Improving Mechanical Properties of Polymer Modified Concrete Using Micro-Steel Fiber and Silica Fume

Muhammad Abed Attiya
University of Kufa\ College of Engineering Civil Department
E-mail: mohammedw.alfatlawi@uokufa.edu.iq

Abstract

The use of Steel Fiber Reinforced Concrete (SFRC) is to improve the structural behavior such as increasing the resistance to cracking and crack propagation. This work has been made to study the properties of polymer modified concrete when micro-steel fiber is incorporated at different volumetric percentages from 0.1 % to 2 %. Two mixes (1:1.5:2 and 1:2:4) have been used and modified with styrene butadiene rubber resin (SBR) and silica fume with maintaining water cement ratio at 0.45. It has been found that increasing steel fiber content in concrete has a significant influence on the increase compressive, tensile, flexural strength, modulus of elasticity and stress- strain relationship. Flexural strength increases from 4.14 MPa (for 0% steel fiber) to 11.83 MPa (for 2% steel fiber). Whereas, the modulus of elasticity is improved by about 77% (for 1:1.5:2 mixes) and 91% (for 1:2:4 mixes).

Keywords: polymer modified concrete, tensile strength, flexural strength, steel fiber, modulus of elasticity.

الخلاصة

تستعمل الخرسانة المسلحة بألياف الحديدِ (SFRC) لتحسّينَ السلوكَ الإنشائي مثل زِيَادَة مقاومة التَصَدُّع والحد من تمدد التشققات. في هذا البحث تم دراسة تأثير إضافة ألياف الحديد (micro-steel fiber) كنسب مئوية حجميه مختلفة تتراوح من 0.1 % إلى 2 % على خواص الخرسانة المعدلة باستخدام مضافات البوليمرات (polymer modified concrete). حيث تم استخدام نوعين من الخلطات ((1:1.5:2 و1:2:4) ومع نوعين من المضافات هما styrene butadiene rubber resin (SBR) و silica fume مع بقاء نسبة الماء/ سمنت ثابته (0.45). وُجِدَ إن زيادة محتوى ألياف الحديد في الخرسانةِ لَهُ تأثير واضح على زيادة مقاومة الانضغاط، الشد والانثناء. وكذلك زيادة قيم معامل المرونة وتحسن علاقةِ الإجهادِ-الانفعال stress-strain relationship.لِوحظ خلال هذه الدراسة إن مقاومة الانثناء ازدادت من 4.14 MPa بدون استخدام ألياف الحديد (0% steel fiber) إلى 11.83 MPa باستخدام ألياف الحديد بنسبة (2% steel fiber). كذلك معامل المرونة تحسن بنسبة 77% للخلطة (1:1.5:2) و بنسبة 91% للخلطة (1:2:4).

الكلمات المفتاحية : خرسانة معدلة بأستخدام مضافات البوليمرات، مقاومة الشد ، مقاومة الانحاء ، الياف الحديد ، معامل المرونة

1-Introduction

Improving mechanical properties of concrete is very necessary to get high values of compressive, tensile, flexural strengths and modulus of elasticity. These improvements reduce the dimensions of structural members such as beams, slabs, columns, foundations. Hence, more economic structures can be obtained. The use of SBR polymer leads to the formation of a continuous three-dimensional network of polymer molecules throughout concrete. Therefore, the bonding between cement and aggregate will be increased due to the good bond characteristics of the polymer SBR (Meraj *et.al*., 2014). Polymer modified concrete with silica fume is widely used in structures. This is because of its good mechanical properties, low permeability, and high durable of concrete. The improved mechanical properties are due to the action of polymers that reduce the cracks in concrete by its bond with aggregates silicates and compounds of cement paste (Soni and Joshi, 2014). The addition of SBR latex in the form of construction chemical in concrete improves the various properties of normal concrete such as strength, adhesion, resilience, water tightness, chemical resistance and durability. Steel fiber and polymer latex may be used to produce recycled course aggregate with considerable improvement in strength (Awchat and Kanhe 2013). The silica fume powder reacts with $Ca(OH)_2$ liberating from hydration of cement compounds to form additional gel. This gel could reduce voids and improve the mechanical properties (Srivastava *et.al*., 2012). Steel fibers can improve the mechanical properties of concrete, such as reduction cracks and arresting cracks propagation under loadings (Mohod 2012). Steel fiber also increases the resistance of concrete to impact load and bombs attack. SFRC is used in special security buildings (Kalman 2010).

This study aims at investigating experimentally the main mechanical properties of high strength concrete such as compressive, tensile, flexural strength and stress-strain relationship of polymer modified concrete by using micro-steel fibers.

2- Experimental work

To achieve the aims previously mentioned, specimens of 42 cubes of (100×100×100*mm*), 42 cylinders (100×200*mm*) and 28 beams (100×100×400*mm*) have been used for testing compressive, tensile, and flexural strength respectively. Then, 24 cylinders (150×300*mm* cylinders) have been used for testing stress–strain relationship and static modulus of elasticity.

2-1 Materials

Coarse aggregates with 10*mm* maximum size and which has gradation as shown in Figure (1). Have been used sieve analysis of fine aggregates that matches zone 2 according to B.S standards as presented in Figure (2), was adopted in this study. Ordinary Portland cement type I were used in all mixes. Styrene butadiene rubber (SBR) has been added as percentage of cement weight (which equals 10%). Silica fume is also added of 10% of cement weight. Figure (3) shows micro- steel fibers used in this study that is added as percentage of the volume of concrete ranged from 0 % to 2%. The properties of steel fiber are listed in Table (1).

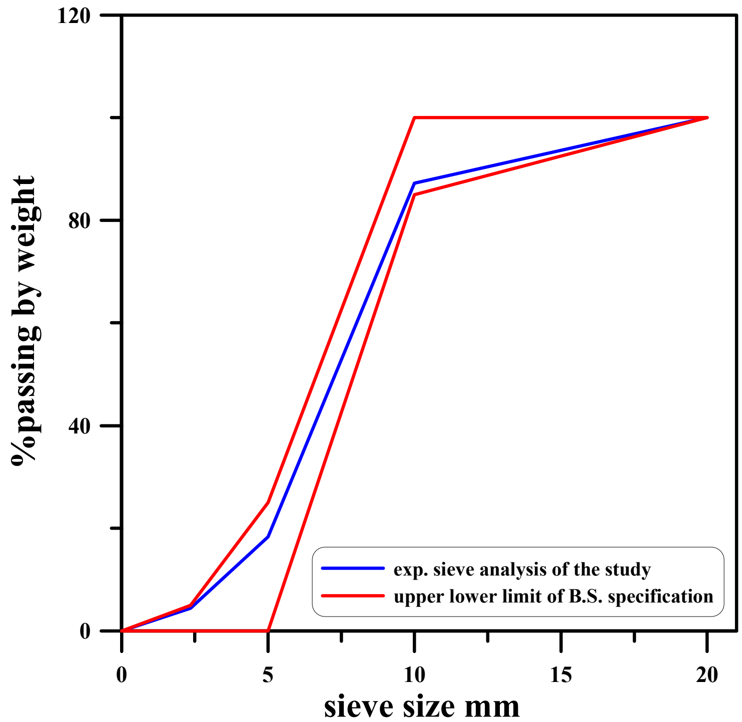

Figure (1) Sieve analysis of coarse aggregate (10*mm* max. size) according to B.S:882

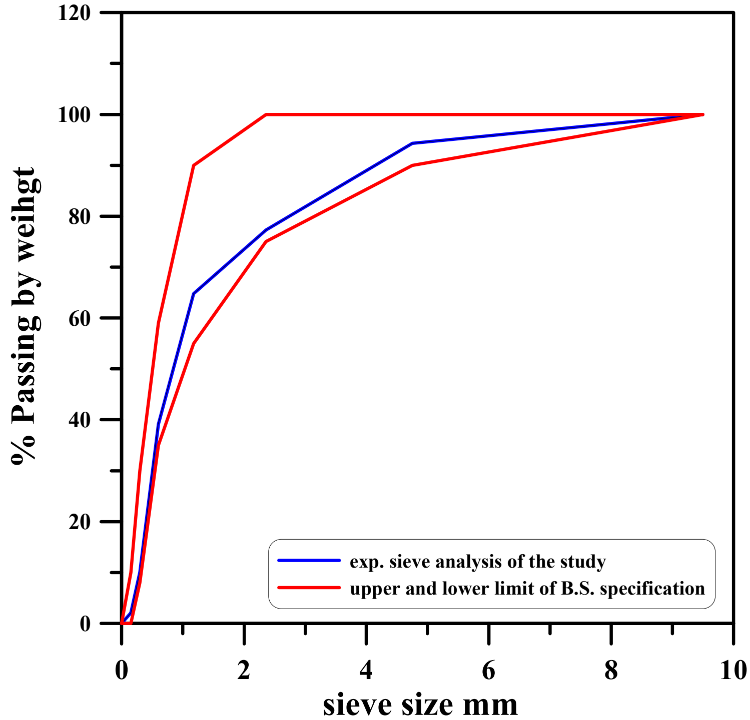

Figure (2): Sieve analysis of fine aggregate confirming with B.S 882 (Zone 2)

Figure (3) Photo of micro steel-fiber

Table (1): Specification of micro- steel fiber used in this work

Length	diameter	Aspect ratio	Tensile strength	Density
13 *mm*	0.2 *mm*	65	2850 *MPa*	7890 *kg/m3*

2-2 **Testing procedure**

Compressive strength tests have been done by using ELE testing machine of capacity of 2000 kN. The specimens of 100X100X100*mm* cubes were used and casting of concrete in molds was done by three layers and was compacted by hand with steel rod. Tensile strength was done by the same ELE machine but by using 100X200*mm* cylinders. Flexural strength test was done by using 100X100X400*mm* beams and loaded by third point loading testing machine to get flexural strength. Figures (4) and (5) show details of specimen and testing machine of flexural respectively. Flexural strength was calculated by equation (2).

Stress–strain test was done by using 150X300*mm* cylinders. All specimens were tested after 28 days age. The mechanical strain gauges were used to obtain strain values and the rate of loading was according to ASTM – C469 SPECIFICATION (ASTM C469-02) and it was 0.254 MPa/sec. Taking readings of stress and strain during loading was done to draw the stress strain behavior for various mixes then, the calculation done for estimating the values of the modulus of elasticity (E_c).

The tests of modulus of elasticity were done according to ASTM, C- 469 Method (ASTM C469-02) as follows:

$E_c = (\sigma_2 - \sigma_1)/(\varepsilon_2 - \varepsilon_1)$ ---- eq. (1)

Where:

E_c : is the chord modulus of elasticity done by 150*300 mm cylinders,

σ_2 : stress corresponding to 40 % of ultimate load,

σ_1 : stress corresponding to strain of 0.00005 mm/mm,

ε_2 : longitudinal strain produced by stress σ_2,and

ε_1: strain of value equal to 0.00005.

And the value of flexural strength calculated from equation (2):

$F_b = pl/bd^2$ ---------------eq. (2)

Where:

F_b : flexural (bending) stress,

p : max load from machine,

l : span between supports,

b : width of beam ,and

d : depth of beam

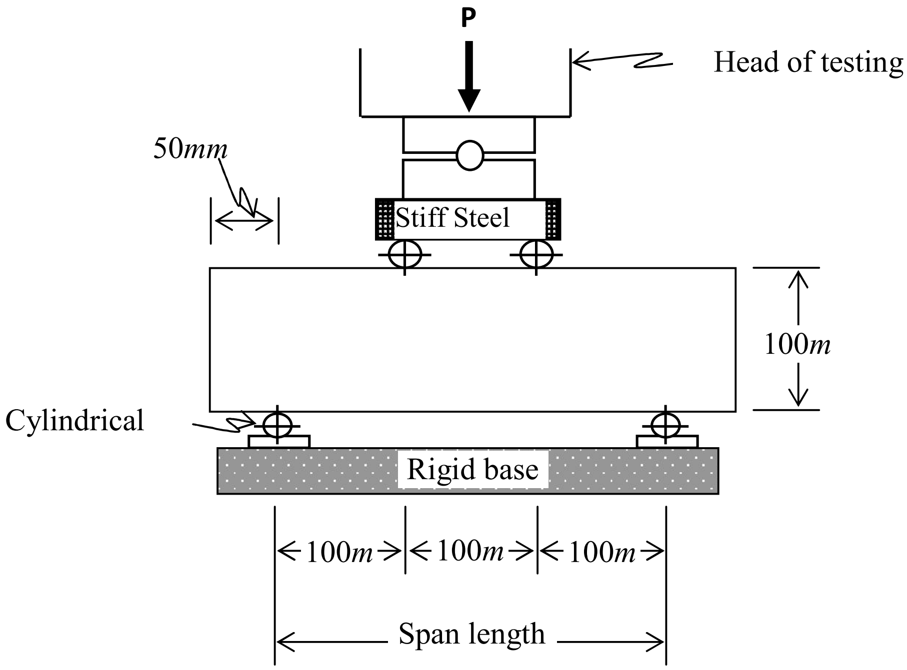

Figure (4) Specimen details for flexurals test

Figure (5) Flexural test machine

3-Results and discussion

3-1 Discussion of compressive, tensile and flexural strength

Effect of adding different percentages of steel fiber with SBR and silica fume on the mechanical properties of concrete for 1:1.5:2 and 1:2:4 mixes is illustrated on tables (2) and (3).

3-1-1 For 1:1.5:2 mix

Using steel fiber has a considerable effect on the compressive strength as shown in Figure (6). It has been improved by about 36% when SBR and silica fume is used only. Adding 2% of steel fiber to the mix that has SBR and silica fume increases compressive strength by about 59%. This value is agree with previous studies such as (Mohammed, 2007) and(Prem *et.al.,* 2012) obtained the compressive strength increases by about 38.8% and 36.6% when they use steel fiber ratio 1% and 2% respectively. From Figure (7), it can be seen that tensile strength is significantly influenced by adding steel fiber. When using 2% of steel fiber, tensile strength has been increased by 60%. Flexural strength shows higher response to adding steel fiber than the other properties, Figure (8). It is increased from 5.11MPa for 0% steel fiber to 14.33MPa for 2% steel fiber. The improvement of flexural strength is about 180%.

3-1-2 For 1:2:4 mix

The considered mechanical properties were significantly affected by adding steel fiber as shown in Table (3) and Figures (6) to (8). Whereas, adding 2% steel fiber increases compressive and tensile strength by 96% and 65% respectively. While the increment in flexural strength was 185%.

Table (2): Mechanical properties of reference and polymer modified mixes improved by steel fibers of mix (1:1.5:2). w/c=0.45.

Mix type and properties		Compressive strength Average of three cubes 100 *100 * 100*mm*	Tensile strength Average of tree cylinders 100 *200*mm*	Flexural strength Average of two beams 100 *100 *400*mm*
Micro-steel fiber content (Percentage of concrete volume)	SBR and polymer silica fume content (Percentage of cement weight)			
0 %	0 %	38.83MPa	3.21MPa	3.76MPa
0 %	10%	52.86MPa	4.27MPa	5.11MPa
0.1%	10%	56.97MPa	4.73MPa	6.90MPa
0.2%	10%	61.67MPa	5.22MPa	7.39MPa
0.3%	10%	63.92MPa	5.71MPa	7.97MPa
0.5%	10%	68.83MPa	5,98MPa	9.71MPa
1%	10%	77.54MPa	6.35MPa	12.18MPa
2%	10%	83.82MPa	6.80MPa	14.33MPa

Table (3): Mechanical properties of reference and polymer modified mixes improved with steel fibers with mix proportions of (1: 2: 4).w/c=0.45

Mix type and properties		Compressive strength Average of three cubes 100 X 100 X 100*mm*	Tensile strength Average of tree cylinders 100 X200*mm*	Flexural strength Average of two beams 100 X100 X400*mm*
Micro-steel fiber content (Percentage of concrete volume)	SBR and polymer silica fume content (Percentage of cement weight)			
0	0	30.03MPa	2.71MPa	2.99MPa
0	10%	38.93MPa	3.36MPa	4.14MPa
0.1%	10%	48.10MPa	4.04MPa	5.88MPa
0.5%	10%	60.02MPa	4.67MPa	7.35MPa
1%	10%	72.28MPa	5.02MPa	10.11MPa
2%	10%	76.51MPa	5.60MPa	11.83MPa

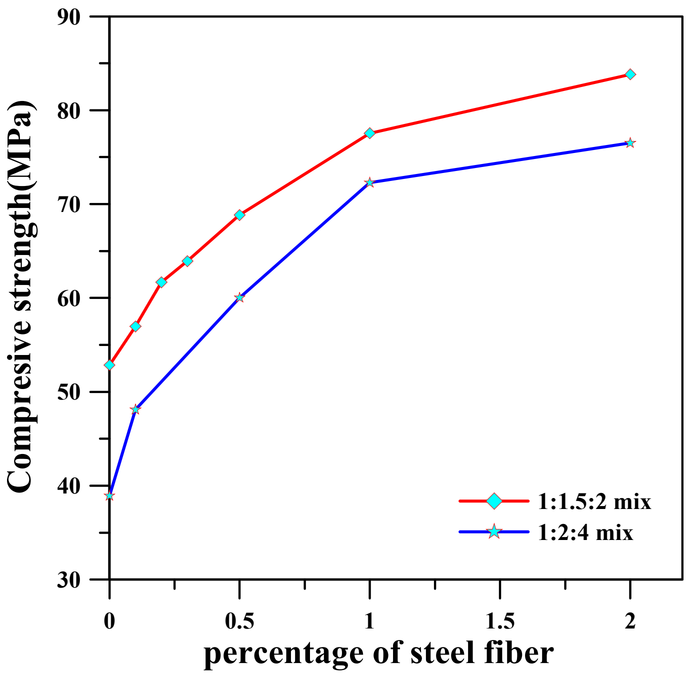

Figure (6): The effect of micro steel fiber percentage on compressive strength

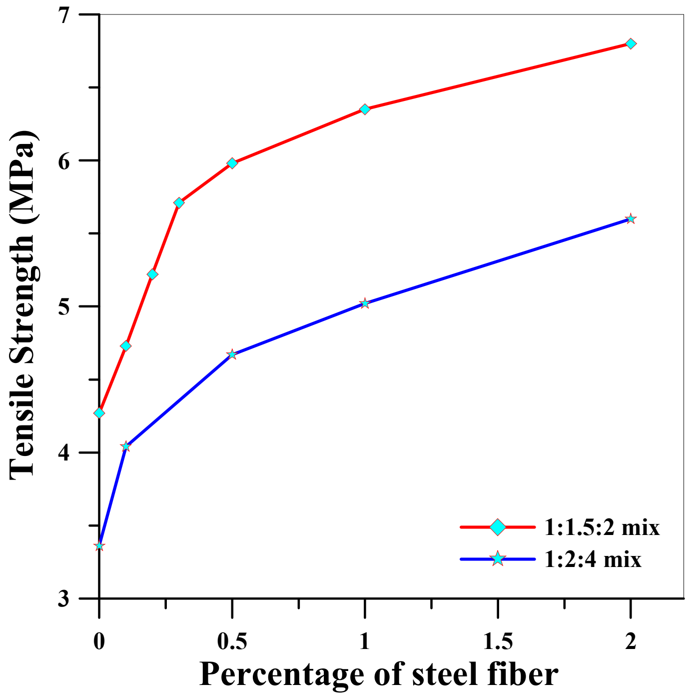

Figure (7): The effect of micro steel fiber percentage on tensile strength (splitting cylinder test)

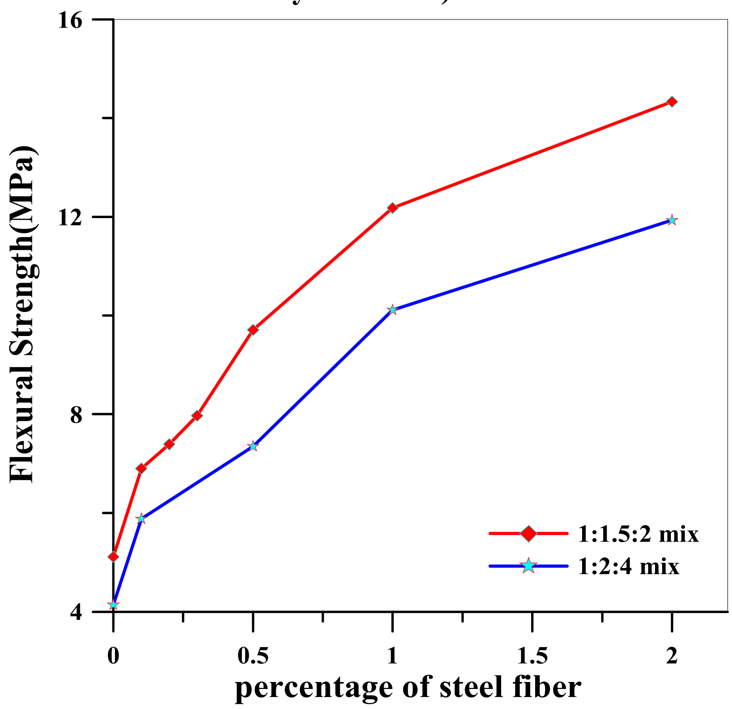

Figure (8): The effect of micro steel fiber percentage on flexural strength (Third point loading)

The improvements in compressive, tensile and flexural strength by adding steel fibers can be attributed to the following reasons:

i) Adding SBR and silica fume only cause decreases the voids in concrete. This is due to silica reaction with some compounds such as $Ca(OH)_2$ forming additional cement gel that filled voids in concrete and increase strength. The SBR action could be represented by polymers films which are formed during mixing. This film bonds with cement gel and external silica of aggregates leads to more bonds between particles and improve strength.

ii) Adding steel fibers restrained crack propagation under loading. In addition to high tensile strength of steel fiber which exceed 2800 MPa.

3-2- Discussing the Stress Strain curves and modulus of elasticity of concrete:

Figures (9) and (10) show the improvement in stress-strain behavior due to using steel fibers. The improvements of modulus of elasticity are listed in Tables (4) and (5). The shape of the ascending part of the stress-strain curve for steel fiber reinforced concrete shows more linear and steeper behavior compared to normal concrete.

Steel fibers reduce cracks growth in concrete under loading and consequently increases load resistance and decreases deformation (Jo *et.al*., 2001) and (Gul *et.al*., 2014). So, high compressive strength and high modulus of elasticity are obtained.

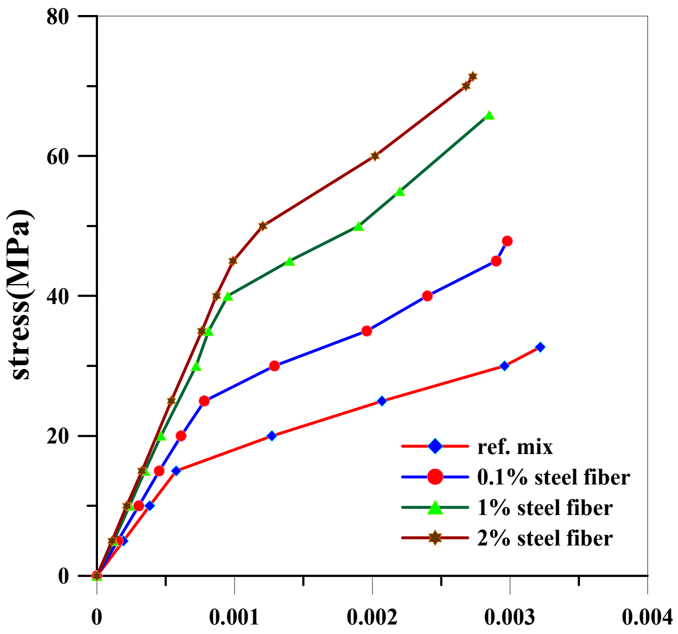

Figure (9): Stress- strain behavior of (1:1.5: 2) mixes of steel fiber polymer modified concrete with various percentages of steel fiber.

The modulus of elasticity increases from 26000MPa to 46000MPa for concrete with 2% steel fiber (for mixes 1:1.5:2). For 1:2:4 polymer mixes, modulus of elasticity is from 22000MPa to 42000MPa when 2% steel fiber is used. It can also be noted that the stress strain curves show much linear ascending portion. These improvements may be due to the presence of steel fibers which leads to the increase of the initial cracking load and arrests the formation and propagation of cracks during loading (Salih *et.al*., 2005)

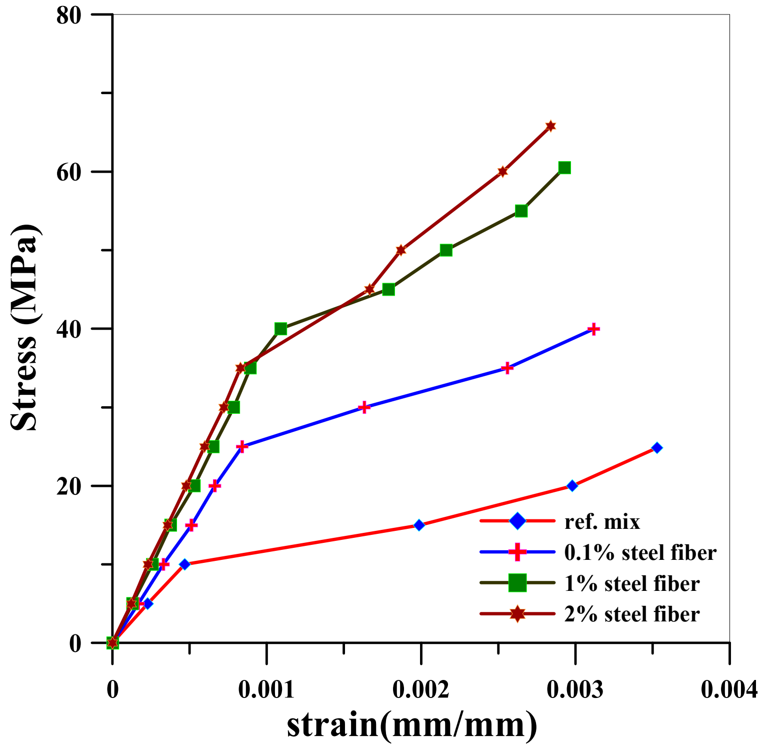

Figure (10): Stress- strain behavior of (1:2: 4) mixes of steel fiber polymer modified concrete with various percentages of steel fiber.

Table (5): Static modulus of elasticity for steel fiber polymer modified concrete (1:1.5:2 mixes)

steel fiber content	Static modulus of elasticity MPa
reference mix 0%	26000
0.1 %	32000
1 %	42000
2 %	46000

Table (4): Static modulus of elasticity for steel fiber polymer modified concrete (1:2:4 mixes)

steel fiber content	Static modulus of elasticity MPa
reference mix 0%	22000
0.1%	29000
1%	39000
2%	42000

4-Conclusions:

This study comes up with the following conclusions:

1-Adding SBR polymers and silica fume powder to reference mixes, and\or the micro steel fibers have improved mechanical properties.

2-Increasing steel fiber until 2% improves the compressive strength to 59%. For 1:1.5:2 mixes and 96% for 1:2:4 mixes. Higher values of compressive strength lead to more economic structural design.
3-Tensile strength increased to 60% for 2% steel fibers for 1:1.5:2 mixes and 66% for 1:2:4 mixes
4-Flexural strength has been highly influenced by adding steel fiber due to the high bond between gradients of concrete and the delay of the propagation of cracks under loading. Thus, adding 2% of steel fiber improves flexural strength to about 180 %.
5-Stress strain relationship shows more straight line (more linearly) in ascending portion compared with concrete without steel fibers. Moreover, high modulus of elasticity is obtained when more amounts of steel fibers are used, this increases to 91% for 1:2:4 mixes and 77% for 1:1.5:2 mixes. High improvement in modulus of elasticity is very important in structural design considerations which reduces the deflection in structural members

5-References:

ASTM C469, (2002). “Standard Test Method for Static Modulus of Elasticity and Poisons Ratio of Concrete in Compression”.

Awchat, G. D. and Kanhe, N. M. (2013). “Experimental Studies on Polymer Modified Steel Fibre Reinforced Recycled Aggregate Concrete”. International Journal of Application or Innovation in Engineering & Management, Vol.2 (12), p.p. 126-134.

Gul, M., Bashir, A. and Naqash, J. A. (2014). “Study of Modulus of Elasticity of Steel Fiber Reinforced Concrete”. International Journal of Engineering and Advanced Technology, Vol.3 (4), p.p.304-309.

Jo, B. W., Shon, Y. H. and Kim, Y. J. (2001). “The Evaluation of Elastic Modulus for Steel-Fiber Reinforced Concrete”. Russian Journal of Non-destructive Testing, Vol. 37(2), p.p.87-96.

Kalmaan, D. (2010). “Use of Steel Fiber Reinforced Concrete for Blast Resistant Design”. Report submitted in partial fulfillment of the requirements for the MSc. degree, Kansas State University, Manhattan, Kansas.

Meraj, T., Pandey, A. K. and Rao, B. K. (2014). “Flexural Behavior of Latex Modified Steel Fiber Reinforced Concrete”. Indian Journal of Engineering and Martials Sciences, Vol. 21, p.p. 216-226.

Mohammed, M. Kh. (2007). “The Effect of Addition of Steel Fibers on Compressive and Tensile Strengths of Structural Lightweight Concrete Made of Broken Bricks”. International Journal of Civil Engineering seventh ISSUE, Feb., p.p. 99-118.

Mohod, M. V. (2012). “Performance of Steel-Fiber Reinforced Concrete”. International Journal of Engineering and Science, Vol.1 (12).

Prem, P.R., Bharatkumar, B. H. and Iyer, N. R (2012) “Mechanical Properties of Ultra High Performance Concrete”. International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol.6, No.8, p.p. 676-685.

Salih, S. A., Rejeb, S. K. and Najem, K. B. (2005). “The Effect of Steel Fibers on the Mechanical Properties of High Performance Concrete”. Al–Rafidain Engineering Journal, Vol.13 (4), p.p.26-44.

Soni, K. and Joshi, Y. P. (2014). "Performance Analysis of Styrene Butadiene Rubber Latex on Cement Concrete Mixes". International Journal of Engineering Research and Applications, Vol.4 (3), p.p. 838-844.

Srivastava, V., Agarwal, V. C. and Kumar, R. (2012). "Effect of Silica Fume on Mechanical Properties of Concrete". Journal of Academic Industrial Res., Vol.1, p.p. 176-179.