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Increased plasticity of nano concrete with steel fibers

V.T. Ngo[a], T.Q.K. Lam[a*], T.M.D. Do[a], T.C. Nguyen[b]
[a] Mien Tay Construction University, Vinh Long city, Vinh Long province, Vietnam
[b] National Research Moscow State Civil Engineering University, Moscow, Russia
** E–mail: lamthanhquangkhai@gmail.com*

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Abstract. High strength concrete or nano concrete, it is often brittle, so it is necessary to study the solutions to increase the plasticity to obtain the structure to ensure the bearing capacity. The main advantage of steel fibers concrete is that it makes concrete with high flexibility, high tensile and compressive flexural strength, with bending components such as beams, the tensile area makes the concrete easier to form cracks and makes the structure quickly damaged. In this paper used the experimental method in order to determine the mechanical properties of nano concrete such as the tensile bending strength, the splitting tensile strength, for nano concrete samples with steel fibers and without steel fibers. In addition to the study also identified the deformation stress state of the two types of nano concrete and nano concrete with steel fibers. The use of steel fibers in nano concrete in the experiment made nano concrete increase plasticity, increase tensile bending strength, increase the splitting tensile strength and further enhance the advantages of new materials: steel fibers nano concrete materials.

1. Introduction

There are many studies on the effects of nanosilica have been conducted in recent years. The results of these studies have brought a lot of efficiency and encouragement to new researches in the future. In studies [1–5] surveyed for many types of particle size and particle distribution to evaluate the influence on the mechanical properties of concrete from the beginning of hydration to the strength formation. Nanosilica in concrete not only activates strongly with hydrate reactions to produce high-quality C-S-H, but they also fill holes with ultra-fine-sized particles to create increased concrete strength andthe reduction of harmful factors of concrete such as permeability and corrosion is significantly improved [6–10].

Similarly, Quercia [11] studied the effect of different types of nanosilica (NS) on the properties of high quality concrete. Two types of NS with surface densities of 200 m^2/g and 380 m^2/g were used for the study. There are many factors affecting the quality of concrete were also considered such as the ratio of water/adhesives and the ratio of NS used to the amount of cement. The results show the obvious influence of NS surface area on the mechanical properties of concrete. NS samples with double the C-S-H content had a higher hardness than silica fume samples. The addition of nanoparticles from 5 to 70 nm, formed by sol-gel method with superplasticizer in Portland cement mortar, created compressive strength reaching up to 63.9 MPa and 95.9 MPa after aging during 1 and 28 days, respectively. In addition, studies on cracking and heat in concrete have been studied by many authors [12–17].

Beside studies on nano concrete, studies on the use of fibers dispersed in concrete as inorganic fibers, organic fibers and high strength concrete were also a lot of interest and are studied by many different authors [18–20]. When using fibers in concrete has significantly improved the durability and mechanical properties of concrete, such as flexural strength, impact strength and resistance to fatigue. With these special features, concrete using dispersed fibers has brought many successes in researches as well as in real buildings.

In particular, when adding fibers to concrete has improved the ductility of concrete, the above issue has not been much research mentioned. Plasticity is a very important property of concrete, which represents the strength of concrete structures under the complex effects of load. When the concrete has low plasticity often leads to structures with very high brittle failure, especially for dynamic or fatigue the load. So, parameters can be used to assess the plasticity of concrete such as tensile strength, tensile strength when bending,

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the stress-deformation relationship or destructive strength. In particular, steel fibers used in concrete or steel fibers nano concrete were used quite effectively [21–27].

In order to determine the deformation stress state of nano concrete and its destructive properties, it is necessary to study mechanical properties such as compressive strength, tensile strength, separation strength, and elastic modulus. This study focuses on two main issues. The first is the influence of SiO_2 nanoparticles on the mechanical properties concrete. The second is the influence of the dispersed steel fibers on the plasticity of high-strength concrete. To solve the two main problems mentioned above, the paper presented experiments with 36 cylinder samples of 10×20 cm size for compressive strength testing were cast, 3 samples of beams of 10×10×40 cm to determine the tensile bending strength, 3 cylinders of 15×30 cm to determine the elastic modulus and the splitting tensile strength, and 3 cylinders of 15×30 cm size to determine the stress and strain curve diagrams on compression.

2. Materials and methods

2.1. Materials

Based on the research objectives, the selected mix will continue to be used in subsequent experiments of the study and are given in Table 1.

Table 1. High strength concrete mixtures.

Mixtures	Nanosilica, %	Silica, %	Symbol
Mixture 1	0	5	HPC
Mixture 2	0.5	5	HPCN0.5
Mixture 3	1.5	5	HPCN1.5
Mixture 4	3	5	HPCN3.0

So, the aggregates are calculated based on the design of high strength concrete components according to ACI 211, 4R-08. The aggregates are synthesized as a basis for calculating batches to conduct casting samples and presented in Table 2. The number and size of samples for experiment concrete with steel fibers and presented in Table 3.

Table 2. Aggregate concrete design with compressive strength of 80MPa.

Ingredient	HPC	HPCN0.5	HPCN1.5	HPCN3.0
Cement, kg	594	594	594	594
Stone, kg	1098	1098	1098	1098
Sand, kg	548	604	592	574
Water, kg	151.8	144.7	146.1	148.5
PG viscocrete, liters	6.53	6.53	6.53	6.53
Nano silic, kg	0	3.15	9.53	19.37
Silica, kg	29.7	29.7	29.7	29.7

The steel fibers content were used in studies varies from 0 to 1.5 % by volume. Recent studies show that, steel fiber to be added in the concrete mix is 1 % by volume was directed to be the optimal result in many of those studies. Based on that basis, the study selected 1 % of steel fibers to add to concrete and serve for experiments of steel fibers nano concrete [21–25]

Table 3. Number and size of samples used for testing with steel fibers.

Experimental content	Mixture	Number of samples	Sample shapes	Size, cm
Tensile strength when bending	HPCN1.5 + 1 % steel fibers (78.5 kg/m^3)	3	Beam samlpe	10×10×40

By some normal steel fibers with flat, a round section. The research has used Dramix steel fibers with round section, technical specifications for steel fibers are given in Figure 1 and Table 4.

Figure 1. Dramix steel fibers used in research.

Table 4. Technical specifications of steel fibers (Dramix).

No	Technical parameters of steel fibers	Steel fiber type			
		Long, flat 38 mm	Long, flat 52 mm	Round SF-35/0.7 mm	Round SF-35/0.55 mm
1	Shape and cross section of steel fibers	Flat steel fiber section with arc shape		Round steel fiber SF round section	
2	Long, mm	38.00	52.00	35.00	35.00
3	Diameter, mm	1.31	1.31	0.70	0.55
4	Fiber direction rate	29.00	39.70	50.00	65.00
5	Total surface area, cm^2/kg	5.340	5.340	6.616	8.978
6	Number of fibers, fiber/kg	2.280	1.840	8.600	19.040
7	Tensile strength, daN/cm^2	10.000			

2.2. Experimental plan

After identifying nano concrete mixes with aggregates, it was named HPC, HPCN0.5, HPCN1.5, HPCN3.0 with number and size of samples are given in Table 5.

Table 5. Sample number and size.

Content of the experiment	Mixture	Number of samples	Shape	Size, cm
Compressive strength 1day, 7days, 28days	HPC HPCN0.5 HPCN1.5 HPCN3.0	36	Cylindrical	10×20
The tensile bending strength	Optimized	3	Beam	10×10×40
The elastic modulus and the splitting tensile strength	Optimized	3	Cylindrical	15×30
The stress and strain curve diagrams on compression	Optimized	3	Cylindrical	15×30

2.3. Preparation and testing methods

The samples are cast for testing, such as in Tables 3 and 5.

– Cylindrical with 10×20cm and 15×30cm section;

– Beam with 10×10×40cm section;

– Molding process: When the mixture has a hardness of more than 20 seconds or a drop below 4cm, pour the mixture into the mold into two layers. After finishing the first layer, the vibrating table at the frequency of 2800–3000 revolutions/minute, the amplitude of 0.35–0.5 mm then vibrate until all the air bubbles are removed and the cement pool floats evenly. Then poured and swamped like that for the 2nd class.

2.4. Moistened samples

Samples are moistened at room temperature until the mold is removed, kept moist in a standard room with a temperature of 23 ± 2 °C, 95–100 % humidity until the day, is shown in Figure 2.

Figure 2. Moisten the sample after casting.

3. Results and Discussion

3.1. Experiment to determine compressive strength (ASTM C39-01).

After preparation of the sample surface, carry out the experiment to determine the compressive strength of the sample. The machine used to test the compressive strength of concrete samples is the TTM2000 electronic compressor with a maximum load of 2000kN, compressing the sample with an increase of 0.3MPa/s as shown in Figure 3.

Figure 3. The sample is destroyed during the compression.

The compressive strength of the test samples obtained at the age of 24 hours (1 day), 7 days, 28 days is presented in Tables **6–**8.

Table 6. Experimental results of compressive strength, 24 hours (1 day).

Experimental results of compressive strength, 24 hours (1 day).							
Type	Sample M1		Sample M2		Sample M3		
	Force, kN	Intensity, MPa	Force, kN	Intensity, MPa	Force, kN	Intensity, MPa	Medium intensity, MPa
HPC	133.9	17.06	138.0	17.58	151.2	19.26	17.97
HPCN0.5	155.8	19.84	152.6	19.44	174.2	22.20	20.49
HPCN1.5	216.2	27.55	206.0	26.25	198.0	25.22	26.34
HPCN3.0	118.6	15.11	103.4	13.17	106.9	13.62	13.97

Table 7. Experimental results of compressive strength at 7 days.

Experimental results of compressive strength, 7days							
Type	Sample M1		Sample M2		Sample M3		Medium intensity, MPa
	Force, kN	Intensity, MPa	Force, kN	Intensity, MPa	Force, kN	Intensity, MPa	
HPC	570.9	72.73	562.8	71.69	547.2	69.71	71.38
HPCN0.5	584.2	74.42	564.1	71.86	590.2	75.18	73.82
HPCN1.5	613.3	78.13	634.9	80.88	619.8	78.96	79.32
HPCN3.0	528.2	67.29	507.5	64.65	545.9	69.54	67.16

Table 8. Experimental results of compressive strength at 28 days.

Experimental results of compressive strength at 28 days.							
Type	Sample M1		Sample M2		Sample M3		Medium intensity,MPa
	Force, kN	Intensity, MPa	Force, kN	Intensity, MPa	Force, kN	Intensity, MPa	
HPC	748.3	95.33	718.3	91.50	722.0	91.97	92.93
HPCN0.5	714.2	90.98	711.6	90.65	702.3	89.46	90.36
HPCN1.5	729.5	92.93	714.3	91.00	755.7	96.27	93.40
HPCN3.0	642.6	81.86	618.2	78.75	648.2	82.58	81.06

Figure 4 shows that the highest compressive strength of HPCN1.5 concrete samples at 24 hours, 7 days, 28 days with the highest results. If compared with concrete using only siliceous soot (HPC), the compressive strength of HPCN1.5 grows faster in 24 hours and 7 days with the results increasing respectively 46.58 % and 11.12 %.

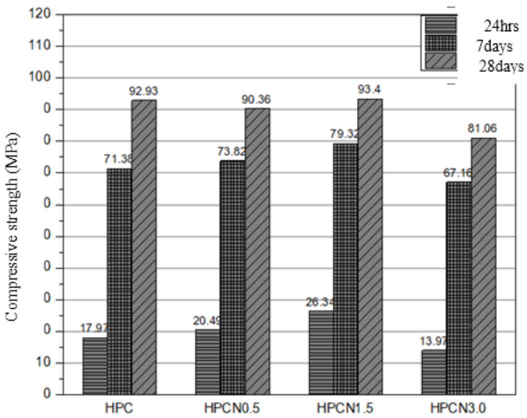

Figure 4. Compressive strength of nano concrete.

With the results of the compressive strength test of HPCN1.5 aggregate, the authors decided to use this aggregate to conduct experiments to determine some other mechanical properties of nano concrete.

The use of nano concrete with steel fibers has increased the compressive strength of nano concrete, especially in the early age (7 hrs – 24 days).

The effect of nano SiO_2 on the strength of high-strength concrete was investigated through different ratio of using NS. As the results shown, with the ratio of 1.5 % nano SiO_2 created concrete samples with the most optimal strength in experiments. When nano SiO_2 was added to the concrete mixture, the compressive strength at 28 days was not significantly different among the ratios. However, the strength of the samples at the early age (24h and 7 days) is very different due to the activation effect of the rate of SiO_2 nanoparticles. Increasing the ratio of SiO_2 nano to 3 % gives the concrete sample a reduction in strength compared to the rate of 1.5 %, the reason is that the dispersion of SiO_2 nano ultrafine particles is uneven in the mixture and forms local weaknessareas.

3.2. The experiment determines the tensile bending strength (ASTM C78-02).

Tensile strength is determined on10×10×40cm size samples. The test is carried out according to ASTM C78-02 with 4-point bending method isdisplayedin Figure 5. Table 9 presents the results of experimental results of tensile strength when bending at 28 days.

Table 9. Experimental results of the tensile bending strength at 28 days.

Sign	Force, kN	Tensile strength when bending, MPa	Medium, MPa
M1	26.9	8.07	
M2	25.1	7.53	7.99
M3	27.9	8.37	

3.3. Elastic modulus (ASTM C469-02)

Elastic modulus of nano concrete is tested according to ASTM C469-02. Sample with diameter of 150mm, height of 300 mm is shown in Figure 6.

Figure 5. Tensile strength test when bending.

Figure 6. Elastic modulus of nano concrete.

Table 10. Experimental results of elastic modulus (HPCN1.5).

Sign	Deformation 1	Deformation 1	Stress 1	Stress 2	Elastic modul	Elastic modul medium
	ε_1	ε_2	σ_1, MPa	σ_2, MPa	E, MPa	E_{tb}, MPa
M1	0.00005	0.00075	1.6	36.8	50286	
M2	0.00005	0.00079	1.9	38.2	49054	50036
M3	0.00005	0.0007	2.9	35.9	50769	

3.4. The experiment determines the tensile strength when splitting (ASTM C496-04).

The strength of splitting of nano concrete is tested according to ASTM C496-04. The cylinder is 150 mm in diameter and 300 mm in height. The experiment was carried out on 3 samples after performing experiments to determine the elastic modulus. Loading speed is 1MPa/s.

Figure 7. Test strength of splitting.

Table 11. Experimental results of splitting.

Sign	Force, kN	Tensile strength when bending, MPa	Medium, MPa
M1	343.1	4.86	
M2	350.8	4.97	4.97
M3	360.5	5.10	

3.5. Experiment to determine the stress and strain diagram.

Determining the stress deformation relationship of nano concrete is carried out to compress the center directly on cylindrical sample size 150×300 mm.

On each specimen tested and two resistors of 60 mm length are pasted along both sides of the cylinder to measure the deformation of the sample. The compression force is measured by Loadcell type 2000KN placed under the test sample is shown in Figure 8.

Figure 9 shows the relationship between stress and strain for 3 test samples M1, M2 and M3.

Figure 8. Experiment to determine stress – deformation.

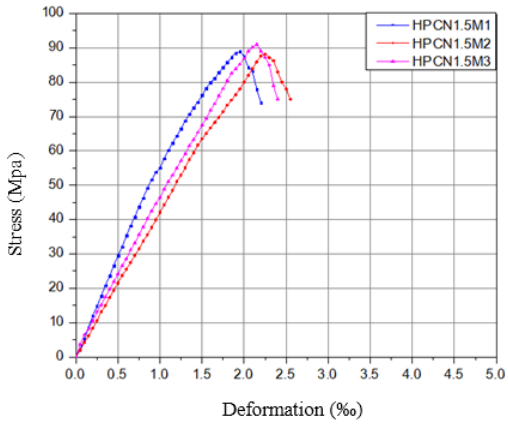

Figure 9. The diagram of stress-strain for HPCN1.5 nano concrete.

When the stress reaches the maximum, the material is damaged, the stress value decreases rapidly compared to the deformation of the material. Based on the graph of Figure 9, the slope of the stress strain line after the top is large, the concrete is suddenly destroyed when the deformation is still very small. From the results in Figure 9 show that the concrete in the study is very brittle.

Nano concrete experiments added steel fibers. The steps of mixing the mixture, casting the nano concrete and Dramix fibers are carried out similarly to the nano concrete without the fibers, Dramix fibers will be added to the mixture at the end-stage is shown in Figure 10. And Figure 11 shows the tensile strength test when bending of nano fiber concrete with steel fibers.

Figure 10. Mixing nano-concrete mixture with steel fibers.

Figure 11. 4-point bending test and sample after destructive.

Tables 12–13 are presented results of the tensile bending strength and tensile strength test when splitting.

Table 12. Experimental results of the tensile bending strength.

Sample	Force, kN	Tensile strength when bending, MPa	Medium, MPa
M1	55.2	16.56	
M2	58.9	17.67	16.93
M3	55.2	16.56	

Table 13. Results of tensile strength test when splitting.

Sign	Force, kN	Tensile strength test when splitting, MPa	Medium, MPa
M1	466.9	6.61	
M2	453.4	6.42	6.43
M3	441.5	6.25	

The relationship between stress and deformation of concrete samples with steel fibers is shown in Figure 12.

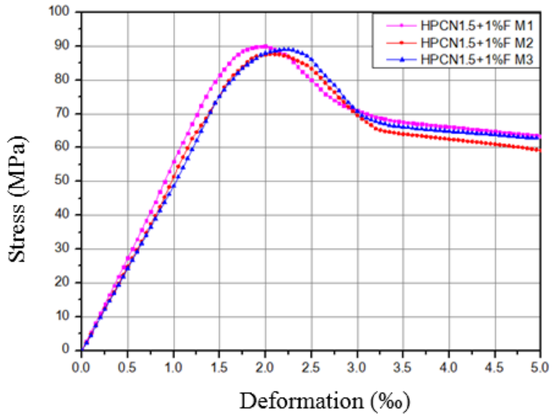

Figure 12. Stress – deformation when compressing of nano concrete with steel fibers.

Based on the test results of the tensile bending strength and tensile strength when splitting (Tables 12, 13) of nano-fiber concrete, the difference can be quite large. When adding steel fibers to the concrete mixture, the tensile bending strength and the splitting tensile strength increased compared to when the concrete without steel fibers was 111.8 % and 29.3 %, respectively.

From Figure 12, the stress-strain curve shows that when the deformation reaches a maximum value, the stress decreases slowly, the area under the curve (destruction energy) increases. It can be seen that the peak load of steel fibers concrete is approximately the same as that of non-steel fibers. However, there is a difference, nano-fiber concrete after cracking appears, stress drops suddenly, but then stabilizes and slows down.

The mechanical properties change, such as the tensile bending strength, the splitting tensile strength and stress deformation relations show that the steel fibers nano concrete are more flexible. The amount of fibers added to a concrete mix has limited the appearance of cracks and after the cracks were stabilized. The steel fibers that link cracks like a thread stitching the surface of cracks, this phenomenon is exacerbated when the base material (concrete) has high strength, can create great adhesion to steel fibers.

4. Conclusions

Based on the results of the study lead to the following conclusions:

1. The effect of nano SiO_2 on the strength of high-strength concrete was investigated through the different ratios of using NS. The results shown with the ratio of 1.5 % nano SiO_2 created concrete samples with the optimal strength in the components in experiments. When nano SiO_2 was added to the concrete, the compressive strength of the sample at 28 days was not significantly different between the ratios. However, the strength of the samples at an early age (24h and 7 days) is very different due to the activation effect of the rate of SiO_2 nanoparticles. Increasing the ratio of SiO_2 nano to 3 % gives the concrete sample a reduction in strength compared to the rate of 1.5 %, the reason is that the dispersion of SiO_2 nano ultrafine particles is uneven in the mixture and forms local weakness areas.

2. Study of the stress-strain state for nano concrete without steel fibers, when the stress reaches the maximum, the material is damaged, the stress value decreases rapidly compared to the deformation of the material. The slope of the stress-strain curve at the post-peak stage is large, the concrete is suddenly destroyed when the deformation is still very small.

3. When adding steel fibers Dramix with a ratio of 1 % to enhance plasticity, bending strength of nano concrete using steel fibers increased by more than 110 % compared to nano concrete don't use steel fibers. Stress-strain relationship curve varies significantly compared to the type without steel fibers. The stress after the peak decreases slowly, the curve becomes less slope, the area under the curve is also much larger. The above results have confirmed the improvement of mechanical properties, especially the flexibility of nano concrete when adding steel fibers.

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Contacts:

Van Thuc Ngo, +84939423461; nvthuc34@gmail.com
Thanh Quang Khai Lam, +84909563055; lamthanhquangkhai@gmail.com
Thi My Dung Do, +84982191146; dothimydung1983@gmail.com
Trong Chuc Nguyen, +7(966)3319199; ntchuc.mta198@gmail.com