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Effect of Nano Silica and Steel Fiber on Properties of Concrete

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Abstract— This study presents experimentally the combined effect of using nano silica (NS) and steel fibers (SF) on mechanical properties of hardened concrete. NS is used as partial cement replacement by 1, 1.5, 2, and 4 wt%, and SF is used as volume substitution by 0.45, 0.9, and 1.35%. Splitting tensile strength, modulus of elasticity and flexural strength are evaluated using different combinations between NS and SF. Significant improvement in the mechanical properties of concrete is observed on using NS due to its high pozzolanic activity confirming the formation of higher amount of C–S–H gel in the presence of nanoparticles. Optimum content of NS is 1.5 wt% improves splitting strength for samples with 0% SF, 0.45% SF, 0.9% SF and 1.35% SF about 35%, 41%, 66% and 72% respectively compared to samples without either NS or SF. Utilizing 2 wt% NS with 0.9% SF leads to improving modulus of elasticity about 94% compared to samples without either NS or SF. Flexural strength is doubled for samples of 2 wt% NS and 1.35% SF compared to samples without NS and SF.

Keywords—Nano silica; steel fiber; splitting strength; flexural strength

I. INTRODUCTION

Many researchers interested in evaluate the effect of using nano silica (NS) on physical, mechanical properties and durability of concrete, nano materials not act only as pozzolanic additive but also as fillers improving the pore structure of concrete and densifying the microstructure of cement paste [1 – 6].

The quantity of C–S–H gel is increased due to high pozzolanic action of fine particles and also mineral admixtures with fine particles can improve the filler effect. Microstructure in the interfacial transition zones improved with low water cement ratio [7]. Nano silica, due to its high special surface, is significantly reactive [8], and produces C-S-H condensed gel as a result of reaction with CH.

Compressive strengths of hardened cement paste and bond strengths of paste–aggregate are increased by incorporating NS, and NS can improve the interface structure more effectively than incorporating silica fume [9]. Filler effect of fine nanoparticles improved the rheological properties by increasing nanoparticles percentage [10].

Addition of variable ratios of nano-silica significantly improved the overall performance of concrete [11]. The presence of steel fibers at various volume fractions give great enhancement in compressive strength, splitting tensile strength and modulus of rupture of high strength concrete [12].

The mechanical properties and durability of self-compacting concrete are significantly improved by using both nano silica and fibers in optimum percentages; however toughness is decreased by increase nano silica more than 2 wt% [13].

In this study several mechanical properties of concrete are investigated and evaluated experimentally by using different combinations of nano silica and steel fibers in concrete to obtain concrete with high characteristics compared with normal concrete.

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II. MATERIAL AND METHODS

2.1. Material and mixtures

Cement

Ordinary portland cement (OPC) is used as the main cementing material. It complies with the requirements of ASTM C 150 [14] as received from the companies of Tourah-Helwan (Egypt). The general chemical composition of the OPC is illustrated in Table 1.

SiO_2 nanoparticles

Nano SiO_2 (NS) with average particle size around (9 to 20) nm is used as received from physical laboratory at housing and building national research centre (HBRC). The utilized NS particles are expected to have high pozzolanic reactivity due to their amorphous structure. XRD test indicates the amorphous structure of NS (illustrated in Fig. 1). As it can be seen, the XRD patterns show an approximately broad peak centered about $2\theta \approx 22^o$ which demonstrates the amorphous structure of utilized NS [1]. Moreover, the general chemical components of the utilized NS are presented by EDAX result (shown in Fig. 2).

Aggregates

Two types of aggregates are used in the concrete mix: fine aggregates and coarse aggregates. Fine aggregates used for the study are locally available natural sand. Fine aggregates pass the 4.75 mm (No. 4) sieve and retain on the 75 lm (No. 200) sieve [15]. Dolomite is used as coarse aggregates with particle size not exceed 14 mm.

Steel fiber

Hooked end steel fibers (SF) made of low carbon steel wire with average length of 30 mm and average diameter of 0.8 mm are used (Fig. 3). SF tensile strength is between 800 N/mm2 to 1100 N/mm2 and meeting the requirements of ASTM A820.

Superplasticizer

Superplasticizer (SP) of polycarboxylate base (Glenium C315, BASF Co.) with 1.08 g/cm3 specific gravity is used.

2.2. Mixture proportioning

A total of twenty mixes are prepared in the laboratory. The control mixture is prepared without using NS or SF, other mixtures are prepared using NS as partial cement replacement by 1, 1.5, 2, and 4 wt%, and SF is used as volume substitution by 0.45, 0.9, and 1.35%. The mixes are divided into four groups and the mixtures proportions are presented in Table 2.

Water to binder ratio (w/b) for all mixtures was set at 0.40. Constant binder content of 450 kg/m3 is used for all mixtures. The amount of superplasticizer is set at 0.8% of the binder weight.

2.3. Mixing procedure and curing

Colloidal NS is applied for 10 minutes to ultra-sonication probe to be vibrated at very high speed to avoid agglomeration and to be more efficient in dispersing NS shown in Fig. 4.

In the performing of concrete, the dry materials are first mixed without fibers to avoid fiber balling for 1 min at low speed to obtain a homogenous mixture, then wet mixed at low speed for another minute, after that colloidal NS is added to prevent any agglomeration which may occurred and finally SF and SP are added and mixed at medium speed for 3 minutes, hence good workability concrete with uniform material is produced [12].

Once the mixing process is completed, the samples are placed into molds and kept under laboratory condition for 24 h. They were then removed from the molds and kept in 22–25 ºC water until the suitable age for each experiment. Each mixing design includes three 150 mm diameter cylinders molds with 300 mm height for splitting test, three 150 mm cubic molds for modulus of elasticity test and three 600 x 150 x 150 mm beam molds for flexural strength test.

2.4. Test methods

Split tensile test was carried out in accordance with the ASTM C 496 [16] standard. After curing period was over, the concrete cylinders were subjected to split tensile test by using universal testing machine. Tests were carried out on triplicate specimens and average split tensile strength values were obtained.

The static modulus of elasticity is determined according to ASTM C 469 [17]. Tested specimens are exposed to uniaxial compression load using universal testing machine. The stress-strain characteristics are determined after 28 days of curing. The modulus of elasticity is measured as a tangent modulus in the elastic range.
Flexural tests are performed in accordance with the ASTM C293 [18] Standard. Tested specimens are exposed to one point load at mid-span. Again, flexural tests are carried out on triplicate specimens and average flexural strength values are obtained.

Table 1: Chemical composition of OPC (wt%).

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	L. O.I
Cement	21.03	4.09	3.03	61.45	1.74	3.50	0.48		0.37 4.08

Table 2: Mixture proportions of SF and NS blended concretes.

Group	Mix	SF (%)	NS (%)	Quantities (kg/m^3)		
				Cement	NS	SF
G1	M1 (control)	0	0	450	0	0
	M2		1	445.5	4.5	0
	M3		1.5	443.25	6.75	0
	M4		2	441	9	0
	M5		4	432	18	0
G2	M6	0.45	0	450	0	30
	M7		1	445.5	4.5	30
	M8		1.5	443.25	6.75	30
	M9		2	441	9	30
	M10		4	432	18	30
G3	M11	0.9	0	450	0	60
	M12		1	445.5	4.5	60
	M13		1.5	443.25	6.75	60
	M14		2	441	9	60
	M15		4	432	18	60
G4	M16	1.35	0	450	0	90
	M17		1	445.5	4.5	90
	M18		1.5	443.25	6.75	90
	M19		2	441	9	90
	M20		4	432	18	90

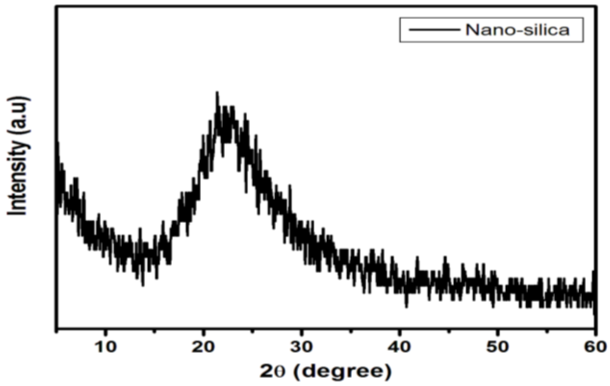

Figure 1. XRD of SiO_2 nanoparticles with average particle size of (9-20) nm.

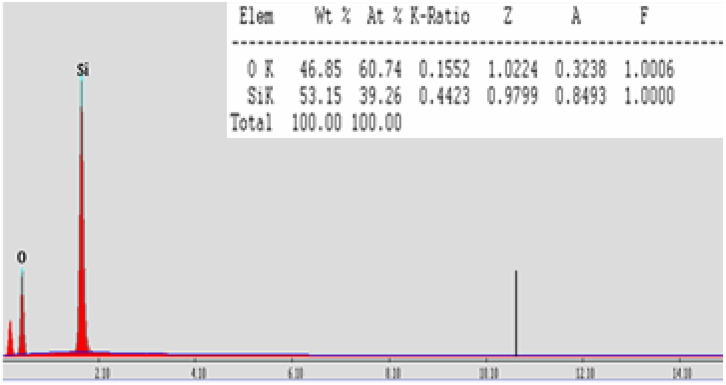

Figure 2. EDAX of SiO_2 nanoparticles chemical components.

Figure 3. Hooked end steel fiber.

Figure 4. Ultra-sonication probe.

III. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Splitting tensile strength

The average test results of splitting strength of SF and SiO_2 nanoparticles concretes for each mix is presented for each group with percentages of gain in Fig. 5 to Fig. 13. The splitting strengths of all concretes increase with the increase of NS and SF content confirming the formation of higher amount of C–S–H gel in the presence of nanoparticles. Steel fiber gives an important effect in controlling and bridging cracks leads to improving tensile strength of concrete. Optimum content of NS is 1.5 wt% improves splitting strength for samples with 0% SF, 0.45% SF, 0.9% SF and 1.35% SF about 35%, 41%, 66% and 72% respectively compared to samples without either NS or SF. Using 1.35% SF without NS increased splitting strength in all mixes compared to that containing NS alone.
Using 4 wt% NS leads to reduction in splitting strength, this may be due to the agglomeration which reduce the amount of crystalline CH.

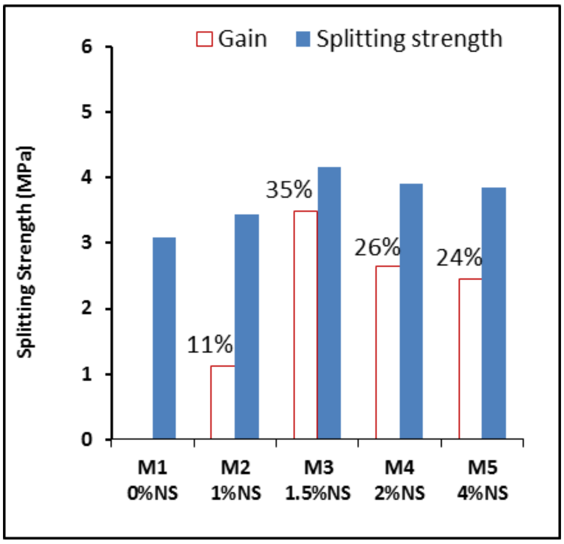

Figure 5 Splitting strength for Group G1 with 0%SF.

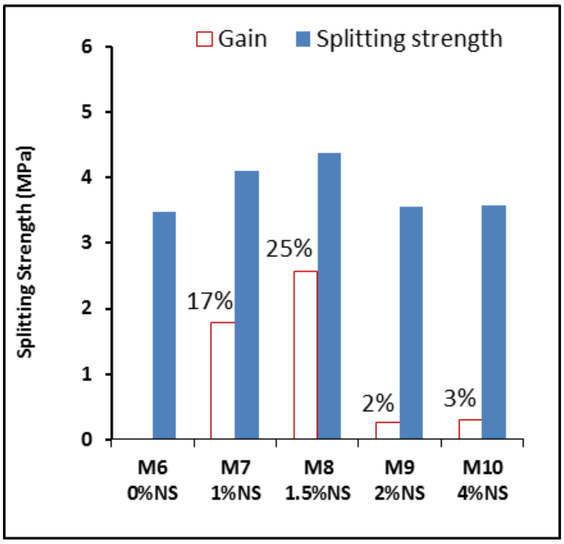

Figure 6 Splitting strength for Group G2 with 0.45%SF.

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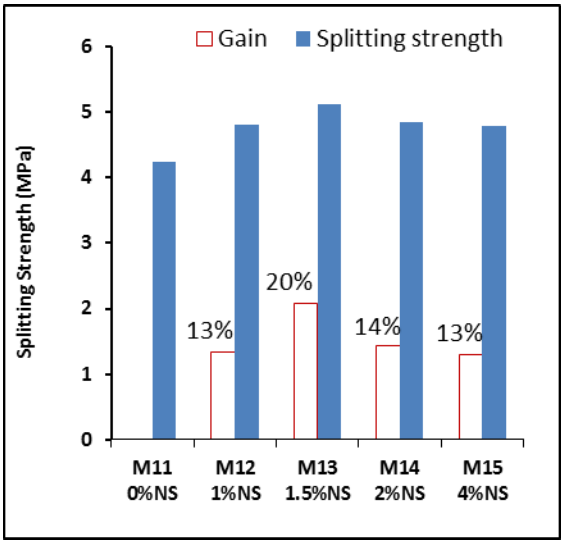

Figure 7 Splitting strength for Group G3 with 0.9%SF.

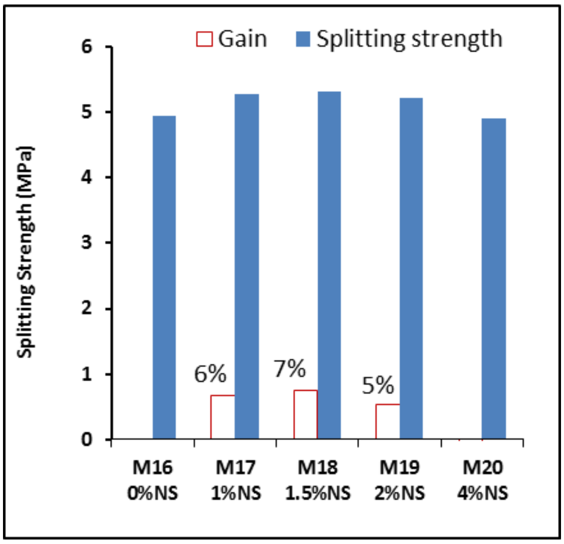

Figure 8 Splitting strength for Group G4 with 1.35%SF.

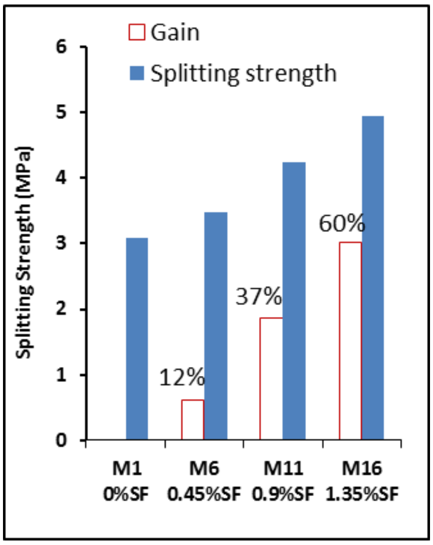

Figure 9 Splitting strength for Group G5 with 0 wt.%NS.

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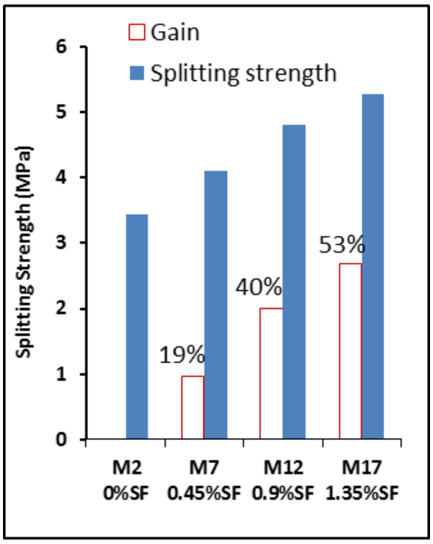

Figure 10 Splitting strength for Group G6 with 1 wt.%NS.

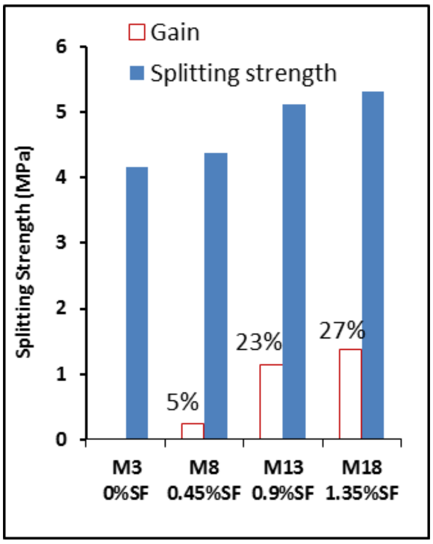

Figure 11 Splitting strength for Group G7 with 1.5 wt.%NS.

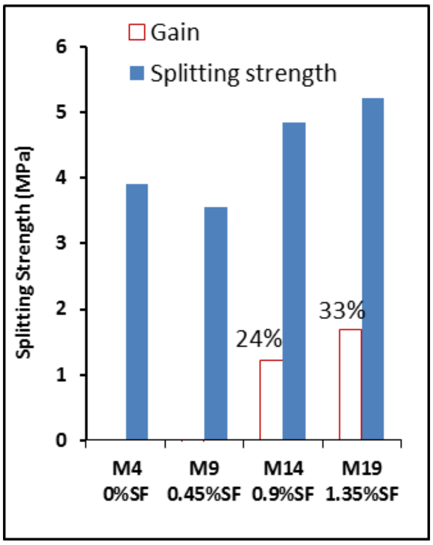

Figure 12 Splitting strength for Group G8 with 2 wt.%NS.

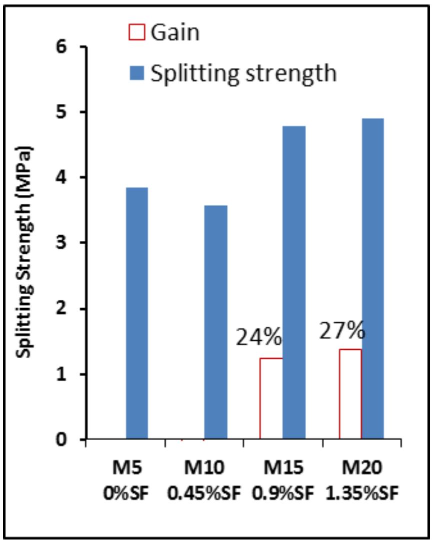

Figure 13 Splitting strength for Group G9 with 4 wt.%NS.

3.2. Modulus of elasticity

The results of modulus of elasticity and gain percentages are presented in fig. 14 to fig. 17. It is found that by adding SF significantly increase modulus of elasticity. It is observed increase also by addition of NS into concrete, this is in good agreement with [19, 20].

When SF content increases to the value of 0.9% optimum modulus of elasticity is reached for the samples with all NS content.

Adding NS by 2 wt% improves modulus of elasticity about 5% compared to samples without NS at 0.9% SF.

The optimum ratios of NS and SF are concluded to be 2 wt% and 0.9% respectively; hence leading to improvement in modulus of elasticity compared to samples without either NS or SF is about 94%.

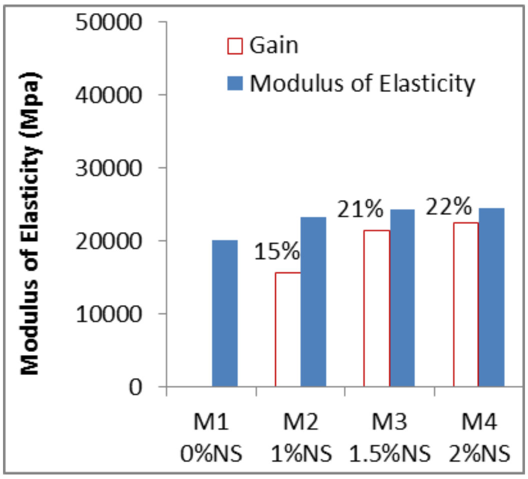

Figure 14 Modulus of elasticity and % gain for mixes with 0% SF.

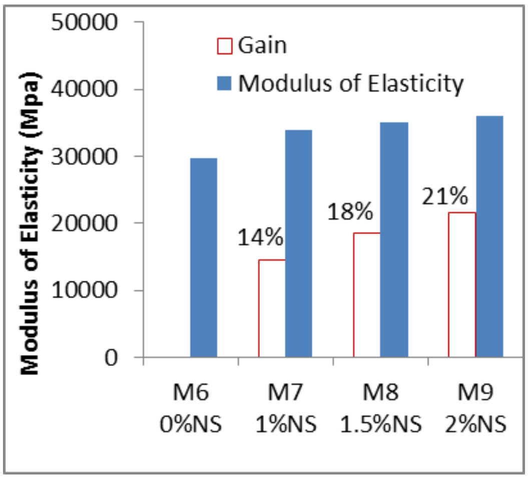

Figure 15 Modulus of elasticity and % gain for mixes with 0.45% SF.

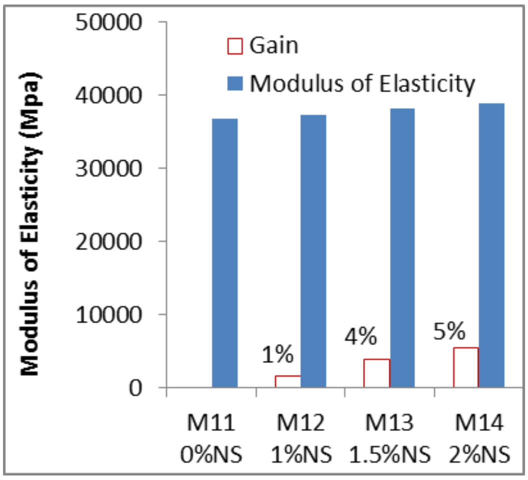

Figure 16 Modulus of elasticity and % gain for mixes with 0.9% SF.

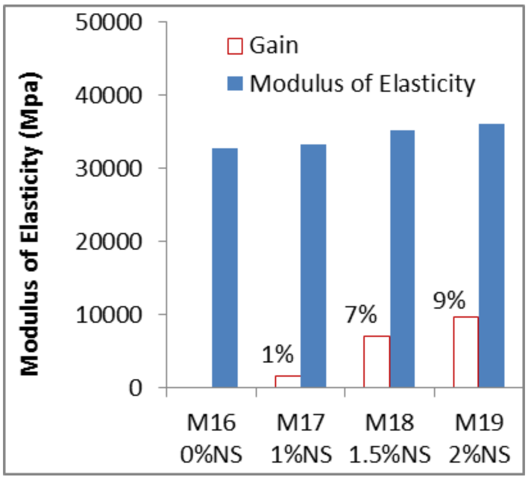

Figure 17 Modulus of elasticity and % gain for mixes with 1.35% SF.

3.2. Flexural strength

The average test results of flexure strength of SF and SiO_2 nanoparticles concretes for each mix is presented in Fig. 18. It is found that increase in the amount of SF increased the flexural strength.

It can be concluded that, the flexural strength increase by increasing either NS or SF, using 2wt% of NS with 0%, 0.45%, 0.9% and 1.35% SF can improve flexural strength about 16.3%, 13.9%, 20.6 and 24.3% respectively compared to samples without NS.

Utilizing 2 wt% NS and 1.35% SF improve flexural strength about 88% compared to samples without neither NS nor SF.

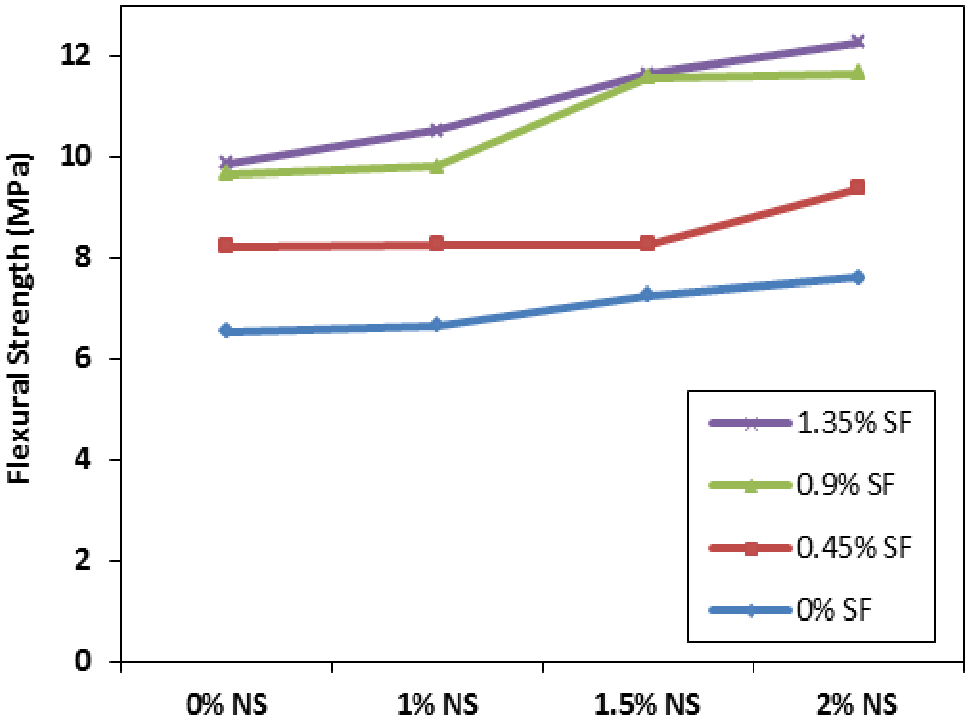

Figure 18 Flexural strength for samples with different ratios of NS and SF.

IV. CONCLUSIONS

The following can be concluded from presented research:

1. Using nano silica as cement substitution leads to great enhancement on mechanical properties of concrete due to its high pozzolanic activity provides huge amount of CSH with reducing the amount of crystalline CH.
2. Optimum content of NS is 1.5 wt% improves splitting strength for samples with 0% SF, 0.45% SF, 0.9% SF and 1.35% SF about 35%, 41%, 66% and 72% respectively compared to samples without either NS or SF.
3. The optimum ratios of NS and SF are concluded to be 2 wt% and 0.9% respectively leading to improving the modulus of elasticity about 94% compared to samples without either NS or SF.
4. Flexural strength improved about 88% for samples of 2 wt% NS and 1.35% SF compared to samples without NS and SF.

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