Impact of Steel Fiber or Nano Silica on Properties of Concrete Containing Various Cement Types

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Abstract: This paper investigates the influence of nano- silica or steel fiber on either the properties of freshly prepared concrete (slump), or splitting tensile and compressive strength what's known as mechanical properties. In addition, the ultrasonic pulse velocity of different types of cement in the concrete is studied. In this study concrete cube specimens of with different types of cement were prepared. Mixtures of OPC and blended cement, sand, water was prepared, where dolomite was mixed with nano-silica. The percentage of nano- silica/ cement was 0, and 3 % at w/c = 0.45. The effect of cement quantities of (350-400 and 450 Kg/m^3) on concrete properties was also considered. The results indicated that, the concrete which contain blended cement together with sand showed an increase in slump values in comparison with concrete containing OPC. Introducing 3% nano silica or 1% steel fiber in concrete mix increases the mechanical properties and ultrasonic pulse velocity of concrete made with OPC or blended cement.

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1. Introduction

The advanced technology which called nanotechnology which concerned with a small particles of materials (1-100 nm). The nano is equal to $^{10-10}$ mm. Nanotechnology is science which paid an attention to the properties of materials at atomic, molecular scales beside macro molecular levels. The physical and mechanical properties are different significantly from small to large sizes of materials. **Mamoun *et al.*, 2014**, reported that the markets of products containing nano materials harvested a high benefits and grow quickly and they expected in the near future to collect hundred billions of Euros from sealing products depending on nanotechnology.

Sadrmomtazi and Barzegar, 2010, studied the influence of nano-SiO_2 (NS) on the concrete strength. They found that NS increased significantly the compressive strength of concretes which supplemented with large quantities of fly ash (FA) at the beginning, by occupying the open spaces in the transition zone between large fly ash and cement particles**.**

Mann, 2006, studied the impact of addition of Nano-particles to the concrete. He found that supplementation of Nano-SiO_2 to the materials containing cement based can improve the durability through controlling of reactions of calcium-silicate hydrate degradation which result from calcium discharge in water, overcrowding water penetration.

Also, **Porro *et al.*, 2005,** found that addition of nano-SiO_2 (NS) particles improved the compressive force of cement pastes. They attributed this improvement due to the formation of a denser microstructure as a result of increase in the silica components in the mixture not due to pozzolanic reaction as mentioned by other authors who returned this improvement in the strength due to low consumption of calcium hydroxide, $Ca(OH)_2$. In addition, **Chen and Lin,2009,** showed that addition of NS increased the compressive strength of concrete in a rate of 15 to 20%.

Colin and Johnston, **2001,** presented research on Nano-SiO_2 with definite area of 200 m^2/g has been supplemented to high-strength cement pastes at a different concentrations (0, 0.5, 1, 2 and 5%). The different formed pastes were examined at different ages with and without super plasticizer for both their structural and mechanical properties. Nano-SiO_2 even at low concentration appears to influence on the structural and mechanical properties of cement of high strength. The supplementation of Nano-SiO_2 (in samples without super plasticizers) was found to generate two antagonistic mechanisms what is called chemo-mechanical reaction of cement pastes. It is observed that adding of more water to the paste lead to increase in the w/c ratio with all the well fixed steps.

Whereas, Nano-particles supplementation to the pastes increased potentially the mechanical properties. In the present study addition of 0.5% up to 2% w/w Nano-particles to cement elevated the flexural and compressive strength by 20 to 25%, even with the increased command in water in the fresh condition.

During the second group of experiments (with super plasticizers) more of obstacles were overcome. It is recorded that supplementation with 1% w/w of super plasticizers in cement diminished the volume of water and increased (30% to 35%) the flexural and compressive strength of pastes.

Perumalsamy *et al.,* 1992, found that the principal function of fibers in strengthen the concrete through modifying the mechanism of the cracks, where the fibers are diminishing the permeability of concrete and induce critical cracking strain, whereas in case of un-reinforced one the concrete may be defragmented at a crack, and thus, decreasing the load carrying ability to zero within the crack, whereas, presence of fibers helping in increasing the capability of carrying a load within the crack. The presence of micro-cracks at the mortar cumulative edge is accountable for the innate weakness of natural concrete. The weakness in the plain concrete can be overcome through addition of fibers in the mixture.

The fiber reinforced concrete (FRC) play an important role in case of small cracks, where it relocate the loads at the internal micro-cracks. Moreover, the fiber reinforced concrete is a combination of materials really composed of normal concrete or mortar reinforced randomly through dispersal of small, discontinuous and distinct tinny fibers of definite geometry. The used fibers are defined as an aggregation of fibers arranged in different forms varies greatly in shape. In this condition, the fibers interconnect around the aggregate particles and significantly decrease the workability whereas, the mixture will be more consistent and low ability for separation**.**

Janesan *et al.,* 2010, reported that the mode of action of steel fiber when added to the concrete in strengthen of reinforced concrete through two-way action by increasing both the critical force and ductility. Principally, the cracks will be divided into two parts when exposed to maximum tensile load and can`t resist more load or twist. Therefore, steel fibers are applied generally to improve both the tensile force and ductility of concrete.

Rui et *al.,* 2005, studied the effect of fiber quantity fraction used in producing steel fiber reinforced concrete. They reported that the addition of fiber at a concentration of 0.5% to 1.5% may decrease the workability of the composite and lead to balling or mat which will be incredibly hard to divide by vibration. On the other hand, the high quantity of fibers can be added to the concrete after modifying methods of the addition and with special processes of placements.

On the other hand, **Fawzy, 2016**, studied the influence of addition of nano-titanium on the properties of concrete using different kinds of cement, particularly the influence on slump, splitting and comprehensive tensile strength During his work, he added a nano-titanium at concentrations 0, 0.5, 1 and 2%, while the quantity of cement were 250, 350 and 400 Kg/m^3, respectively. The w/c ratio for all mixtures was 0.5.

Zemei *et al.,* 2017, investigated the effect of using steel fiber in the presence of nano silica (NS) on the mechanical properties of concrete. The NS dosage ranged from 0% to 2% by weight of cement. After testing, the results showed that 1%NS is the most effective percentage which gives high performance and good bond properties. The increase in compressive strength reached 35%. They also noticed that the strength decreased with percentages more than 1%. Mass transport properties enhanced achieving low porosity. Finally, the chemical properties C-S-H enhanced at later ages.

Moustafa, 2017, studied the impact of both steel fiber and nano-silica (NS) on mechanical and structural properties of concrete containing OPC and gravel 20 mm as a coarse aggregate. He reported that, compared to control mix, introducing Nano Silica in concrete led to decreasing the concrete workability except for at 0.5 % Nano Silica, and also a noticeable decrease in slump value happened with increasing the nano particles percentage from 0.5% to 3% as more reactions happened between the cement and fine particles.

The compressive strength has significantly increased with increasing the percentage of Nano Silica. Concrete with nano silica achieved the maximum strength at 3% NS.

Most of studies on nano-materials specially nano-silica concerned with its impact on fresh concrete and its mechanical and structural properties of the formed concrete and not paid an attention to the concrete containing different kinds of cement with addition of silica nano particles and study the properties of the mix., and its effect on ultrasonic pulse velocity of concrete. Therefore, the present study focuses on the impact of nano silica or steel fiber on different properties of concrete formed from different kinds of cement.

The nano-silica was added at a rate of 0 and 3%, to the cement quantity weighted 350, 400 and 450 Kg/m^3. The w/c ratio which used for all experiments was 0.45. The present experimental program was based on the study of the effect of replacement nano-silica to cement percentage (3%) and using steel fiber percentage (1%) with different cement content (350,400,450 kg/m^3) on fresh concrete properties such as slump as a workability and mechanical properties (compressive and splitting strength) and waves transport properties such as ultrasonic pulse velocity).

Further experimental procedures are described in details in the relevant sections.

2. Experimental Program

2.1 Materials

Two types of cement were used in this investigation: The first type was ordinary Portland cement, delivered from "Beni-Suef cement company", Type CEMI 42.5 N. The second type was blended cement with sand, delivered from “Al Qumia cement company”. Testing of cements was carried out per the Egyptian Standard Specifications (ESS 2421/2005) for OPC, whereas, per the Egyptian Standard Specifications (ESS 1078/ 2005) for blended cement with sand. The chemical and physical analysis of two cement types is presented in Table 1.

Natural siliceous sand with fineness modulus 2.73 was used as fine aggregates. Dolomite with 10 mm maximum nominal size was used as coarse aggregates; tap water was used for mixing and curing.

Nano silica was produced locally in Nano Materials Laboratory of Faculty of Advanced Sciences in Beni-Suef University. The grain size is 50 nm, it consists of pure silica. The NS used has a particle size of 14nm and specific surface area of 200 m^2/gm. Nano particles (NPs) were used to replace part of cement.

Steel fibers are produced by International Company for Pulling Wires and Manufacturing in Qalyoubia. Steel fibers were corrugated round of length (30 mm+/-3mm), diameter (0.9mm+/-0.05mm). Super plasticizer, of density 1.06 gm/cm^3 was used as admixture by 3% by weight of cement to improve the workability.

2.2 Mixture proportions

Sixteen mixtures were tested in this research, these mixtures were made with percentage of nano silica to cement = 0 and 3 %. Dolomite of 10 mm maximum nominal size was mixed with cement, sand, nano silica, steel fiber, super plasticizer and water. The mix constituents were 350,400 and 450 Kg cement, 1200Kg dolomite and 600 Kg sand per cubic meter of concrete at w/c = 0.45 and 3% super plasticizer. The percentage of steel fiber was 1% per volume of concrete.

Table 1: Chemical and physical analysis of cement types.

Property	OPC	Blended cement with sand
a-Chemical composition, %		
SiO_2	20.56	12.65
Al_2O_3	5.59	9.46
Fe_2O_3	2.65	8.51
CaO	63.13	-
MgO	1.94	2.39
Na_2O	0.43	-
K_2O	0.22	-
SO_3	2.61	-
$CaCO_3$		57.54
MoO_2		8.35
Ca		36.38
b- Physical properties		
Initial setting time, min	135	100
Final setting time, min	300	250
Specific surface, m^2/kg	370	330
Soundness, mm	2	3
c- Compressive strength, kg/cm^2		
3 days	250	160
7 days	350	270

Table 2: Mix proportions used for experimental program 1m^3 concrete with 3% super plasticizer

MIX NO.	W/C ratio	Cement kg	Sand kg	Dolomite kg	water	Nano-SiO_2 %	Cement type	Steel fiber to volume of concrete%
1	0.45	350	600	1200	157.5	-	OPC	-
2	0.45	400	600	1200	180	-	OPC	-
3	0.45	450	600	1200	202.5	-	OPC	-
4	0.45	350	600	1200	157.5	-	OPC	1
5	0.45	400	600	1200	180	-	OPC	1
6	0.45	450	600	1200	202.5	-	OPC	1
7	0.45	400	600	1200	180	3	OPC	-
8	0.45	400	600	1200	180	3	OPC	1
9	0.45	350	600	1200	157.5	-	blended	-
10	0.45	400	600	1200	180	-	blended	-
11	0.45	450	600	1200	202.5	-	blended	-
12	0.45	350	600	1200	157.5	-	blended	1
13	0.45	400	600	1200	180	-	blended	1
14	0.45	450	600	1200	202.5	-	blended	1
15	0.45	400	600	1200	180	3	blended	-
16	0.45	400	600	1200	180	3	blended	1

Table 3: The specimens and age of testing

Test	Test specimens	Age of testing
Compressive strength	100 mm cube	7,28 and 56 days
Splitting tensile strength	Cylinder of 150 mm diameter and 300 mm height	28 days
Ultra sonic pulse velocity	100 mm cube	28 days

These constituents of concrete were mixed in mechanical mixer for two minutes, and then placed in cube moulds, 10×10×10 cm for compressive strength testing and ultrasonic pulse velocity technique., whereas, the specimens for splitting tensile testing were cylinders 15x30 cm. Table 2 presents the masses of materials used (kg/m^3). Table 3 shows the tests that were conducted, sizes of specimens and testing ages.

2.3 Testing

In this research work, slump test was carried out on fresh concrete, whereas, the following tests on hardened concrete were carried out:

(a) Compressive strength: The compressive strength test was carried out according to the Egyptian Standard Specifications (ESS 1658/2006) at 7, 28 and 56 days age.

(b) Splitting tensile strength: The splitting tensile strength test was carried out at 28 days age according to the Egyptian Standard Specifications (ESS1658/2006).

(c) Ultrasonic pulse velocity test: The ultrasonic pulse velocity test was carried out at 28 days age according to IS: 13311(part1)-1992, method of non-destructive testing of concrete, part1: ultrasonic pulse velocity.

3. Results and Discussions

3.1 Slump

The impact of cement type on slump of concrete containing 1% steel fiber at various quantities of cement is presented in fig 1. The figure illustrated that, there is positive correlation between quantity of cement and slump values, where increasing in the cement content was associated with elevation in the slump value. In addition, the concrete made by blended cement and sand showed an elevation in slump values in comparison with concrete containing OPC. This finding may be returned to the components of blended cement and sand which contain lime stone. The presence of lime stone in this mix. Increased the workability of concrete via lowering of the concrete viscosity. This result is compatible with the results obtained by **Fawzy Y.A, 2016.** The results indicated also, introducing 1% steel fiber in concrete mix increases the workability of it.

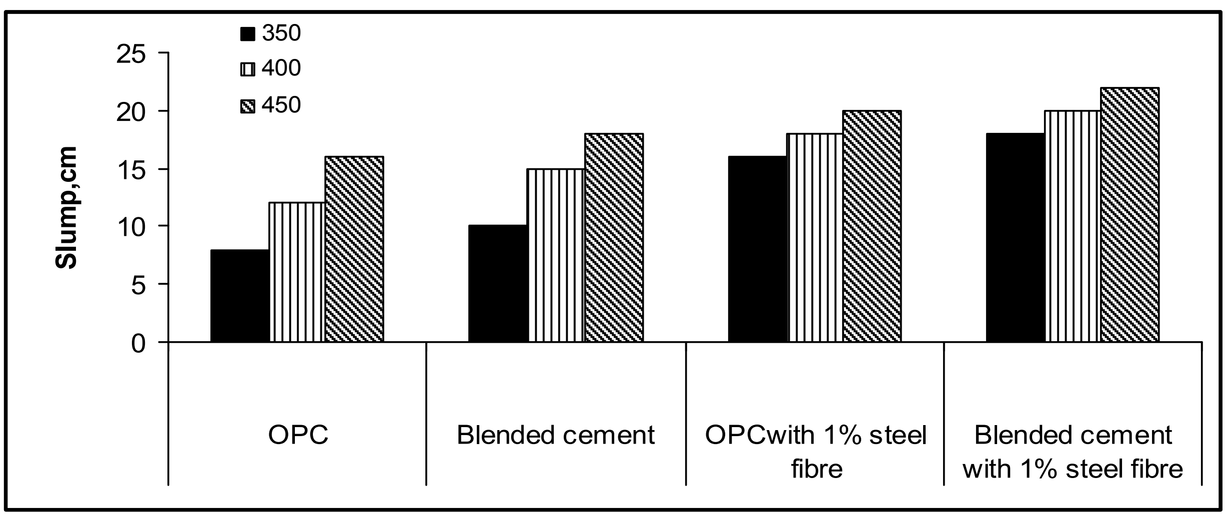

Figure 1: Effect of cement types and steel fiber on slump of concrete containing various quantities of cement.

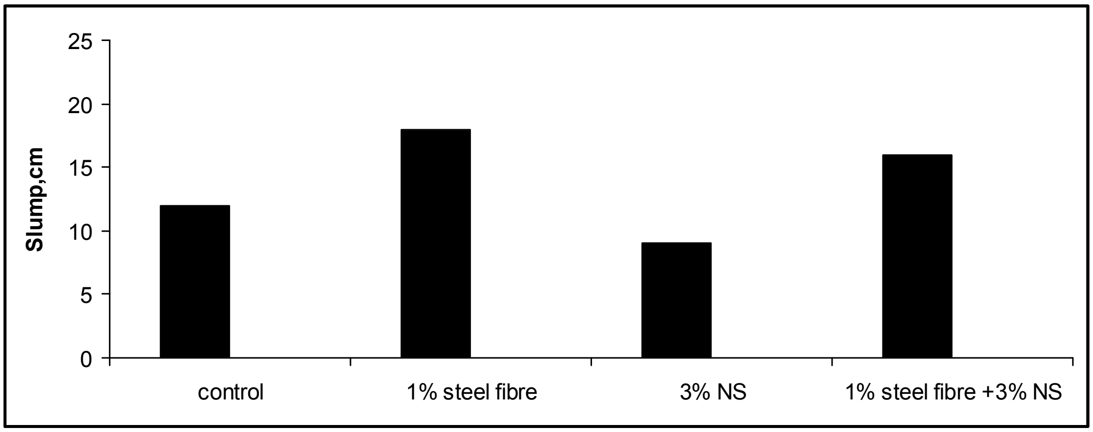

Figure 2: Effect of nano silica and steel fiber on slump of concrete containing OPC at 400 Kg/ m^3 quantity of cement.

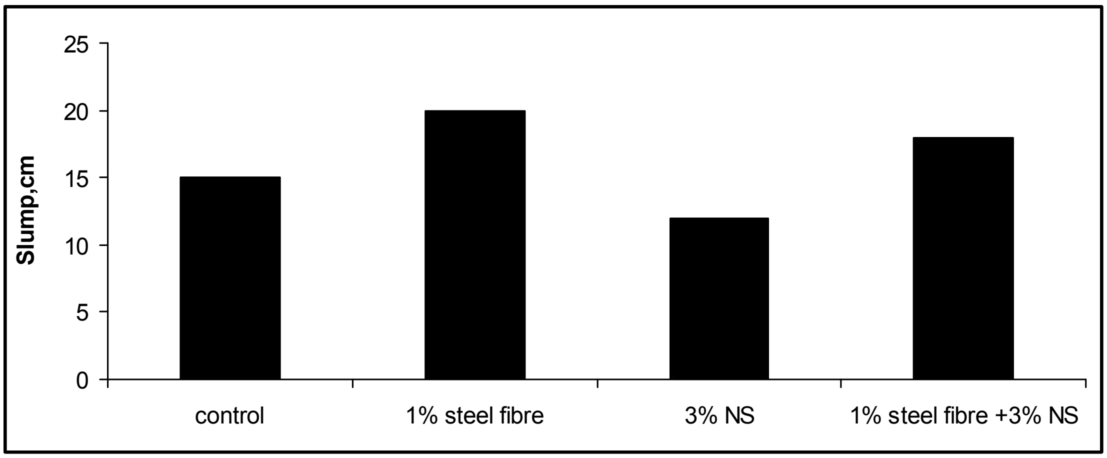

Figure 3: Effect of nano silica and steel fiber on slump of concrete containing blended cement at 400 Kg/ m^3 quantity of cement.

Figs2 and 3 show the effect of 3% NS and 1% steel fiber on slump of concrete made with OPC and blended cement at 400 Kg/ m^3 quantity of cement. It is apparent from these figures that, compared to control mix, 3% NS led to decreasing the slump of concrete made with OPC or blended cement, this result agrees with the result reported by **Moustafa, 2017.**

3.2 Compressive strength

As shown in figures 4 and 5 which represent the influence of cement types and 1% steel fiber on the compressive strength of concrete containing various quantities of cement at different intervals (7, 28 and 56 days) of concrete age. The figures showed that, an increase in the age of concrete was associated with an increasing in the compressive strength of concrete, where, the percentile of compressive strength after 7 & 28 days was averaged 75-85 % and 70 - 80% for OPC and blended cement, respectively. While the compressive strength at 56 days vs. 28 days reached to 115 versus 125% for various cement types, respectively. The results obtained indicated that the compressive strength was higher in case of concrete formed from OPC than concrete contained blended cement with sand.

As shown in figure 6 which illustrate the impact of nano-silica on the compressive strength of concrete containing various kinds of cement (OPC-blended cement with sand) after 7,28 and 56 days of concrete ages at 400 Kg/m^3. It is noticed that, an increase in concrete age was associated with an increase in the compressive strength of concrete, compared to control mix, introducing 3% NS led to 36% and 46% increasing in the concrete compressive strength after 28 days for OPC and blended cement, respectively. Introducing 3% NS with 1% steel fiber in concrete mix increase the compressive strength of concrete by 48% and 60% corresponds to OPC and blended cement, respectively.

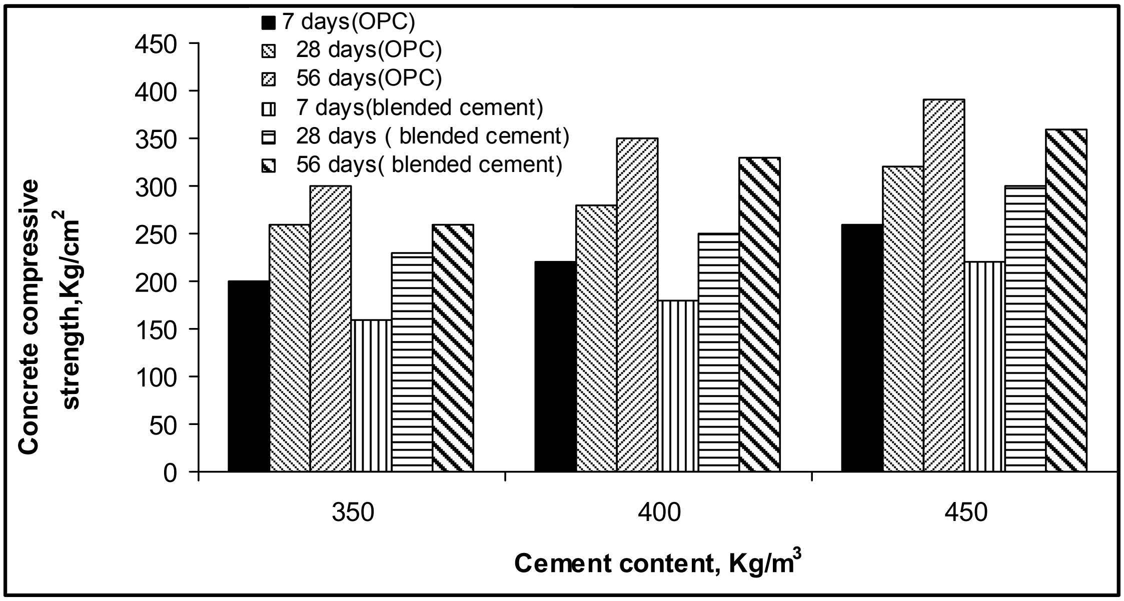

Figure 4: Effect of cement types on compressive strength of concrete containing various quantities of cement at different ages.

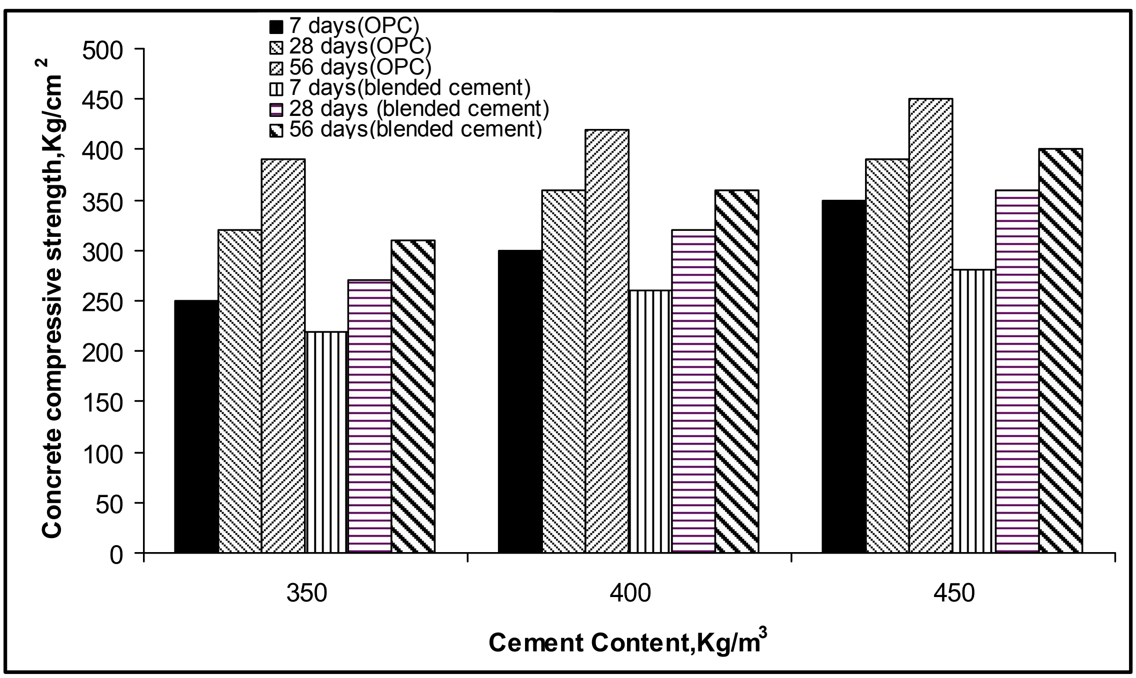

Figure 5: Effect of 1% steel fiber on compressive strength of concrete containing various quantities of cement at different ages.

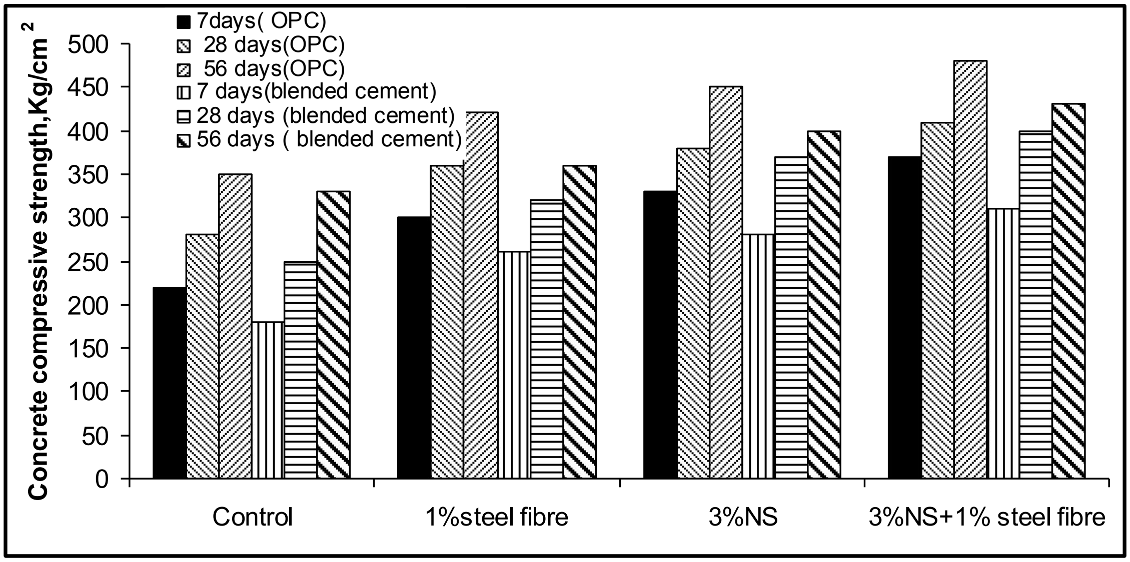

Figure 6: Effect of nano silica and steel fiber on compressive strength of concrete containing 400 Kg /m^3 cement at different ages.

3.3: Splitting tensile strength

Fig. 7 represents the impact of steel fiber added to the concrete containing various kinds of cement (OPC--blended cement with sand) on the splitting tensile strength after 28 days of concrete at 350,400 and 450 Kg/m^3. The results revealed that the concrete contain OPC was higher in the splitting tensile strength than concrete contained blended cement with sand. Also the results pointed to a parallel relationship between the cement quantity and strength of the splitting tensile, where an increase in the cement quantity was associated with increase in the splitting tensile strength. Figs 8 and 9 show the influence of nano silica and steel fiber on splitting tensile strength of concrete at 400 Kg/ m^3 cement for OPC and blended cement, it is apparent from these figures that, addition of nano-silca to the concrete mixes improved the concrete splitting strength. Compared to control mix, the values of splitting tensile strength of concrete made with 1% steel fiber, 3% NS and 3% NS with 1% steel fiber were increased by 7%, 15% and 30% respectively. This may be referred to the combined effect of N.S. & steel fiber on improving the tensile strength of concrete

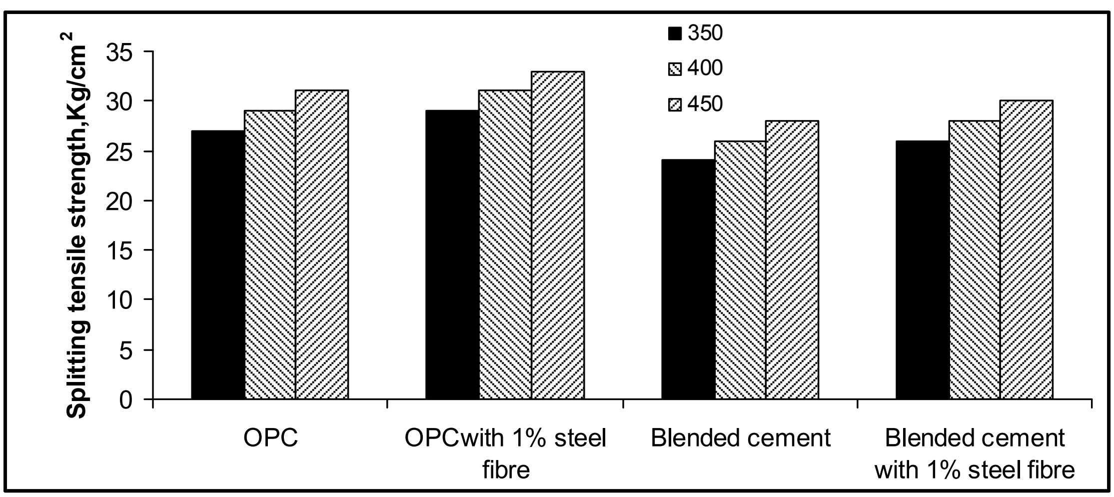

Figure 7: Effect of cement types and steel fiber on splitting tensile strength of concrete containing various quantities of cement at 28 days.

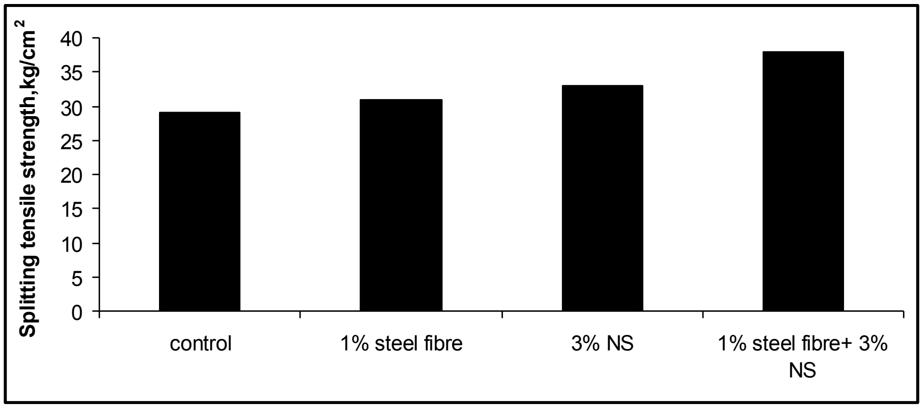

Figure 8: Effect of nano silica and steel fiber on splitting tensile strength of concrete containing 400 Kg /m^3 OPC at 28 days.

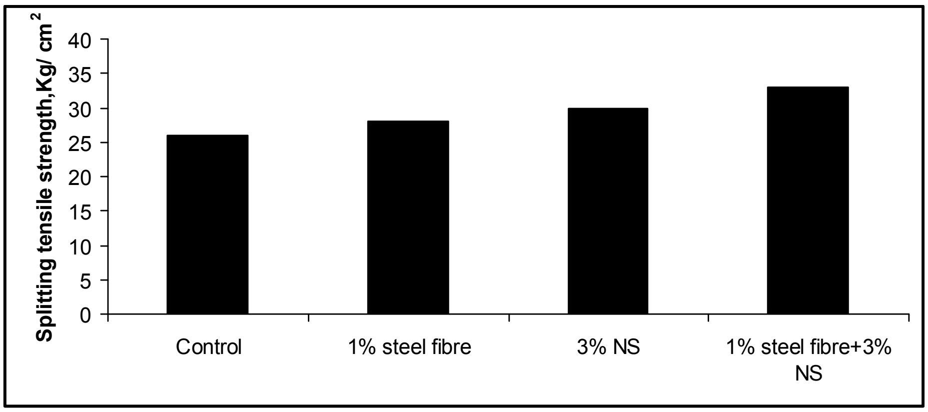

Figure 9: Effect of nano silica and steel fiber on splitting tensile strength of concrete containing 400 Kg /m^3 blended cement at 28 days.

3.4 Ultrasonic pulse velocity

Figs. 10 and 11 present the effect of steel fiber and nano silica on the ultrasonic pulse velocity of concrete containing various cement types (OPC- - blended cement with sand) for 400 Kg/m^3 cement tested at 28 days age of concrete. It is apparent from these figures that the values of ultrasonic pulse velocity of concrete containing blended cement are higher than that of OPC. Compared to control mix. Nano silica and 1% steel fiber with 3% NS increased the ultrasonic pulse velocity of concrete, also.

These results are combatable with **Fawzy Y.A. 2016**.

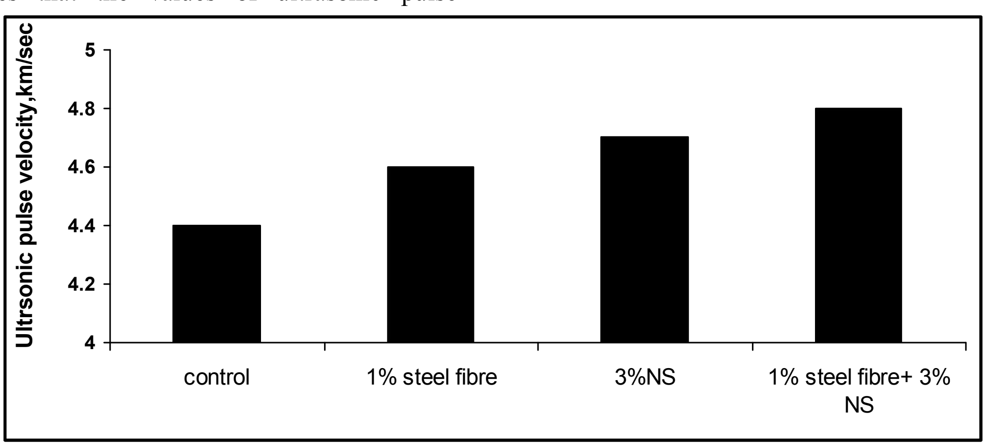

Figure 10: Effect of nano silica and steel fiber ultra pulse velocity of concrete containing 400 Kg /m^3 OPC at 28 days.

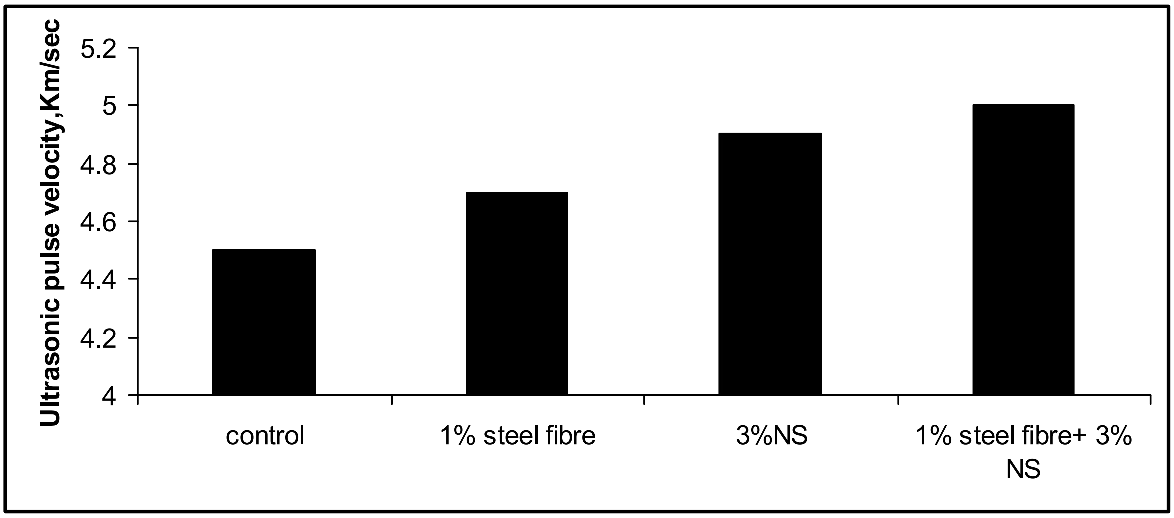

Figure 11: Effect of nano silica and steel fiber on ultra sonic pulse velocity of concrete containing 400 Kg /m^3 blended cement 28 days.

4. Conclusion

It is concluded from the results obtained from the carried experiments that:

- The concrete formed from blended cement with sand resulted in a raise in slump values as compared with concrete composed of OPC cement in constant of w/c ratio.
- Introducing 3% nano silica in concrete mix led to decreases the concrete slump, whereas, 1% steel fiber increases the slump of concrete.
- The compressive strength of concrete containing NS or steel fiber improved by increasing the age of concrete and the amount of cement added.
- Addition of 3% NS can improve the concrete compressive strength by 36% and 46% at 28 days age for OPC and blended cement, respectively. Introducing 3% NS with 1% steel fiber in concrete mix increased the compressive strength of concrete by 48% and 60% for OPC and blended cement, respectively.
- Compared to control mix, the values of splitting tensile strength of concrete made with 1% steel fiber, 3% NS and 3% NS with 1% steel fiber were increased by 7%, 15% and 30% respectively.
- Compared to control mix, nano silica and 1% steel fiber with 3% NS increased the ultrasonic pulse velocity of concrete.

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