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Effect of Concrete Strength on the Mechanical Properties of Fiber Reinforced Concrete

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الملخص العربي

اكتسبت الخرسانة المسلحة بألياف الصلب (SFRC) شعبية في العقود الأخيرة بسبب أدائها العالي. تشمل مزاياها الرئيسية على إعاقة تقدم الشروخ الدقيقة، وتحسين الليونة والمقاومه المتبقية بعد تكون الشرخ الأول، ومنع نمو الشروخ وتقدمها إلى مستويات أعلى والصلابه العاليه. تبحث هذه الدراسه تأثير إضافة ألياف الصلب بمحتويات مختلفة على الخواص الميكانيكية للخرسانة مع ثلاث مستويات من المقاومة تمثل خرسانة عادية وخرسانة متوسطة المقاومة وخرسانة عالية المقاومة. وقد تماستخداماالأليافذاتالنهايات المعكوفهبطول 3,5 سم ونسبة الطول إلى القطر تساوى43,75 وبنسب حجمية 0,5٪ و 0,1٪ و 1,5٪. وتم إعداد ودراسة إثناعشر مزيجًا من الخرسانة. وقد أشارت النتائج إلى أن إضافة محتوى مختلف من ألياف الصلب إلى الخرسانة ذات ثلاث مستويات من المقاومة بانواعها الثلاثة تسببت في تغيير كبير في الخواص الميكانيكية للخرسانة مثل مقاومة الضغط ومقاومة الشد غير المباشر ومقاومة الانحناء وكان هذا التأثير اكثر وضوحًا فى الخرسانة العادية مقارنةً بالخرسانة عالية المقاومة.

ABSTRACT

Steel fiber reinforced concrete (SFRC) has gained popularity in the last decades because of its higher performance. Its main advantages include hindrance in macro crack propagation, improvement in ductility and residual strength after formation of the first crack, prevention of growth of micro cracks to macroscopic level and high toughness. This study investigates the effect of adding steel fibers with different content on the mechanical properties of concrete for three values of concrete strength representing normal strength concrete (NSC), moderate strength concrete (MSC) and high strength concrete (HSC). Hooked ended fibers of length 35 mm and fiber aspect ratio of 43.75 were used by volume fractions of 0.5%, 1.0% and 1.5%. Twelve concrete mixes were prepared and investigated. The results indicated that the addition of different content of steel fibers to the three types of concretes caused a significant effect on their mechanical properties involving compressive strength, indirect tensile strength and flexural strength. The effect was more pronounced in NSC compared to HSC.

1. INTRODUCTION

Plain concrete is a brittle material and exhibits extensive cracking and undergoes brittle failure under dynamic loading. The concrete is weak in tension and to overcome this problem concrete is reinforced using steel bars thus called as reinforced concrete. In this modern civil engineering constructions have their own structural and durability requirements. It can usually to be reinforced with materials that are strong in tension.Fiber is such a reinforcing material. Fibers are small pieces of reinforcing material has characteristics and properties [1]. The addition of steel fibers (SF) in high performance concrete (HPC) can improve the brittle behavior and the energy absorption capacity [2–3]. Steel fiber reinforced concrete (SFRC) plays a significant role in developing modern concrete technology, which represents a new class of construction concrete. In recent years, extensive researcheswereperformed to explore the use of SF in producing high strength fiber reinforced concrete (HSFRC). The comparison between mechanical properties of HSFRC has been presented [4].

Dahake and Charkha [5]carried out an experiment work to study the effect of different types of SF on concretes having various strengths. They found that adding different types of SF to plain concrete with 35MPa enhanced the mechanical properties of concrete. All the properties of concrete like compressive strength and flexural strength are increased. The significant improvement in various strengths is observed with the inclusion of hooked end SF in plain concrete and with increasing fiber content.Mode of failure is changed from brittle to ductile when subjected to compression and bending.High strength fibers with different contents were found to have positive effect on the mechanical properties of the high strength concrete [6]. Steel fibers with hook ends were recommended to be used for further studies for better workability and were reported to increase the ductility [6]. The investigation carried out on mechanical properties of HSFRC by Song and Hwang [7]showedthat the brittleness with low tensile strength and strain capacities of high strength concrete (HSC) can be reduced by the addition of SF.

Rahul Pandit and Jamkar [8] carried out an experiment work to study the effect of types of fibers and volume fraction on compressive strength, splitting tensile strength and flexural strength of HSFRC of grade 80MPa.They found that,HSC without fibers is relatively brittle and fails suddenly when compared with HSFRC with different types of fibers. The compressive, tensile and flexural strength of HSC improvedwiththeaddition of hooked end SF [8]. Higher compressive strength led to lower ductility under flexural loading [9]. Experimental work had been carried out to investigate the effect of the fiber volume content on the mechanical properties of HPC[10]. The post peak behavior of HPC has been significantly improved by the inclusion of the SF. In addition, the increase in fiber volume fraction had significant effect on the properties of HPC[10]. Mechanical properties of concrete with different grades using different content of fibers were experimentally investigated [11]. The increase in the fiber volume fraction had increased the mechanical properties of the concrete. In addition, predictive models were presented for the mechanical properties of FRC using different fiber volume fractions[11].

In this paper the effects of adding hooked end SF with different contents on the mechanical properties (compressive, tensile and flexural strengths) of concrete having different levels of strengths will be experimentally investigated.

2. EXPERIMENTAL WORK

The experimental work conducted in the present paper included the effect of fiber volume fraction (V_f%), 0, 0.5, 1 and 1.5% on the mechanical properties of concrete having three levels of compressive strength. The first concrete strength (MI) represented normal strength concrete, NSC, (f_{cu} ≈25 MPa). The second mix (MII) represented moderate strength concrete, MSC, (f_{cu}≈50MPa). The third concrete strength level (MIII) represented HSC (f_{cu} ≈75MPa).

2.1. Materials

Ordinary Portland Cement CEM I 42.5 N was used for MI mixes and CEM I 52.5 N was used for MII and MIII mixes. Natural siliceous sand was used in this investigation for the preparation of all mixes. Dolomite having a maximum aggregate size of 12.5 mm was used as coarse aggregate. Physical properties of the used fine and coarse aggregates are given in Table 1. Clean drinking tap water was used for casting and curing of all specimens, which was free from deleterious material. Hooked end steel fibers having a length of 35mm and diameter0.80mm was used as addition by V_f% of 0.5, 1 and 1.5% from concrete volume as shown in Photo1. The tensile strength of the used steel fibers was 1000MPa.High-range water-reducing (HRWR) modified chemical admixture ViscoCrete-3425 complies with ASTM C-494,Addicrete BVF complies with ASTM C-494 type F and MasterGlenium RMC 315 complies with BS 5075 Part 3 and EN934-2 based super plasticizer were used for preparing MI, MII and MIII mixesrespectively.Mineral admixture modified Silica fume that complies with ASTM C-1240 was used as partial replacement of cementweight by the percentages of 5% from cement for mix MII and 10% from cementweight for mix MIII.The previous materials were used for the design the three concrete mixes of different strengths with the aid of ACI mix design methodand the materials required to produce one cubic meter from each mix are presented in Table 2.

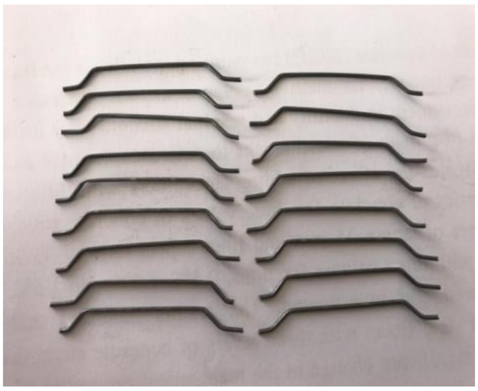

Photo 1: Hooked end steel fibers

Table 1: Physical properties of the used fine and coarse aggregates

Properties	**Sand**	**Dolomite**
Specific gravity (G_s)	2.51	2.65
Compacted density $\gamma_{compact}$ (ton/m^3)	1.70	1.67
Loose density γ_{loose}(ton/m^3)	1.52	1.42
Fineness modulus	2.55	
Impact value	-	19.25%

Table 2: Material required for producing 1 m^3 from each concrete

Mix Code	Strength Level(MPa)	Water content, kg/m^3	Cement, Kg/m^3	Silica fume(Kg)	W/c ratio	Sand, kg/m3	Dolomite kg/m3	Steel fiber volume fraction, V_f %				Super plasticizer (kg)
								0 %	0.5 %	1%	1.5%	
MI	25	216	300	0.0	0.72	821	960.25	0	39.5	79	118.5	1.5
MII	50	157.5	427.5	22.5	0.35	847	960.25	0	39.5	79	118.5	11.25
MIII	75	137.5	495	55	0.25	818	960.25	0	39.5	79	118.5	13.75

2.2 Specimens, Mixing, Casting and Curing

Cubes 150×150×150 mm were used for compression test. The splitting tension test was carried using cylinders having 300 mm height and 150 mm diameter. Beams 100×100 cross section and 500 mm total span and 400 mm loaded span were tested under four points bending for the estimation of flexural strength. Three specimens were cast from each mix and the average was taken. Twelve mixes were designed for the experimental program. Laboratory drum mixer was used. The mixing procedures were as follows:Putting fine, coarse aggregate and binding materials in the mixer and mixing in dry state for a time. Two third of water was added gradually to the dry materials and mixing for a time. After that stirring the required dosage of super-plasticizer to the remaining third of mixing water and adding the mixture to the concrete in the mixer and continue mixing until homogenous mix was reached. This followed by adding steel fibers gradually and with high speed rate and mixing for other two minutes until getting homogeneous paste. The mixture was transformed to the molds and mechanically compacted. The specimens were removed from the molds 24 hours after casting and were placed in the curing water for 28 days.

2.3 Testing

A universal testing machine with maximum capacity of 2000 kN was used for compression and indirect tension test. A universal testing machine with maximum capacity of 1000 kN was used for conducting flexural test. Set up of the flexure test is shown in Photo 2. The deflection at mid span of the beam was measured using LVDT of 0.001accuracy. The load- deflection data were received using data acquisitionsystemas shown in Photo 2.

Photo2: Flexure test set up

3. RESULTS AND DISCUSSION

In this section the results obtained will be explained and discussed. The mechanical properties (compressive strength, tensile strength and flexural strength) for all investigated mixes are given in Table 3.

Table 3: Mechanical properties of different concrete mixes.

Mix code	W/C Ratio	(V_f) %	Compressive strength		Tensile strength		Flexural strength	
			σ_c , MPa	σ_c/σ_{co} %	σ_t , MPa	σ_t/σ_{to} %	σ_f , MPa	σ_f/σ_{fo} %
MI	0.72	0	24.00	100	2.48	100	2.65	100
		0.5	27.50	114.58	3.04	122.58	3.08	116.23
		1	28.22	117.58	3.33	134.27	3.57	134.72
		1.5	26.00	108.33	3.50	141.13	3.73	140.75
MII	0.35	0	51.11	100	4.46	100	5.28	100
		0.5	53.78	105.22	5.43	121.75	6	113.64
		1	64.22	125.65	6.65	149.10	8.49	160.80
		1.5	63.11	123.48	7.00	156.95	8.88	168.18
MIII	0.25	0	74.00	100	6.30	100	7.52	100
		0.5	75.41	101.91	7.24	114.92	8.42	111.97
		1	77.63	104.91	7.95	126.19	10.14	134.84
		1.5	76.59	103.5	8.35	132.54	10.47	139.23

3.1. Effect of the fiber volume fraction on the compressive strength

The effect of V_f% on the compressive strength of concrete having different strength levels is shown in Fig. 1. It can be seen that the addition of fibers to concrete increased the compressive strength up to V_f% equals 1% and after that it decreased for the three investigated strength levels. For NSC (f_c = 24 MPa), the compressive strength increased by 14.58%, 17.58% and 8.33% for V_f% equals respectively 0.5%, 1% and 1.5%. For MSC (f_c = 51 MPa), the compressive strength increased by 5.22%, 25.65% and 23.48% for V_f% equals respectively 0.5%, 1% and 1.5%. For HSC (f_c = 74MPa), the compressive strength increased by 1.9%, 4.91% and 3.5% for V_f% equals respectively 0.5%, 1% and 1.5%. These results clearly indicated that the ratio of enhancement in the compressive strength is more pronounced in NSC compared to HSC and this agrees with the results found the previous studies [12,13]. The increase in the compressive strength with the addition of steel fibers may be assign to the confining effect provided by the fibers to the concrete [12].

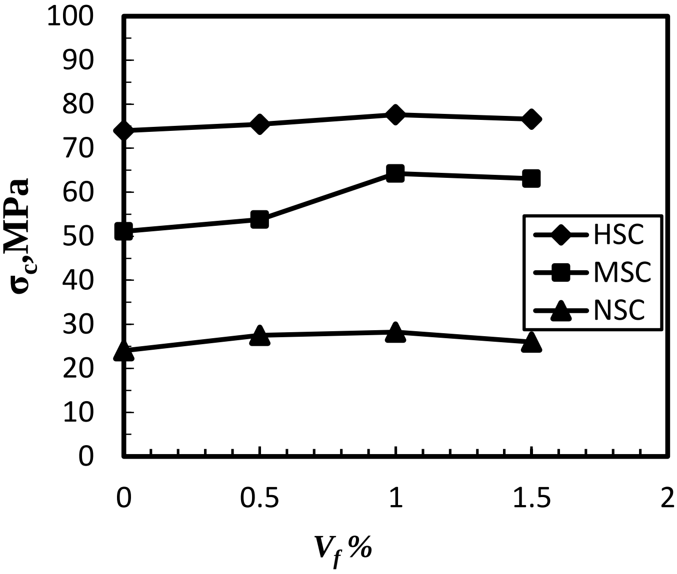

Fig.1: Effect of V_f% on the compressive strength of concrete.

3.2. Effect of the fiber content on the tensile strength

The effect of V_f% on the tensile strength of concrete having different strength levels is shown in Fig. 2. It can be seen that the addition of fibers to concrete increased the tensile strength up to V_f% equals 1.5% but with a decreasing rate for the three investigated strength levels. For NSC, the tensile strength increased by 22.58%, 34.27% and 41.13% for V_f% equals respectively 0.5%, 1% and 1.5%. For MSC, the tensile strength increased by 21.75%, 49.1% and 56.95% for V_f% equals respectively 0.5%, 1% and 1.5%. For HSC, the tensile strength increased by 14.92%, 26.19% and 32.54% for V_f% equals respectively 0.5%, 1% and 1.5%.It is also clear that the ratios of enhancement in the tensile strength are higher than those of compressive strength. The enhancement in tensile strength

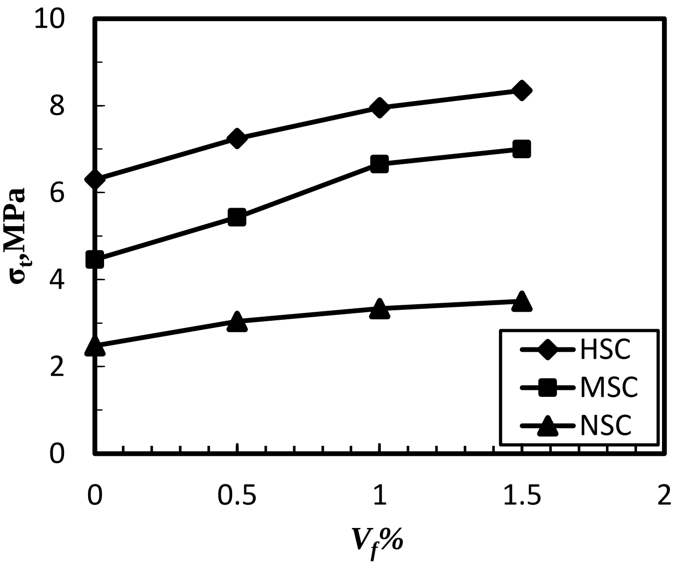

Fig.2: Effect of V_f% on the tensile strength of concrete.

was more pronounced in NSC,owing to the decreased toughness of the matrix and occurrence ofcrack arrest through fiberbridging. The benefit of the fiber for the enhancement in the tensile strength of concrete is dependent upon the crack arrest and the fiber transferring energy. Those results of split tensile strength are consistent with the previous studies [14, 15].

3.3. Effect of the fiber content on the flexural strength

The effect of V_f% on the flexural strength of concrete having different strength levels is shown in Fig. 3. It is clear that the addition of fibers to concrete increased the flexural strength up to V_f% equals 1.5% but with a decreasing rate for the three investigated strength levels. For NSC, the flexuralstrength increased by 16.23%, 34.72% and 40.75% for V_f% equals respectively 0.5%, 1% and 1.5%. For MSC, the flexural strength increased by 13.64%, 60.8% and 68.18% for V_f% equals respectively 0.5%, 1% and 1.5%. For HSC, the tensile flexural increased by 11.97%, 34.84% and 39.23% for V_f% equals respectively 0.5%, 1% and 1.5%.It is also clear that the ratios of enhancement in the flexural strength are higher than those of compressive strength. The effect of V_f% on the load-deflection behaviorfor NSC, MSC and HSC are respectively shown in Figs 4 to 6. It is observed that the deflection corresponding to the ultimate load increases with the increase in the fiber content. The initial portion of the load deflection curves for all levels of concrete strengths with different fiber contents are observed to be linear. The linearity of this portion of the curve increased with increasing concrete strength. It is clear also that, the stiffness of concrete, as indicated by the initial slop of the tangent to the load-deflection curve, increased with increasing concrete strength and increasing fiber volume fraction. It can be seen that the concrete with higher fiber content has a descending load deflection curve as shown in Fig.6,whereas at the different fiber content, after the first crack load, an increase inload with increasing deflection is observed, which can be attributed to the deflection hardening behavior of concrete. The enhancement in flexural load-deflection curves was more pronounced in the concrete with low strength levels. Those results of flexural strength are agreement with previous studies [12, 14]

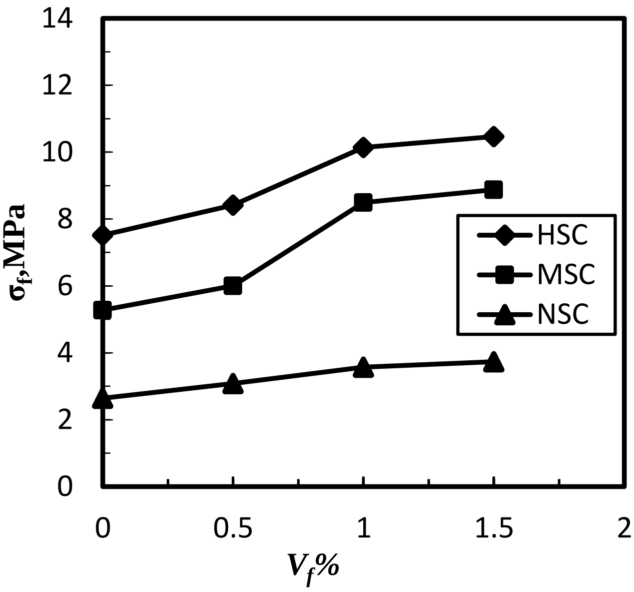

Fig.3: Effect of V_f% on the flexure strength of concrete.

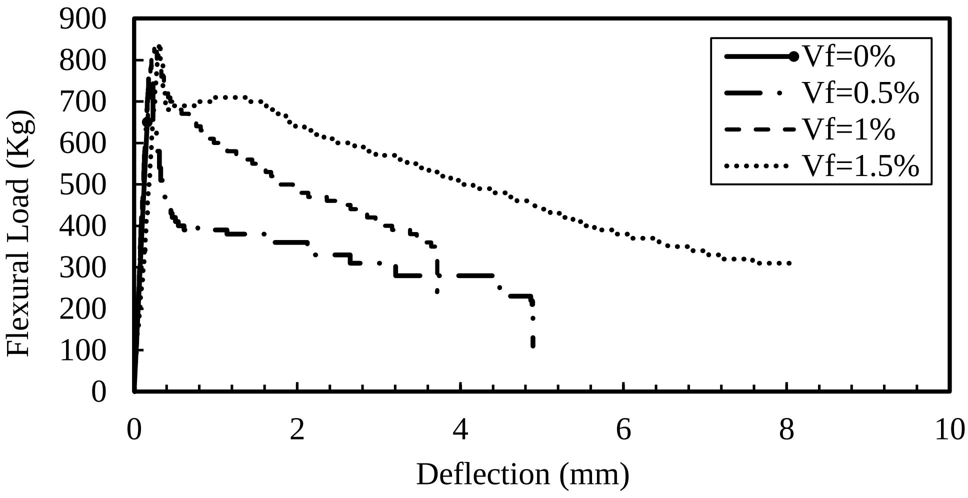

Fig. 4: Load-deflection curves for NSC

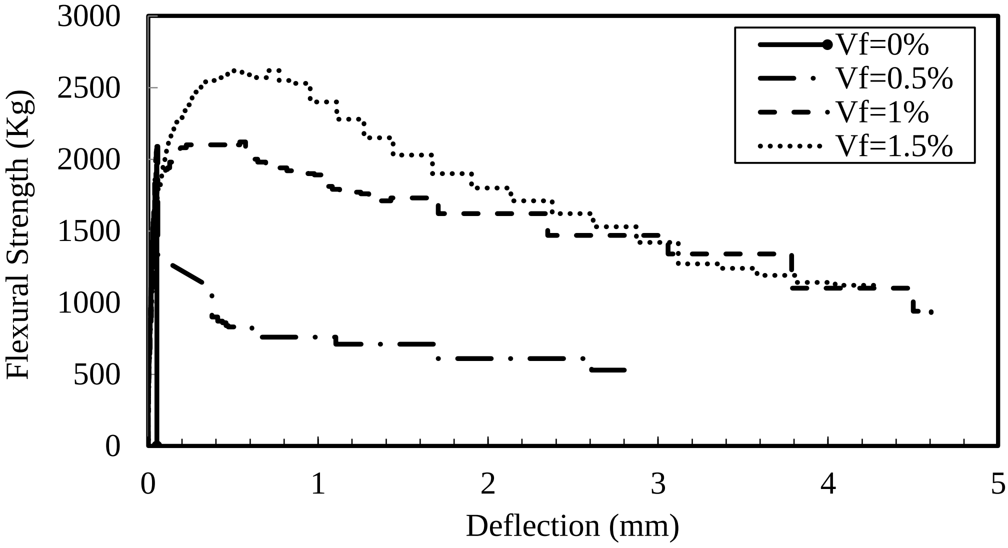

Fig. 5: Load-deflection curves for MSC

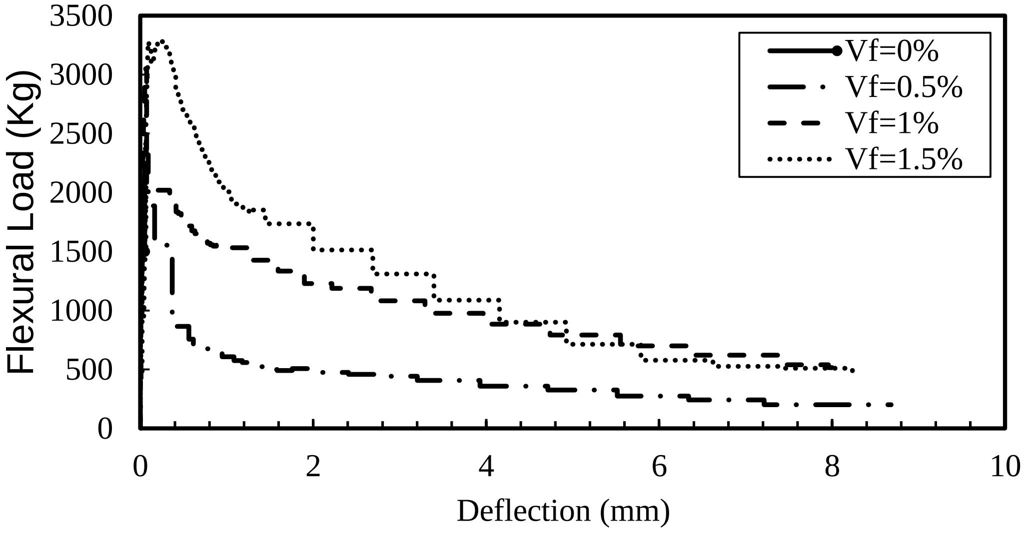

Fig. 6: Load-deflection curves for HSC

3.4. Failure mode of specimen with different contents of fiber

Concrete without fiber is brittle material, that lead to the suddenly failure mode compared to the FRCS with three levels of concrete strengths. Adding fiber to the concrete will sustain load after the first crack until the fiber pullout occurs and interfacial stress reaches the ultimate bond strength. The failure of steel fiber reinforced concrete observed as progressive debonding of the fibers with slow crack propagation. This slow propagation of crack ultimately leads to unstable crack propagation causing the failure of specimen. It can be observed the enhancement of the ductile failure material with increasing the fiber content from 0.5% to 1.5%. That increasing of fibers content causes an increase in load carrying capacity and the toughness of concrete.

4. CONCLUSION

The results of the present worl support the following conclusions

1. The addition of fibers to concrete increased the compressive strength up to V_f% equals 1% and after that it decreased for the three investigated strength levels. The enhancement in the compressive strength is more pronounced in NSC compared to HSC.
2. The addition of fibers to concrete increased the tensile strength up to V_f% equals 1.5% but with a decreasing rate for the three investigated strength levels. It is also clear that the ratios of enhancement in the tensile strength are higher than those of compressive strength. .
3. The addition of fibers to concrete increased the flexural strength up to V_f% equals 1.5% but with a decreasing rate for the three investigated strength levels. It is also clear that the ratios of enhancement in the flexural strength are higher than those of compressive strength.
4. Increasing fiber volume fraction increased concrete toughness and changed the mode of failure from brittle to semi ductile.

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