Improving The Modulus of Elasticity of High Performance Concrete by Using Steel Fibers

Dr. Shakir A.Salih — *Department of Building and Construction*, *University of Technology*
Dr. Saeed K. Rejeb — *Civil Department*, *Technical Institute –Mosul*
Khalid B. Najim — *Civil Engineering Department*, *Engineering College-Anbar University*

ABSTRACT.

The aim of this paper is to study experimentally the effect of steel fibers content on the modulus of elasticity of High Performance concrete HPC in different curing age. The results showed that adding steel fibers to HPC led to a considerable improvement in static and dynamic modulus of elasticity where at 90 day water curing the percentages of increasing in static modulus of elasticity of High Performance Steel Fiber Concrete HPSFC relative to HPC were 8.2%, 9.98%, and 11.88% at 0.5%, 1%, and 1.5% steel fibers by total concrete volume, respectively. While, the improvement of dynamic modulus of elasticity of HPSFC relative to HPC at 28 day were 8.09%, 10.7%, and 11.07% % at 0.5 %, 1 %, and 1.5 % respectively.

Keywords: Concrete, Mechanical properties, High performance concrete, Strength, Admixtures, Modulus of elasticity.

1. INTRODUCTION.

High Performance Concrete HPC can be defined as a modern class of concrete that made using the main constituents of conventional concrete in addition to mineral and chemical admixtures with modifying the traditional mix design. It has a superior structural performance especially in aggressive environment due to its high durability that obtained by the admixtures actions on its microstructures. With considering mix design, mixing procedure, transportation, placement, consolidation, and curing, HPC can be employed to minimize the durability problems in addition to the excellent mechanical performance during its design age [1].

The effect of steel fibers content, High Range Water Reducing Agent (HRWRA) and the combined effect of Rice Husk Ash RHA and HRWRA on producing Ultra High Strength Fiber Reinforced Concrete was investigated by Zaid H. Al-Sakiny [2]. It has been found that at the early age, compressive strength decreased slightly with adding steel fiber at 2%, 2.5% and 3% by volume, unlike the other mechanical properties which increased significantly. The results also demonstrated that the incorporation of HRWRA in concrete led to a considerable improvement in compressive, splitting tensile and flexural strength, static modulus of elasticity, Poisson’s ratio and impact resistance. Where, the inclusion of 8% RHA, as a partial replacement by weight of cement, with HRWRA showed superior performance in these properties in compassion with adding HRWRA only.

Ameir G.T. [3] investigated the engineering properties of high performance lightweight aggregate concrete containing various types of chemical, mineral admixtures and steel fibers. The results indicated that, HRWRA fiber reinforced lightweight aggregate concrete showed a considerable improvement in compressive, splitting and flexural strengths, impact resistance, static modulus of elasticity and Poisson's ratio at 60 and 90 days of curing compared to fiber reinforced lightweight aggregate concrete without HRWRA. On the other hand, the inclusion of 8% RHA as partial replacement by weight of cement with optimum dosage of HRWRA showed superior performance over those of HRWRA fiber reinforced concrete.

The effect of Pozzolanic admixtures such as silica fume on the properties of high-strength semi-light weight fiber reinforced concrete and the effect of various amounts of hooked-end steel fibers on the properties of this concrete was studied by Balagurn and Dipsia [4]. Results indicated that although the compressive, tensile, flexural, strength and modulus of elasticity increased with adding 15% silica fume (as a partial replacement by weight of cement), the behavior of produced concrete became brittle under all the modes of loading. They found also that the increase in fiber contents up to 90Kg/m^3 provided a substantial increment in splitting tensile strength and modulus of elasticity up to 160% and 80% respectively.

The behavior of high performance steel fiber concrete exposed to oil products was study by Ammar S. [5]. The experimental results showed that the HPSFC deteriorated less than plain concrete when exposed to oil products. Test results indicated that oil product have a significant effect on the dynamic modulus of elasticity and damping capacity.

2. EXPERIMENTAL WORK.

2.1. Materials.

2.1.1. Cement.

The cement used throughout this work was Ordinary Portland Cement CEM I produced by Kubaysa Cement Factory. It stored in airtight plastic containers to avoid exposure to different atmospheric conditions. The chemical analysis and physical test results conformed to the Iraqi specification No. 5/1984 [6]. The specific surface area (Blaine method), initial setting time, final setting time, soundness, compressive strength of the mortar at 3 days and compressive strength of the mortar at 7 days of the used cement were 379 m^2/kg , 3hour:17min, 4hour:45min, 0.2%, 15.8 N/mm^2 and 27.5 N/mm^2 respectively. The CaO, SiO_2, Al_2O_3, Fe_2O_3, SO_3, MgO, L.O.I, L.S.F., and I.R. of the used cement were 61.8%, 22.2%, 4.4%, 2.76%, 2.7%, 2.5%, 1.9%, 0.87% and 1.5% respectively. Chemical and physical tests were made by the National center for construction laboratories.

2.1.2. Fine Aggregate.

Al-Ukhaider natural sand of 4.75-mm maximum size was used in this study. The particle size distribution is shown in **Fig.(1)** which conforms to the limits of Iraqi specification No. 4/1984, Zone (3). The specific gravity, absorption, sulfate content and material passed from sieve No. 200 (75 µm) were 2.62, 1.19%, 0.2% and 0.8% respectively. These tests were performed according to ASTM C 128-88 [7].

2.1.3. Coarse Aggregate.

Crushed and washed 10mm from Al-Nibaey region was used as coarse aggregate. The particle size distribution is shown in **Fig.(2)**. It conforms to the Iraqi specification No. 45/1984. The specific gravity, absorption, sulfate content and material passed from sieve No. 200 (75 µm) were 2.68, 1.07%, 0.07%, and 0.2% respectively. These tests were performed according to ASTM C 127-88 [8].

2.1.4 Mixing Water.

Ordinary potable water was used for mixing and curing purposes.

2.1.5. Steel Fibers.

High tensile steel fibers crimped type was used with different volume fractions of 0, 0.5, 1 and 1.5% vol.% of concrete. The Density, Ultimate strength, Modulus of elasticity, Poisson's ratio, Length, Diameter , and Aspect ratio of the used steel fibers were 7860 kg/m^3, 1500 MPa, 2 *10^5 MPa, 0.28, 50 mm, 0.5 mm, and 100 respectively.

2.1.6. HRWRA Melment L10.

The melamine formaldehyde condensate Type (F) according to ASTM C494-86 [9] was used as superplasticizer SP. It is commercially known as Melment L10 produced by Baghdad Company for building chemicals. In this study a 28.2% water reduction was obtained by adding 6% SP by cement weight.

2.1.7. Polyvinyl Dispersion (BVD).

It was used as a chemical admixture (retarder) as it recommended by the SP manufacturer to avoid any hardening before place the concrete in the formwork. Polyvinyl dispersion BVD was supplied by Al-Zahaf Al-Kabir Company. The recommended dosage is about (0.4%) by weight of cement. This type of admixture meets the requirements of the ASTM C 494-86 type B and D.

2.1.8. Rice Husk Ash (RHA).

Rise husks are the shells produced by de-husking process of paddy rice. In this investigation, rice husks were burned in a furnace with controlled temperature in order to establish the optimum burning temperature and burning time. It was found that the best ash with desired properties can be produced in about 550°C and 2 hrs burning time.

The chemical analysis indicates that the RHA consists of 84.52% SiO_2 and the loss on ignition was low (4.32%). The RHA that used in this work conforms to the chemical and physical requirements of ASTM (618), class N pozzolan [10]. The Fineness, Specific gravity, SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, and SO_3 of the used rice husk ash were 18650 cm^2/gm, 2.03, 84.52%, 0.72%, 2.95%, 1.3%, 0.83%, 0.07%, 2.15%, 1.93% and 4.32% respectively. The chemical tests were made by the National center for construction laboratories.

2.2. Mix Design and Mixing Procedure.

The reference concrete mix was designed according to the 1986, British Standard Method. Its targeted compressive strength at 28 days was about 50MPa and slump of 100 $\pm$ 5 mm. The weight proportions were 1:1.15:1.73 and water/cement ratio of 0.41, **Table (1)** shows the details of reference and high performance concrete with and without steel fiber mixes that used throughout this work.

A rotary mixer of (0.1) m^3 capacity was used in this work. The interior surface of the mixer was cleaned and moistened before placing the materials. For reference concrete the mixer was fed by the dry constituents and mixed for about 1.5 minutes followed by the mixing water and continue mixing for further two minutes.

For HPC preparation, the prior procedure was followed noting that the cement was blended with 8% RHA [1,4,10] before adding the cement to the dry ingredients. The water content of admixture (HRWRA and BVD) was deducted from the initial mixing water. The HRWRA and BVD were added to the mixed raw materials after adding the mixing water by 3 minutes and the mixing process continued until uniform mix attained.

To mix HPSFC, the coarse and fine aggregate were mixed firstly with 1/3 of the mixing water for a minute, then cement with RHA and remaining water were added, and the ingredients were mixed for 3 minutes. After that, the admixtures and fibers were added, and the mixing was contained for suitable time (until the concrete becomes homogenous in consistency).

2.3. Casting Compaction and Curing.

The molds were lightly coated with oil before placing concrete, according to ASTM C 192-88 [11], concrete casting was carried out in different layer each layer of 50 mm. Each layer was compacted by using a Vibrating **Table (15-30)** second until no air bubbles emerged from the surface of the concrete, and the concrete is leveled off smoothly to the top of the molds. Then, the specimens were kept covered with polyethylene sheet in the laboratory for about (24 ± 2) hrs. After that, the specimens remolded carefully, marker and immersed in water until the age of test. The ages of tests were 7, 28 and 90 days.

3. TESTING OF HARDENED CONCRETE.

3.1. Compressive Strength Test.

For compressive strength tests a 100mm concrete cubes were prepared according to BS 1881: part 5 [12]. The compressive strength was determined according to BS.1881 part 4, 1970 [13]. The average of compressive strength of three cubes was recorded for each testing age (7, 28 and 90 days).

3.2. Static Modulus of Elasticity (E_c) Test.

150×300mm concrete cylinders were prepared according to ASTM C192-88 [11], for static modulus of elasticity test. The strain was measured using compress meter according to ASTM C469-87a [14]. The static modulus of elasticity was determined by the following formula and the average of three specimen results of age 90 days was adopted.

$$E_s = [(S_2 - S_1) / (e_2 - 0.000050)] \times 10^{-3} \qquad (1)$$

Where:

E_s = Static modulus of elasticity, GPa
S_2 = Stress corresponding to 40% of ultimate load, MPa.
S_1 = Stress corresponding to a longitudinal strain, e_1, of 50 Millionths, MPa.
e_2 = longitudinal Strain produced by stress S_2.

3.3. Dynamic Modulus of Elasticity (E_d) Test.

100×100×400mm concrete prisms were prepared according to B.S.1881.Part.5. 1970 [12]. The dynamic modulus of elasticity was determined on the laboratory specimens subjected to longitudinal vibration on their natural frequency; according to B.S.1881.1970 [12] using the following formula:

$$E_d = 4 \rho n^2 L^2 \times 10^{-12} \qquad (2)$$

Where:

E_d = dynamic modulus of elasticity, GPa.
n = Fundamental longitudinal frequency, Hz
ρ = Density, kg/m^3
L = length of specimens, mm
The average result of three specimens for each testing age 7,28, and 90days was adopted.

4. RESULTS AND DISCUSSIONS.

4.1. Compressive Strength.

There was a positive correlation between compressive strength and curing age for all concrete types. The compressive strength increment at various curing ages for all types of concrete are presented in **Table (2)**. The addition of steel fiber to HPC (up to volume fraction of 1.5%) caused an increase in compressive strength of concrete at early ages. Where, at 7 days curing the increasing percentage were 63.7%, 63.7% and 62.3% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete respectively.

Table (2) clearly showed that adding 1.5% steel fiber did not cause any increase in compressive strength at 7 days. This could be attributed to the increment of air voids in concrete that caused by increasing W/C which is required to maintain a given workability. As it well known, compressive strength is very sensitive to the water content and consequently to these voids. After 28 days curing the percentage of increase in compressive strength of HPC relative to reference concrete was 16%, while the increase for high performance concrete with steel fiber (HPSFC) were 12.1%, 29.8% and 20.19% for 0.5%, 1% and 1.5% steel fiber by volume of concrete respectively.

4.2. Static Modulus of Elasticity (E_c).

E_c increased considerably with incorporating steel fibers as shown in **Table (3)**, and plotted in **Fig.(3)**. In comparison with reference concrete, HPC showed a significant increase in E_c, such behavior is mainly attributed to action of HRWRA in producing uniform dispersion of cement particles and, then distribution of hydration products throughout the fine and coarse aggregate particles producing a dense Interfacial Transition Zone ITZ between the cement paste and aggregate. Beside the role of RHA that react with Calcium hydroxide $Ca(OH)_2$ to produce C-S-H that contribute in strengthen the cement paste itself and the ITZ as well with ,in turn, improve the strength and modulus of elasticity.

The percentage increase in static modulus of elasticity at 90 days of curing measured relative to reference concrete were 13.3%, 15.16%, and 17.16% for HPC with 0.5%, 1%, and 1.5% steel fiber by volume respectively, **Fig.(4)**. And the percentage increase in E_c of HPSFC relative to HPC were 8.2%, 9.98%, and 11.88 % for HPC with 0.5%, 1%, and 1.5% steel fiber by volume respectively **Fig.(4)**.

4.3. Dynamic Modulus of Elasticity (E_d).

Fig.(5) shows that E_d increased generally with age of curing. It can be seen that there is an important increment in E_d for all HPSFC compared with the reference mix. This behavior is due to the fact that Ed has a positive relation with the strength of concrete where it was found that the high mechanical properties specimens produced higher E_d.

HPC was exhibited increment in E_d compared with reference concrete at all ages, see **Fig.(5)**. This behavior may be explained in terms of pore size air voids, where, these are considered to be lower in HRWRA concrete mainly due to significant reduction in water content of the mix. Additionally, at 90 days the pozzolanic reaction of RHA , as mentioned earlier , produce an extra gel instead of $Ca(OH)_2$ which closed the internal pores. In other words, the defects of concrete will be minimized therefore the wave passes faster which improved E_d.

E_d of HPC relative to reference concrete improved by 2.64%, 3.72%, and 4.01% at 7, 28, and 90 days respectively. HPSFC demonstrated further increment in E_d over these of reference and HPC at all ages of curing, **Figs.(5, 6 and 7)**. The inclusion of steel fiber restricted the micro-cracks, which disperse the wave and delay transfer it from side to another of specimen, therefore, Ed increased with increasing steel fiber content as shown in **Fig.(6)**.

HPSFC E_d at 7 days increased relative to HPC by 4.47%, 6.29%, 8.34%, for HPC with 0.5%, 1%, and 1.5 steel fibers by volume respectively, **Fig.(6)**, while at 28 days these improvement were 8.09%, 10.7%, and 11.07% for HPC with 0.5%, 1%, and 1.5% steel fiber by volume respectively. Finally, at 90 days the percentage increase of E_d were 7.68%, 10.27%, and 10.59% for HPC with 0.5%, 1%, and 1.5% steel fiber by volume of concrete respectively, **Fig.(7)**.

5. CONCLUSIONS.

Depending on the results of this investigation, the following conclusions can be drawn: -

- At optimum dosage of superplasticizer 6% by weight of cement, the maximum water reductions were 28.2% for HPC and 26.2%, 24% and 21.9% for HPC with 0.5%, 1% and 1.5% steel fiber by volume of concrete, respectively.
- The optimum fraction of steel fiber, RHA, and SP were 1% by concrete volume, 8% RHA and 6% SP by cement weight. Compressive strength of HPSFC improved by 0.89%, 11.57% and 21.6% at 7, 28, and 90 days, respectively.
- The static and dynamic modulus of elasticity of concrete increased with steel fiber contents up to 1.5%. where, the percentage increase in Ec at 90 days were 13.3 %, 15.16 %, and 17.16 % at 0.5 %, 1 %, and 1.5 % steel fiber by volume respectively while at 90 days the increment of Ed were 7.68%, 10.27%, and 10.59% at 0.5%, 1%, and 1.5% steel fiber by volume of concrete respectively.

6. ABBREVIATIONS.

Co	Reference Concrete
HPC	High Performance Concrete
HPSFC	High Performance Steel Fiber Concrete
$HPC_{0.5}$	High Performance Concrete with 0.5% Steel Fiber by Volume
$HPC_{1.0}$	High Performance Concrete with 1.0% Steel Fiber by Volume
$HPC_{1.5}$	High Performance Concrete with 1.5% Steel Fiber by Volume

7. REFERENCES.

[1] Forster, S.W. "High-Performance Concrete-Stretching the Paradigm ", Concrete International, Vol. 16, N. 10,Oct., p.p. 33-34, 1994.

[2] Zaid H. Al-Sakiny "Engineering Properties of Ultra High Strength Fiber Reinforced Concrete ",M.Sc. Thesis, University of Technology, Baghdad, 2002.

[3] Ameir, G. T."Engineering Properties of High Performance Fiber Reinforced Lightweight Aggregate Concrete", M. Sc. Thesis, University of Technology, Baghdad, 2002.

[4] Balagurn P., and Ramakishnon. V., " Mechanical Properties of Superplasticizer Fiber Reinforced Concrete Developed For Bridge, Deck and High Way Pavement ", ACI – Journal, Sp (93-62)(Sep.- Oct.), 1986.

[5] Ammar, S. Al-Rahamy, "Properties and Durability of Admixured Fiber Concrete Exposed to Oil Products", M. Sc. Thesis, University of Technology, Baghdad, 2002.

[6] Iraqi specification No.45, "Portland Cement" , 1984.

[7] ASTM C128-88 "Standard Test Method for Specific Gravity and Absorption of Fine Aggregate", Annual Book of ASTM Standard, Philadelphia, Vol. 04-02, pp. 68-71, 1989.

[8] ASTM C127-88 "Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate", Annual Book of ASTM Standard, Philadelphia, Vol. 04-02, pp. 63-65, 1989.

[9] ASTM C496-86 "Standard Specification for Chemical Admixture for Concrete", Annual Book of ASTM Standard, Philadelphia, Vol. 04-02, pp. 245-252, 1988.

[10] ASTM C618, "Standard Specification for Chemical Admixtures for Concrete", Annual Book of ASTM Standard American Society for Testing and Materials, Vol. 04. 02, pp. 291-293, 1989.

[11] ASTM C192-88 "Standard Practice for Making and Curing Test Specimens in the Laboratory". Animal Book of ASTM Standard, Philadelphia, Vol.04-02, pp. 112-118, 1989.

[12] British Standard Institution "Method of Testing Hardened Concrete for Other Strength". B.S. 1881, Part 5, London, 1970.

[13] British Standard Institution "Method of Testing Concrete For Strength", B.S. 1881, Part 4, London, 1970.
[14] ASTM C469-87a, "Standard Test Method For Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression", Annual Book of ASTM Standard, Philadelphia, Vol.04-02, pp. 236-239, 1989.

Table (1): Details of the experimental program, mix proportions, 1:1.15:1.73 (by weight), with slump 100 mm.

Mix designation	Cement content Kg/m^3	(W/C) or (W/Cm)* to give slump 100 ± 5 (mm)	Water reduction (%)	Steel fiber content by volume (%)
C_0	550	0.41	0	0
HPC	506	0.294	28.2	0
$HPC_{0.5}$	506	0.303	26.1	0.5
$HPC_{1.0}$	506	0.311	24	1
$HPC_{1.5}$	506	0.32	21.9	1.5

* W/Cm ratio: Water/ cemented materials ratio

Table (2): Average compressive strength results.

Mix designation	(W/C) or (W/Cm) to give slump 100 ± 5 (mm)	Water reduction (%)	Compressive strength (MPa) at		
			7 days	28 days	90 days
C_0	0.41	0	34.5	52	54
HPC	0.29	28.2	56	60.5	62.5
$HPC_{0.5}$	0.30	26.1	56.5	63	72.25
$HPC_{1.0}$	0.31	24	56.5	67.5	76
$HPC_{1.5}$	0.32	21.9	56	62.5	73

Table (3): Average static modulus of elasticity results.

Mix designation	Cement content Kg/m^3	(W/C) or (W/Cm) to give slump 100 ± 5 (mm)	Water Reduction (%)	Static modulus of elasticity at 90 days (GPa)
C_0	550	0.41	0	38.87
HPC	506	0.294	28.2	39.97
$HPC_{0.5}$	506	0.303	26.1	43.25
$HPC_{1.0}$	506	0.311	24	43.96
$HPC_{1.5}$	506	0.32	21.9	44.72

Table (4) : Average dynamic modulus of elasticity results.

Mix designation	**Cement content Kg/m^3**	**(W/C) or (W/Cm) to give slump 100 ± 5 (mm)**	**Water Reduction (%)**	**Dynamic modulus of elasticity (GPa) at different ages (days)**		
				7	**28**	**90**
C_0	550	0.41	0	43.84	45.60	46.34
HPC	506	0.294	28.2	45.00	47.30	48.20
$HPC_{0.5}$	506	0.303	26.1	45.80	49.29	49.90
$HPC_{1.0}$	506	0.311	24	46.60	50.50	51.10
$HPC_{1.5}$	506	0.32	21.9	47.50	50.65	51.25

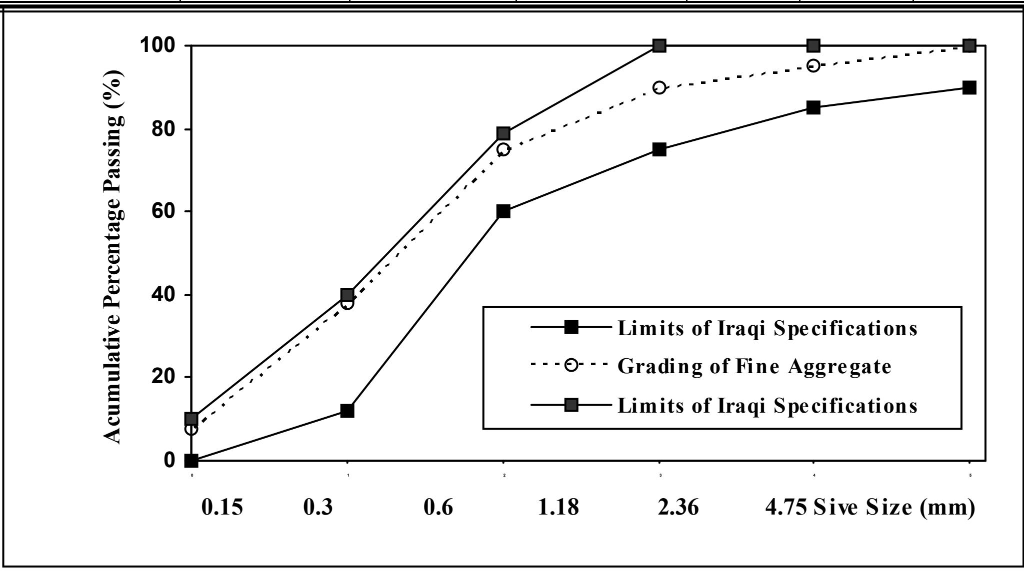

Figure (1): Grading curve of fine aggregate.

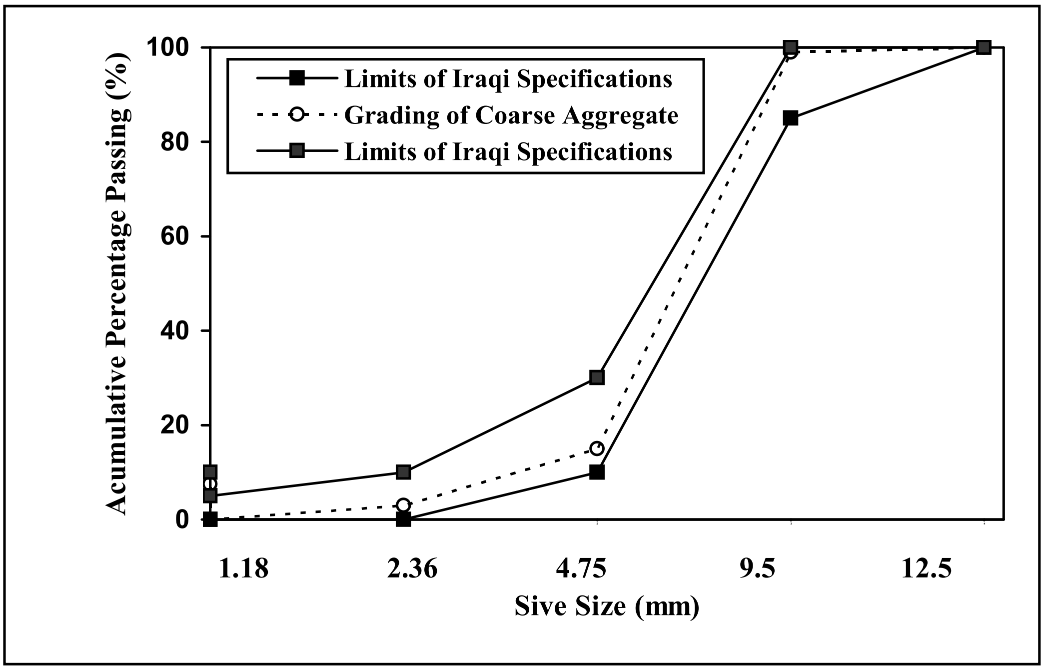

Figure (2): Grading curve of coarse aggregate.

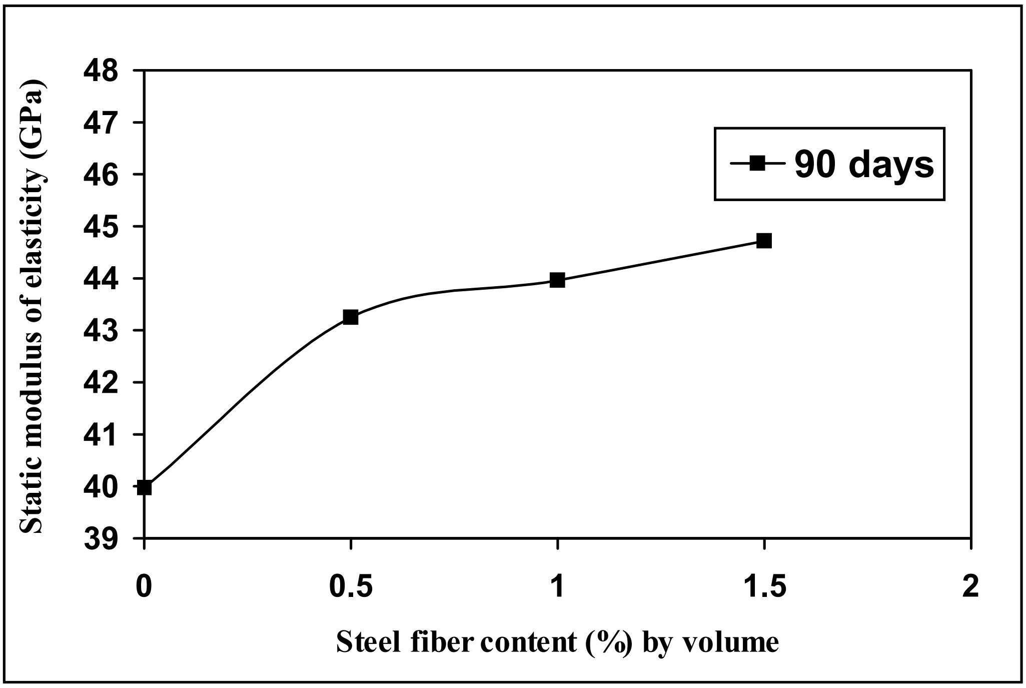

Figure (3): Static modulus of concrete with different steel fiber content at 90 days.

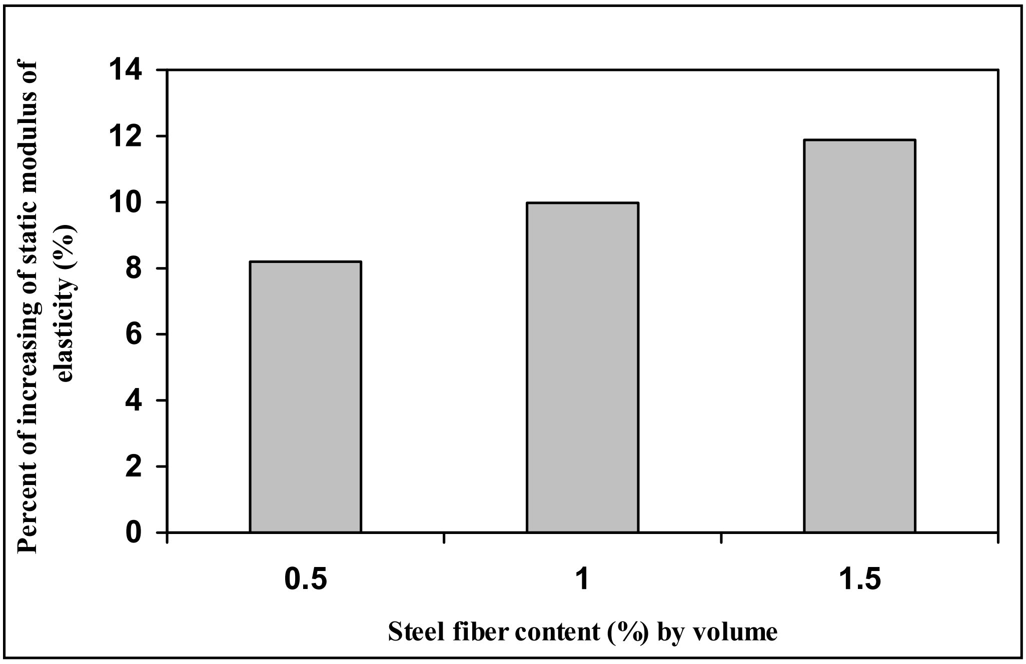

Figure (4): Relationship between the steel fiber content and percent of increasing of E_c of HPC at 90 days

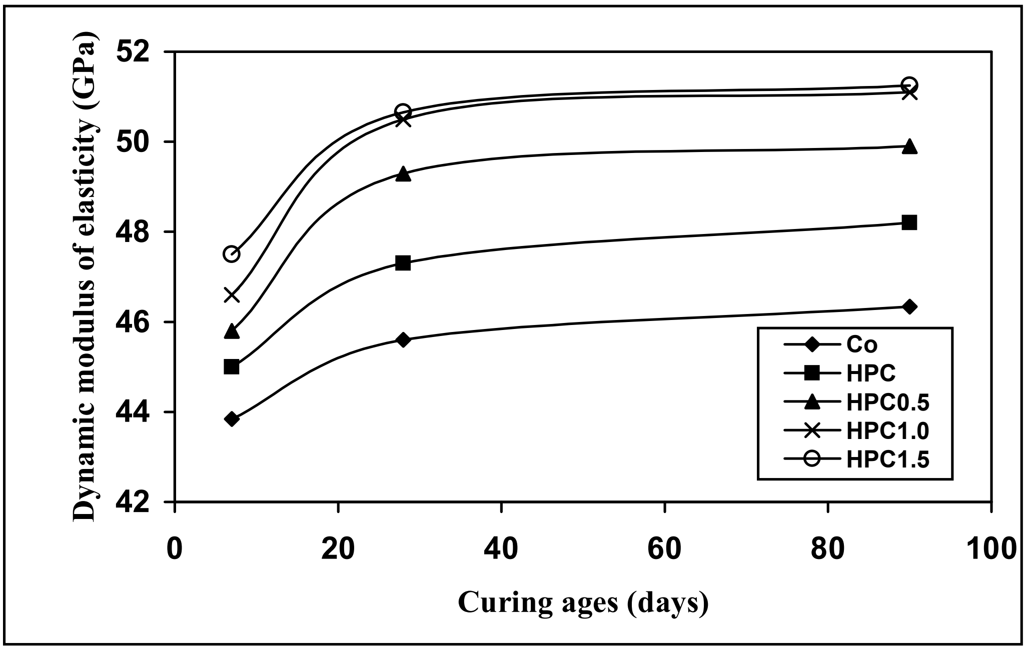

Figure (5): Dynamic modulus of various types of concrete at different ages.

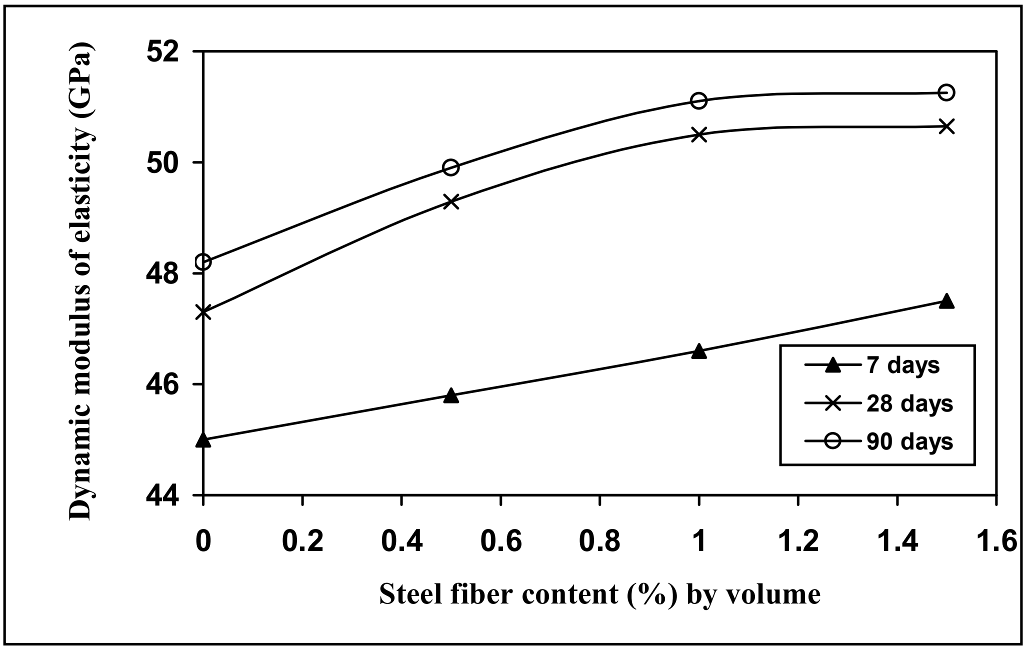

Figure (6): Effect of steel fibers content on the dynamic modulus of elasticity of HPC at different ages.

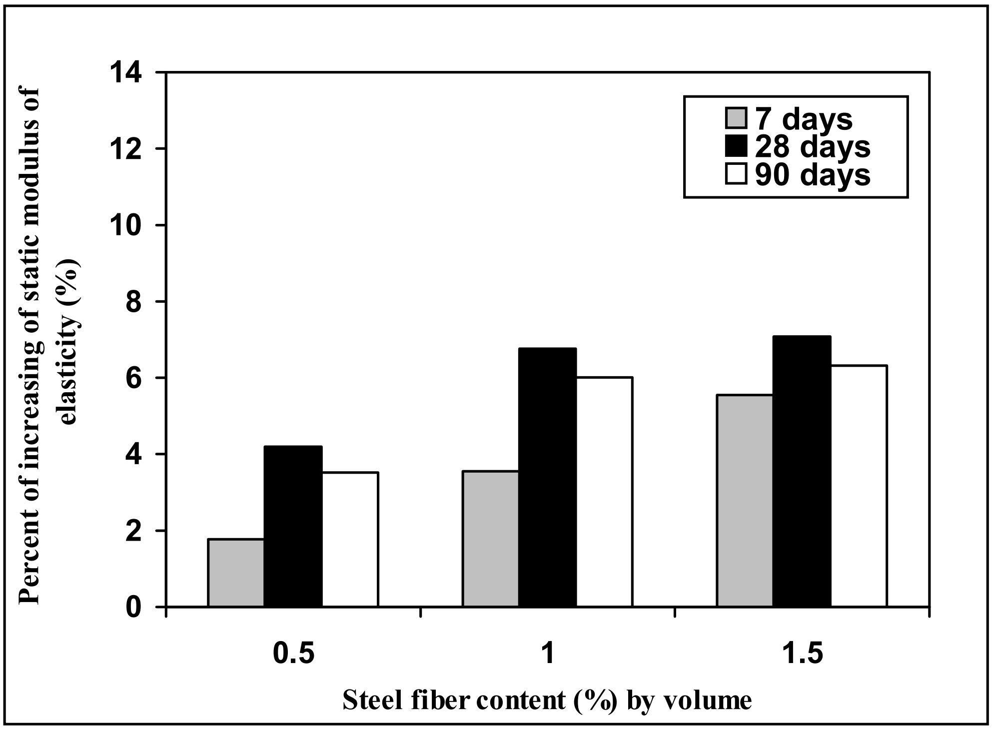

Figure (7): Relationship between the steel fiber content and percent of increasing of dynamic modulus of elasticity of HPC at different ages.

تحسين معامل المرونة للخرسانة عالية الاداء باستعمال الالياف الحديدية

أ.د. شاكر احمد المشهداني
قسم البناء والانشاءات
الجامعة التكنولوجية

أ.م.د. سعيد خلف رجب
قسم الهندسة المدنية
المعهد الفني– الموصل

أ.م. خالد بتال نجم
قسم الهندسة المدنية
كلية الهندسة – جامعة الانبار

الخلاصـة.

إن الغاية الرئيسية لهذا البحث هودراسة تأثير محتوى الألياف الحديدية على معامل المرونة للخرسانة العالية الأداء. بينت النتائج المختبرية بان استخدام الألياف الحديدية في الخرسانة العالية الأداء أدى إلى تحسين مميز في معاملي المرونة الساكن والديناميكي. من النتائج المختبرية، عند90 يوم معالجة، نسب الزيادة في معامل المرونة الساكن للخرسانة العالية الأداء والمسلحة بالألياف نسبة إلى للخرسانة العالية الأداء كانت 8.2 %، 9.98 % و 11.88% للخرسانة العالية الأداء والمسلحة بنسب 0.5 %، 1.0 % و 1.5% من الألياف الحديدية بالحجم ، على التوالي. نسب الزيادة في معامل المرونة الديناميكي للخرسانة العالية الأداء والمسلحة بالألياف نسبة إلى للخرسانة العالية الأداء بعمر 28 يوم كانت8.09 %، 10.7 % و 11.07% للخرسانة العالية الأداء والمسلحة بنسب 0.5 %، 1.0 % و 1.5% من الألياف الحديدية بالحجم ، على التوالي.

الكلمات الرئيسية: الخرسانة،الخصائص الميكانيكية،الخرسانة عالية الأداء،مقاومة،مضافات الى الخلطة،معامل المرونة،التخثير،عكورة،معالجة،إزالة.