Silicate-hydrate) gel, which filled the pores in the concrete matrix. The compressive strength of concrete significantly increased with the content of silica nanoparticles within the selected range of content (1.5-2.5%). Still, there is a limitation, probably due to the agglomeration of nanoparticles, which destroyed the salient features of the nanoparticles.*

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

I. INTRODUCTION

In this paper, we aim to investigate the effect of partial replacement of cement with silica nanoparticles (by weight of cement) on the ultrasound pulse velocity and compressive strength of concrete, with the goal of achieving a high-performance concrete structure. Amorphous silica nano-particles exhibit pozzolanic reaction, on account of their small size and pozzolanic reaction this, 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 the decreased porosity within concrete, its strength will increase. Thus, nanoparticles can reduce porosity and provide a denser microstructure [1]. Further, the addition of silica nanoparticles also reduces the setting time [3, 4]. In addition, SNPs are supportive in reducing 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 can improve the compressive strength and durability of concrete through chemical and physical action [7]. Nano-silica acts as an activator to Pozzolanic reaction, which leads to the production of more C-S-H gel, In addition to this, it also can refine the pores of the system and densification of the interfacial transition zone (ITZ) [7]. Several investigators observed that on the addition of SNPs to the cementing system, the hydration of concrete is increased, which enhances 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 increase 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, leading to a 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 the relationship between UPV and the compressive strength of concrete changes with its mix proportion. Of course, the regression models to some extent predict the relationship between USV and compressive strength [13,14].

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.
*Correspondence Author(s)
Dr. Anil Kumar Singh*, Department of Physics, VKS University, Ara (Bihar), India. E-mail: anilkrvksu.ara@gmail.com, ORCID ID: https://orcid.org/0000-0003-3597-4625
Chaitanya Chauhan, Department of Mechanical Engineering, Manipal Institute of Technology, Manipal (Karnataka), India. E-mail: shankychaitanya@gmail.com, ORCID ID: https://orcid.org/0000-0003-3969-8840

In some instances, with a particular mix proportion, a good correlation existed between UPV and the compressive strength. This indicates that the compressive strength and USV correspond with the mixture proportion. Mixture proportions, aggregate type, age of concrete, moisture content, etc, influence UPV [15].

The compressive strength increases with a decrease in the w/c ratio, and this ratio can be reduced by incorporating a superplasticiser (SP) into the concrete mix. Superplasticisers are referred to as high-range water reducers, as they reduce the w/c (water-cement ratio) while maintaining the same workability. SP would have accelerating and significant effects on the properties of concrete due to a reduction in the water content of concrete [16]. It has been reported further that the compressive strength improved due to the addition of superplasticizer after 28 days of curing [17] The investigator showed that, the optimum amount of admixture must be 1.0 %; however, overdosing with SP would deteriorate the properties of concrete, with an indication of lower compressive strength [16].

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

II. METHODOLOGY

A. Sample Preparation of Concrete Specimens

For measuring UPV or compressive strength, we needed to cast concrete cubes of 150mm in size and calculate the 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 would prevent particle agglomeration. The ingredients were mixed in a high-speed blender to achieve a uniform distribution of the nanoparticles in the mixture and to avoid the agglomeration of these particles due to Van der Waals forces.

All the ingredients of concrete were mixed to prepare the concrete mixture. For the mixes containing silica nanoparticles in concrete, the nanosilica powder was added to one litre of water with superplasticiser (i.e., 2% of cement by weight). Silica nanoparticles were added to the concrete mix in a small fraction by replacing a portion of the cement (expressed as a percentage). An experimental test was conducted on 150mm cube-size specimens with silica nanoparticle contents of 0%, 0.5%, 1.0%, 1.5%, 2.0%, and 2.5% by weight of cement (b.w.c.).

After the mixing was completed, the concrete paste was poured into a cubic mould (dimensions 150mm × 150mm × 150mm) with precautions to prevent the formation of voids, strictly following the provisions laid down by the Bureau of Indian Standards. All constituents and their respective quantity (water content, cement, superplasticiser, 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, with their content varying from 0% (sample without nanoparticles) to 0.5%, 1.0%, 1.5%, 2.0%, and 2.5%, respectively. The samples without silica nanoparticles (0% SNPs) were used as the control.

Curing: After successful casting, the specimens' cubes were removed from the specimen holders (moulds) after 24 hours and submerged in dirt-free water at room temperature (approximately 280 °C) until the testing day (i.e., on the 7th or 28th day). The surface of the 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%, 1.5%, 2.0% and 2.5% silica nanoparticles by weight of cement, respectively.

B. Ultrasound Pulse Velocity: Measurement Technique

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

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

The pulser-receiver setup is used to excite the transducers, generating ultrasonic pulses. This unit consisted of an electronic circuit that generated pulses, and the receiver unit received these signals. The third component is a CRO, which is a data acquisition system used to display and analyse the received output. We used a 100 MHz oscilloscope (Iwatsu SS-5711C with a Universal counter). The transit time or Time Delay (in seconds or microseconds) was directly displayed on the counter of the CRO and 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 an electrical pulse to produce an ultrasonic pulse, which passed through a concrete block and was received by the receiver. The signal, after passing through the specimen, was fed to a CRO (cathode ray oscilloscope, CRO-5511C, with a sampling

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

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

rate of 100 MHz and an A/D data acquisition board). We can adjust the pulse repetition rate (PRR) between 20 Hz and 2 kHz, thanks to the inbuilt facility in the pulser-receiver setup, which provides an output of 1.0 V.
ASTM recommends a transducer frequency in the range of 20 kHz to 100 kHz for measuring ultrasound pulse velocity. We, therefore, used 54 kHz transducers for the 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 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.
The time of travel (transit time) in a sample of precisely known thickness or length was recorded in microseconds (µs) from the universal display unit of the CRO. The distance travelled in the sample divided by the Transit time would give the ultrasound pulse velocity. In 1951, Whitehurst reported soniscope tests on a concrete structure (Proceedings ACI Vol. 47, pp 433 (1951).

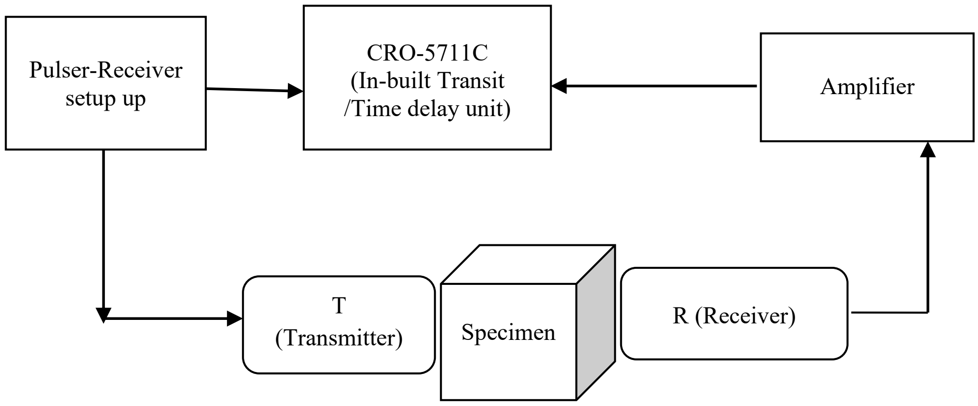

Fig. 1. Block diagram of Ultrasound Pulse Velocity Test, T and R are the Transmitting and Receiving Transducers. The test specimen is placed between the Transmitting Transducer on the left and the receiving transducer on the right.

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

Table 1: Criteria for Grading of Concrete Quality based on 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 the guidelines for the quality classification of concrete based on UPV. Higher velocity would suggest better quality and continuity within the material, while decreased velocity implies poor quality, such as cracks, bubbles, or voids, within the concrete structure. Thus, in the defective domain of concrete, the compression wave velocity becomes slower than in the normal (undamaged) region, and the signal amplitude is also attenuated. If the structure contains a large gap or intense voids, the signal may be attenuated. Additionally, the signal may become distorted due to a honeycomb defect. UPV depends on the modulus of elasticity and density of the medium through which it propagates; consequently, it provides information about internal defects or imperfections, the location of defects, and the compactness and homogeneous or heterogeneous regions within the concrete. Ultrasound pulse velocity was calculated for six samples of each group, with varying silica nanoparticle content, over 7 and 28 days.

C. Measurement of Compressive Strength

The compressive strength test is a destructive test in which a concrete specimen is subjected to compression in a **compressive** testing machine. The **test** determines characteristics of concrete. It is calculated using the given formula.

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 millimetre).
The surface of the specimens was investigated under dry conditions by the Indian Standard IS: 516-1959 norms. The compressive strength tests were accomplished on a compressive test machine. The specimens' cubes (size 150 mm) were allowed to dry. 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 a rate of 140 kg/cm^2 (13.7293 N/mm^2) until the specimen broke. For example, on a cubic sample of 15 cm × 15 cm × 15 cm, the break loads were 56, 57, and 58 tons. The compressive strength turned out to be 24.42, 24.85, and 25.29 N/mm^2, respectively. The average compressive strength was 24.85 ≈ 25 N/mm^2. There

were six cubes of specimens in each group, in which the cement content was 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 to calculate the average compressive strength.

III. RESULT AND DISCUSSION

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

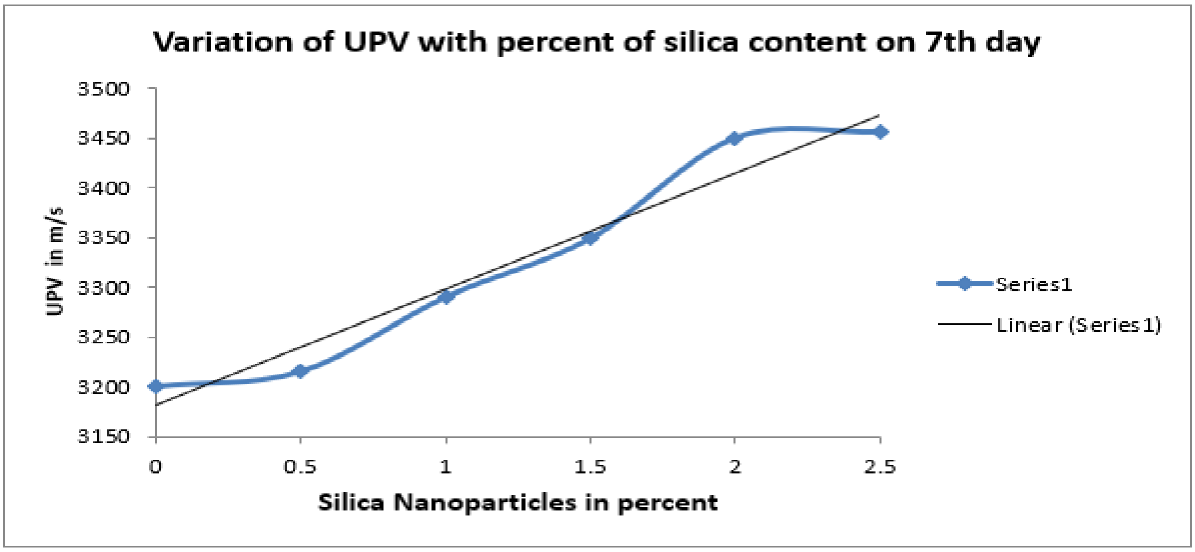

Fig. 2. Variation of Ultrasound Pulse Velocity with Content of Silica Nanoparticles After 07 days.

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 concerning 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 of the rise of UPV could be linear, as shown in Fig. 2.

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

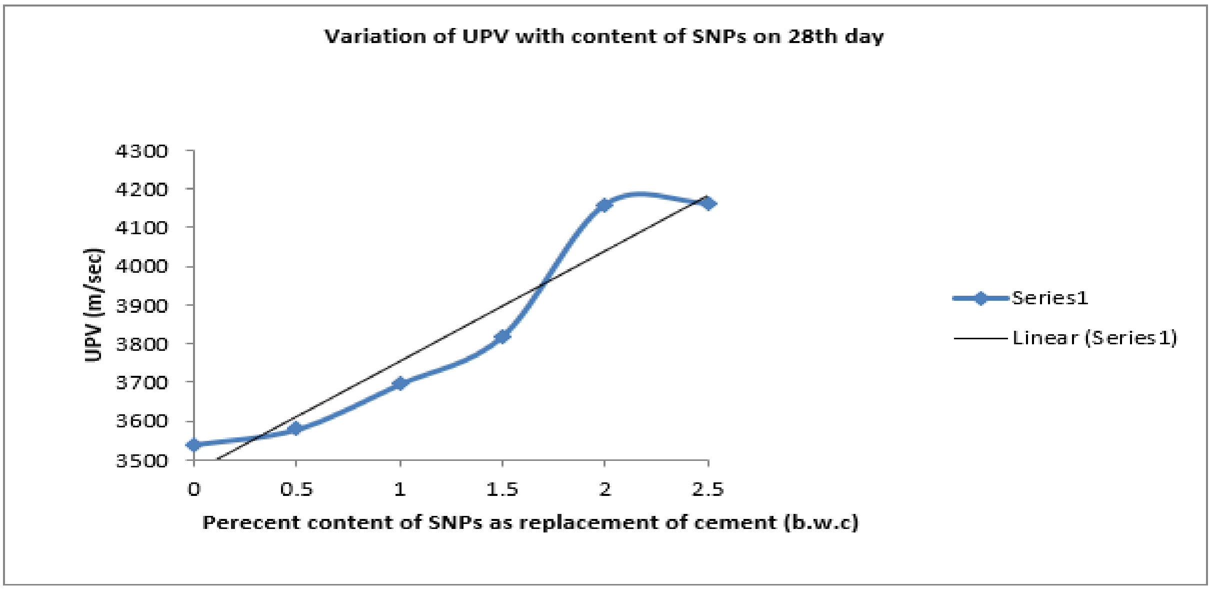

Fig. 3. Variation of Ultrasound Pulse Velocity with Concentration of Silica Nanoparticles After 28 days.

The ultrasound pulse velocity (UPV) for the control sample was 3540 m/s on the 28th day. UPV increases with the content of nanoparticles up to 2.0%, but remains nearly the same for content 2.5% (not decreased). Furthermore, there was no significant change in USV for the sample content between 0% and 0.5% change in silica nanoparticles. 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 the rise of UPV was observed as shown in Fig. 3. A comparison of the results on UPV on 7th and 28th days are shown in (Fig. 4), it was observed that the overall quality of concrete was excellent in terms of ultrasonic velocity on 28 days (Fig. 4) as it went on increasing with content of silica nanoparticles. Furthermore, the maximum value of UPV was observed in specimens that contained SNPs between 2.0% and 2.5% of the cement weight. This would mean that there is a limitation on adding silica nanoparticles to the concrete mix. As the ultrasound pulse velocity continued to increase over time, the compressive strength of the specimen also increased, because the concrete blocks were becoming stronger with time. A comparison of UPV with the content of SNPs (shown in Fig. 4) reveals that UPV was consistently higher on the 28th day than on the 7th day.

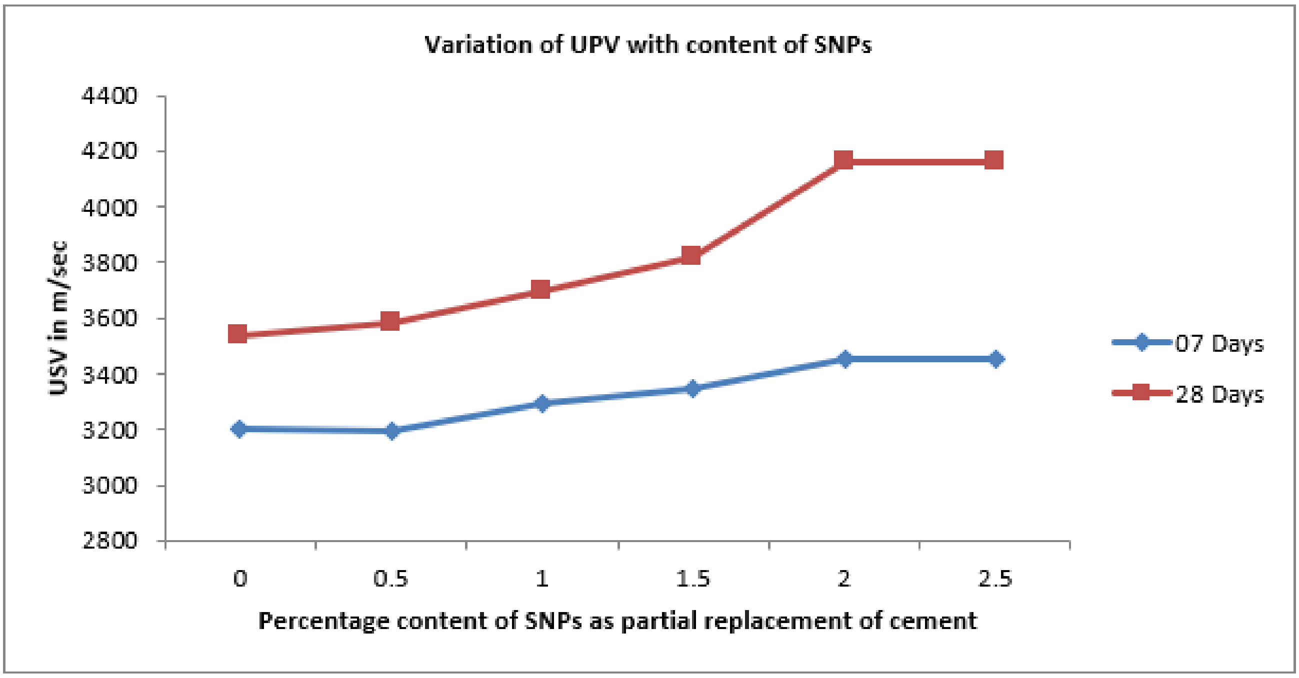

Fig. 4. Comparison of Variation of Ultrasound Pulse Velocity with Content of Silica-Nano Particles on 07th day and 28th day.

UPV results indicated a rise in compressive strength due to the higher pulse velocity resulting from the substitution of SNPs.

The compressive strength test results show a variation in compressive strength on the 7th day (Fig. 5). The results indicate that the compressive strength increased with the content of silica nanoparticles between 1.0% and 2.0%, with the maximum value for the specimens with nearly 2.0% content. Furthermore, there was no significant difference in strength at 2.5% compared to that at 2.0%. Furthermore, there was no substantial change in compressive strength for the control samples (samples without silica nanoparticles) and specimens with 0.5% nano-silica substitution. From the compressive strength results, it has been observed that an increase in compressive strength of concrete is due to the addition of a certain minimum quantity of nano-SiO_2. The increase in strength was found to be maximum for a 2.0% substitution of SNPs.

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

Variation of compressive strength on the 28th day is also shown in Fig. 5. The compressive strength of the control specimen was 38 MPa (compared to 25 MPa on the 7th day). A higher compressive strength was observed with increasing substitution of silica nanoparticles, reaching 48.8 MPa by the 28th day, following the impact of silica nanoparticle substitution. This may be due to a higher hydration rate initiated by pozzolanic activity, as well as the filling of pores and voids with particles of smaller dimensions. It appears that the pozzolanic impact was initiated during the initial days and continued until the 28th day (the duration of experimentation) of curing.

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

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

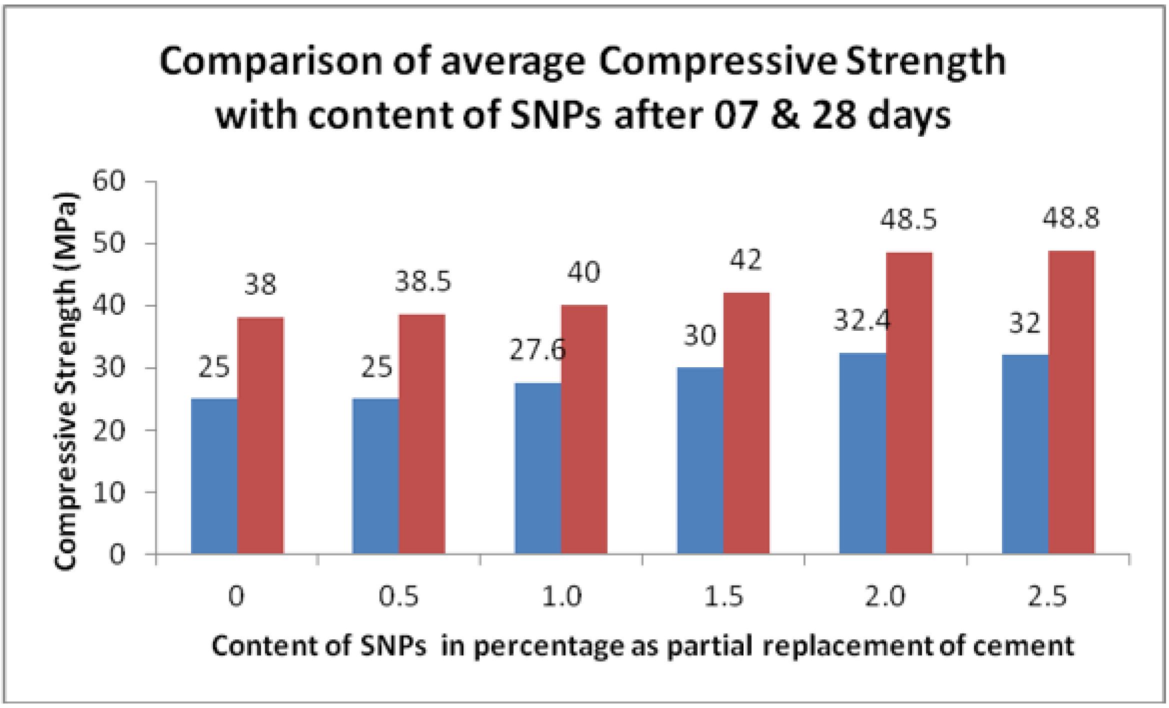

Fig. 5. Variation of Compressive Strength with Concentration of SNPs Expressed in Per cent. Nanoparticles Were Added as a Partial Replacement of Cement (b.w.c.).

The comparison of average compressive strength on the 7th day and 28th day is shown in Fig. 5. The results indicate that the compressive strength on the 28th day increased nearly 1.5 times higher than that on the 7th day. Furthermore, the effect of nanoparticles was significant, primarily due to the partial replacement of cement, resulting in a substantial increase in compressive strength. We also observed that the compressive strength increased considerably during the early age, increasing with the content of SNPs in the specimens between 1.5% and 2.5%. However, for contents 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 and 2.5%. It appears that the optimum value of SNPs was likely at 2.0% or between 2.0% and 2.5%. Above this threshold value, the compressive strength decreased even after adding a higher amount of nano-SiO_2, as reported by some investigators. This could probably be due to the agglomeration of nanoparticles. It appears that within the specified range of 1.5 to 2.5% silica nanoparticle content in the samples, the ultrasound velocity was higher, indicating an increase in the strength of the concrete due to the partial replacement of cement with nanoparticles. This may be due to the enhanced hydration processes and pore-filling effects of silica nanoparticles. In concrete mix, the replacement of cement by amorphous nano-silica particles accelerates the 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 entirely or partially filled, this resulted into higher strength of concrete structure. Furthermore, the nanoparticles reduced the setting time [3, 4], porosity, and provided a denser microstructure [1]. The strength of concrete material increases with the addition of silica nanoparticles, a finding also supported by several investigators. Some investigators have noted that the substitution of SNPs increases early-stage compressive strength, specifically on the 7th day of curing, due to a faster hydration rate [8]. Furthermore, it could prevent the corrosion of iron in concrete structures by reducing the penetration of chloride ions [8]. Moreover, the addition of an appropriate amount of SNPs to the cement in a concrete mixture can increase the interface strength (between the cement matrix and aggregates), refine the pores, and effectively reduce the water permeability of concrete [12].

In a nutshell, the increased compressive strength is attributed primarily to the two critical factors (i) Hydration of cement and (ii) Pore filling effect (or activities). In cement, the addition of nanoparticles accelerates the hydration process. On account of small size, large surface area, and the pozzolanic nature, SNPs can 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 a 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 the setting time of the sediment was shortened [5, 6]. Silica nanoparticles possessed the ability to improve the compressive strength and durability of concrete through chemical and physical action [7] by increased non-evaporable water content and hence the degree of hydration of cement paste [13].

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

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

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

A. Correlation Between Compressive Strength and Ultrasonic Pulse Velocity

There is a correlation between compressive strength and ultrasonic pulse velocity. In the present study, we have chosen the mixture proportion based on various regression models. We observed that all the models exhibited a nearly similar trend above 300 kg/m³ for the M30 grade concrete mix.

The variation of average compressive strength as a function of ultrasound pulse velocity on the 28th day is shown in Fig. 6.

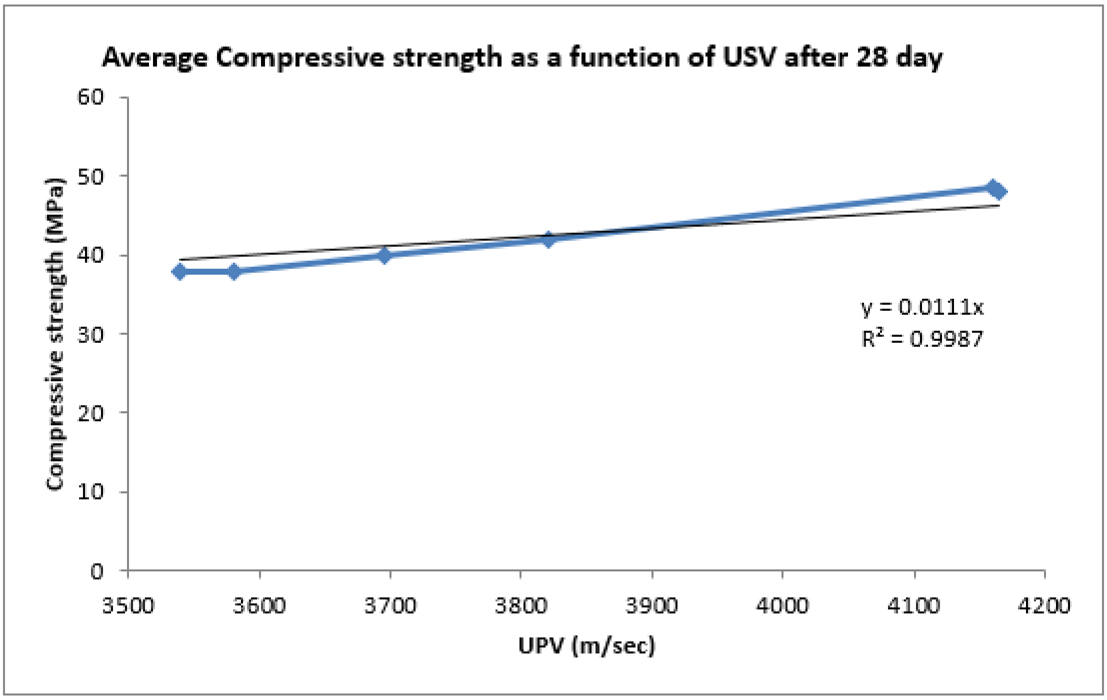

Fig. 6. Variation of Average Compressive Strength as A Function of Ultrasound Pulse Velocity on the 28th day.

Here, R^2 = 0.87, implying that 87% of the variation in compressive strength can be explained by the variation in ultrasonic pulse velocity for the specimens that acquired their compressive strength on the 28th day, as shown in Fig. 6.

There is a strong correlation between compressive strength and ultrasonic pulse velocity for the concrete cubical specimen after 28 days, as evidenced by a correlation coefficient of 0.997. Furthermore, the intercept is -22.97347412 and the slope is 0.0170873; hence, the regression line is represented by Y = 0.303X – 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 the 28th day was 3540 ± 36, 3580 ± 38, 3696 ± 42, 3820 ± 39, 4160 ± 40, and 4163 ± 41 for the same amount of substitution of SNPs, respectively.

Furthermore, the UPV was higher in specimens where cement was replaced by silica nanoparticles (SNPs). However, there was no significant change in UPV for the replacement of cement with silica nanoparticles at a 0.5% concentration. It appears that the UPV increased with the content of silica nanoparticles above 1.0% and was maximum between 2.0% and 2.5%.

Similarly, the average compressive strength on 7th day was 25, 25, 27.6, 30, 32.4 and 32 N/mm², however, but, on 28th day the average compressive strength turned out to become, 38, 38.5, 40, 42, 48.5 and 48.8 N/mm² for the duplicate 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 a strong correlation (correlation coefficient 0.997) between USV and compressive strength and variance (R2 = 0.87), which meant 87% of the variation of compressive strength could be explained by the variation of USV for the specimens (which acquired their compressive strength) on the 28th day.

Compressive strength and USV increased due to the hydration reaction, leading to the formation of C-S-H (Calcium-Silicate-hydrate) gel, which filled the pores in the concrete matrix. The compressive strength of concrete significantly increased with the content of silica nanoparticles within the selected range of content (1.5-2.5%). Still, there is a limitation, probably due to the agglomeration of nanoparticles, which destroyed the salient features of the nanoparticles.

DECLARATION

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

REFERENCES

1. Sanchez, F. & Sobolev, K. Nanotechnology in concrete: a review," *Construction and Building Materials*, 24 (11), 2060–2071 (2010).View at: Publisher Site | [Google Scholar] [CrossRef]
2. Li, L. G., Zhu, J., Huang, Z. H., Kwan, A. K. H. & Li, L. J. Combined effects of micro-silica and nano-silica on durability of mortar, *Construction and Building Materials*, 157, 337–347 (2017). [CrossRef]
3. Li, W.S., Shaikh, F.U.A., Wang L.G., Lu Y.L., Wang B., Jiang C.Y., et al., Experimental study on shear property and rheological characteristic of superfine cement grouts with nano-SiO_2 addition, *Constr. Build. Mater.*, 228, 117046 (2019). [CrossRef]
4. Ltifi, M., Guefrech, A., Mounanga, P. & Khelidj, A. Experimental study of the effect of addition of nano-silica on the behaviour of cement mortars, *Procedia Engineering*, 10, 900-905 (2011). Available online at www.sciencedirect.com. [CrossRef]
5. Zhang, A., Ge, Y., Yang W.C., Cai X., P. & Du Y.B., Comparative study on the effects of nano-SiO2, nano-Fe2O3 and nano-NiO on hydration and microscopic properties of white cement, *Constr. Build. Mater.*, 228(1), 116767 (2019). doi:10.1016/j.conbuildmat.2019.116767 [CrossRef]
6. Zhang, S., Qiao, Weiguo, Yanzi, Li, Kai, Xi. & Chen, Pengcheng. Effect of additives on the rheological and mechanical properties of microfine-cement-based grout, *Advances in Materials Science and Engineering*, (2019). Open Access. https://doi.org/10.1155/2019/1931453 [CrossRef]
7. Mohammed, B.S., Awang, A.B., Wong, S.S. & Nhavene, C.P. Properties of nano silica modified rubbercrete, *J. Clean. Prod.*, 119, 66-75 (2016). http://dx.doi.org/10.1016/j.jclepro.2016.02.007 [CrossRef]
8. M., Liu, Tan H.B., He X.Y., Effects of nano-SiO_2 on early strength and microstructure of steam-cured high volume fly ash cement system, *Constr. Build. Mater.*, 194, 350-359 (2019). Search in Google Scholar [CrossRef]
9. Panzera, T.H., Christoforo, A.L., Cota, F. P. & Bowen, C. R. Ultrasonic pulse velocity evaluation of cementious materials, (2011). doi:10.5772/17167 [CrossRef]
10. Eskandari, H., Vaghefi, M. & Kowsari, K. Investigation of Mechanical and Durability Properties of Concrete Influenced by Hybrid Nano Silica and Micro Zeolite, Procedia Mater. Sci., 11, 594-599 (2015), *ScienceDirect*, doi: 10.1016/j.mspro.2015.11.084 [CrossRef]
11. Jo W. B., Kim, C. H. & Lim, A.H. Investigations on the development of powder concrete with nano-SiO_2 particles, KSCE J. Civ. Eng., 11(1), 37-42 (2007). [CrossRef]
12. Liu, R., Xiao, H. G., Liu, J. L., Guo, S. & Pei, Y. F. Improving the microstructure of ITZ and reducing the permeability of concrete with various water/cement ratios using nano-silica, *J. Mater. Sci.*, 54(1), 444-456 (2019). **doi:**10.1007/s10853-018-2872-5 [CrossRef]
13. Singh, L. P. et al., Hydration studies of cementious material using silica nanoparticles, *Journal of Advanced Concrete Technology*, 13(7), 345-354 (2015). DOI: 10.3151/jact.13.345 [CrossRef]
14. Yamakawa, I., Kishtiani, K., Fukushi, I. & Kuroha, K. Slump Control and Properties of Concrete with a New Superplasticizer. II. High strength in situ concrete work at Hicariga-Oka Housing project, RILEM Symposium on "Admixtures for Concrete. Improvement of Properties", Editor: E. Vasquez, Chapman & Hall, London, 94-105 (1990). http://worldcat.org/isbn/0412374102
15. Muhit, I. B. Dosage Limit Determination of Superplasticizing Admixture and Effect Evaluation on Properties of Concrete, *International Journal of Scientific & Engineering Research*, 4(3), 1 (2013). http://www.ijser.org.
16. Mahure, N. V., Vijh, G. K., et.al., Correlation between Pulse Velocity and Compressive Strength of Concrete, *International Journal of Earth Sciences and Engineering*, ISSN 0974-5904, 4(6) SPL, 871-874 (2011).
17. Sturrup, V. R., Vecchio, F. J. & Caratin, H. Pulse Velocity as a Measure of Concrete Compressive Strength, In-Situ/Nondestructive Testing of Concrete, SP-82, V. M. Malhotra, American Concrete Institute, Farmington Hills, Mich., 201-227 (1984).
18. Lin, Y., Changfan, H. & Hsiao, C. Estimation of High-Performance Concrete Strength by Pulse Velocity, *Journal of the Chinese Institute of Engineers*, 20(6), 661-668 (1998). [CrossRef]
19. Popovics, S., Rose, L. J. & J. S. Popovics. The Behaviour of Ultrasonic Pulses in Concrete, Cement and Concrete Research, 20(2), 259-270 (1990). [CrossRef]

AUTHORS PROFILE

Dr. Anil Kumar Singh is an Associate Professor in the Department of Physics at VKS University, Ara, Bihar, India. He Is in Charge of the Nano-science Centre in the Department of Physics. At present, five scholars have already been awarded the Ph.D. degree under his supervision, and some of the scholars (as many as six in number) are registered and working on a Ph.D. degree. He has been the external supervisor for the M.Tech. Students from various institutions across the country are working in the field of applying nanomaterials in mechanical engineering. He has nearly twenty publications to his credit in national and international journals. The author is a life member of the Ultrasonic Society of India and the Indian Science Congress. Dr Singh completed his M.Phil. and Ph.D. from Jawaharlal Nehru University, New Delhi, and worked on various projects as a Research Scientist/Project Scientist. Dr Singh worked in the fields of ultrasound, bio-electromagnetism, and the effects of extremely low-frequency signals on experimental species.

Chaitanya Chauhan has completed his M.Tech degree in Mechanical Engineering from the Manipal Institute of Technology, Manipal, Karnataka. He worked on "Impact of Silica Nanoparticles on Strength of Concrete concerning nanoparticles prepared from Rice Husk Ash"**.** He obtained his B.Tech from the same institute. His area of interest is Computer-Aided Design.