Some Mechanical Properties of Reactive Powder Light Weight Concrete

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Abstract.

In General, original reactive powder concrete (RPC) consists of a superplasticized cement mixture with silica fumes, steel fiber and ground fine sand (150-600 μm). The main purpose of the present work is to produce and study some mechanical properties of lightweight reactive powder concrete using a superplasticized cement mixture with high reactivity metakaolin (HRM) instead of silica fume, steel fiber (with different ratios) with ground fine sand (150-600 μm) and light weight material called (Perlite) also with different ratios .

This investigation was carried out using several tests, these tests were compressive strength, modulus of rupture, modulus of elasticity, density and absorption, and performed for specimens at ages of 3, 7, 28 days, respectively. The tests results were compared with a reference mix. The experimental results shows that , with different ages, (for constant Perlit ratio for 0% to 10% as additional cementtitious materials) addition of 1% steel fiber will improve about (8.3%-10% , 3.2%-11%and 0.25%- 8%) for compressive strength , modulus of rupture, and modulus of elasticity respectively, and increase density, absorption about (0.8%-1.8%,4.5%-8.2%) respectively. Also an increase of steel fiber ratio to 2% will improve about (16.5%-20.3%, 9.0%-17%, and 1.7%-11.5%) for compressive strength , modulus of rupture and modulus of elasticity respectively, and increase density, absorption about (1.7%-2.3% , 7.3%-8.3%) respectively. For same steel fiber ratio about 0% to 2%, increasing Perlite ratio to 2.5% will decrease about (17.3%-18.8%, 9.5%-15.5%, 4.4%-16.6%, and 4.98% - 6.9%) for compressive strength, modulus of rupture, modulus of elasticity and density respectively and increase absorption to about (55.5% - 66.5%). Increasing the ratio to 5% will also make a decrease of about (36%-36.77%, 33.7%-37%, 16.5%- 21.88%and 15.91%-19.74%) for compressive strength, modulus of rupture, modulus of elasticity and density respectively and increase absorption for about (106%- 110.5%) . Increasing the ratio to 10% will also decrease about (45.98%-47.2%, 46.5-54.2%, 30.6%- 35.57%and 19.4%-23.36%) for compressive strength, modulus of rupture, modulus of elasticity and density respectively and increase absorption about(183%- 192.6%). To produce structural lightweight concrete, the tests results show that the optimum steel fiber is 1% by volume and optimum Perlite ratio is 2.5% by weight of cement as additional materials.

Keywords: Reactive powder, Light weight concrete, Steel fiber, Mechanical properties.

1. Introduction.

Concrete materials past, present and future will remain for long time the major construction materials. The concrete as a material was developed and reached advanced stages according to the design and execution procedures using modern design methods and recent construction technology equipments. Nowdays researches focus on improving mechanical properties of concrete to satisfy structural and economical requirements [1,2].

The term Reactive Powder Concrete (RPC) has been used to describe a fiber–reinforced, superplasticized, silica fume-cement mixture with very low water-cement ratio (w/c) characterized by the presence of very fine quartz sand (150-600 μm) instead of ordinary aggregate [3]. In fact, it is not a concrete because there is no coarse aggregate in the cement mixture. The absence of coarse aggregate was considered by the inventors to be a key aspect for the microstructure of the reactive powder concrete [4], in order to reduce the heterogeneity between the cement matrix and the aggregate.

Moreover, with respect to the original manufacturing process [5] – where additional sophisticated treatment is also used to remove the excess of mixing water through compacting pressure of the mixture in the mould before and during setting , or to prolong the heating process at 90-400 ºC to dry the hardened material-traditional casting by vibration of fresh mixtures and conventional curing processes where adopted in the present investigation.

The main purpose of the present investigation is to study some mechanical properties of light weight reactive powder concrete using a superplasticized cement mixture with high reactivity metakaolin (HRM) instead of silica fume and very low water cement ratio, steel fiber (with different ratios from 0% to 2% by volume) with ground fine sand (150-600 µm) instead of ordinary aggregate and light weight material called (Perlite) also with different ratios from 0% to 10% by weight of cement as additional cementtitious materials .

However, due to use of very fine sand instead of ordinary aggregate, the cement factor of the RPC is as high as 900-1000 kg/m^3. The unusual cement factor could increase drying shrinkage and creep strain of the RPC with respect to ordinary concrete with cement factor usually in the range of 300-500 kg/m^3. Three different ratios of steel fiber were used to study the effect of the mechanical properties of concrete; 0%, 1% and 2% , also, four different ratios of Perlite were used (0%, 2.5%, 5.0% and 10%).

A total of (72) specimens of a 70×70×70 mm cube, (72) specimen of a 100×100×500 mm prism and (72) specimen of a 150 ×300 mm cylinder were tested at Anbar University concrete laboratory.

The aim of the research was to produce and test some mechanical properties for structural reactive powder lightweight concrete using Perlit material by weight of cement (additional materials) and steel fiber by volume.

2. Materials.

2.1 Cement.

Ordinary Portland cement produced in Kubesa Factory were used. Table(1) shows physical properties of the cement, chemical composition is presented in Table(2).

2.2 Fine Sand.

Fine ground quartz sand (150-600 µm) with a specific gravity (2.65) was used for manufacturing the RPC mixture, the distribution of particle size for fine sand is shown in Table (3).

2.3 Steel Fiber.

Steel fibers 20 mm long with a 0.4 mm diameter and an aspect ratio of 50 were used in different ratios including 1% and 2% by volume.

2.4 Perlit.

A light weight material called (Perlite) which is a commercial name for natural materials in the form of glassy cell with high porosity. According to the manufacturing manual, the Perlite produced by subjecting Perlite particles to high temperature (about 870^oC) , so the materials despots any roots of water (combined water) and the materials expanded about 4-20 times the original volume producing swelled Perlite with very high porosity. The Perlite is useful for thermal, sound and noise isolation, also it is natural, an organic, fire resistance and energy saving. Table (4) shows the chemical properties of Perlite [7].

2.5 Superplastizicer.
A high range water reduction superplasticizer was used (commercial name Top Flow 703). Typical properties is shown in Table(5), the normal dosage about 0.75-2.5 liter/100 kg cementation materials. It is free from chlorides and complies with ASTM C494 Type A[8].

2.6 SBR.
A polybond SBR was used to increase water resistance and durability, chemical properties of SBR is as shown in Table (6)[9].

2.7 Metakaolin.
Kaolin is a fine, white clay material that has been traditionally used in the manufacturing of porcelain. The structure of the kaolin minerals is based on the combination of two layer structure, one layer, known as the silica layer is composed of silicon and oxygen atoms, and the second, known as the gibbsite and hydroxyl groups kaoline after calcinations at specific temperature and under controlled conditions forms High reactivity Metakaoline (HRM) that exhibit pozzolanic properties[10].

$$Al_2O_3.2SiO_2.2H_2O \text{ (Kaoline)} \longrightarrow Al_2O_3.2SiO_2 \text{ (Metakoaline)} + 2H_2O \text{ (Steam)}$$

3. Concrete Specimens.
Total of 324 concrete specimens were cast in different molds including (70) mm cubes, (100×100×500) mm prism and (150×300) mm cylinder

4. Concrete Mixes.
Three sets of concrete mixes were prepared, with total mix job (12 mixes), Mix 1 as a reference mix [4]. The steel fiber and Perlit were used in different ratios by volume and by weight of cement (additional) respectively. Table (7) shows the quantities of materials used for each mix .

All concrete specimens were consolidated by vibrations and measurements were carried after an adequate curing time .

5.Test Results and Discussion.
In this study, many tests are carried out for different types of specimens (cubes, prisms and cylinders) including compressive strength ,modulus of rupture , modulus of elasticity, absorption and unite weight . The test results shown in Table(8).

5.1.Compressive Strength.
compressive strength tests were conducted on a (70) mm cubes using an electrical testing machine with a capacity 200 kN at loading rate 15 MPa per minute. The test was determined according to B.S. 1881: part 116:1984 [11], the average of three cubes was adopted for each test.

For the results shown in Fig. (1), generally, an increase of Perlite reduces the compressive strength. In Figure (2), results shows that increasing Perlite material 2.5,5 and 10% the compressive strength reduced about 17.28, 36.32 and 45.98% respectively at 28 days without steel fiber. Also, there is no considerable change because of adding 1, 2% steel fiber since increase of steel fiber has significant effect on tensile strength more than compressive strength.

5.2 Modulus of Rupture.
Modulus of rupture tests were conducted on a (100×100×500) mm prism electrical testing machine with a capacity of 50 kN. The tests were determined according to ASTM C78-02

[12]. The prisms were subjected to two point load, average of three samples were adopted for each age.

Modulus of Rupture improved at various curing ages for all types of mixes of 3, 7 and 28 days . Added Perlite will reduced modulus of rupture while increasing steel fiber improves it as shown in Fig.(3). The results in Fig.(4) shows that increasing Perlite material to 2.5,5 and 10% the modulus of rupture reduced about 9, 32.2 and 48.2% respectively at 28 days without steel fiber, these ratios reduces about 2 to 20%.when steel fiber increases to 1% and 2%.

5.3 Modulus of Elasticity.

Modulus of elasticity of concrete was measured on (150×300) mm cylinder specimens. The influence of using Perlit and steel fiber on modulus of elasticity are presented in Fig.(5). In general, increase steel fiber will improve modulus of elasticity.

The results shown in Fig.(6) indicate that increasing Perlite material to 2.5,5 and 10% the modulus of elasticity reduced about 6, 21 and 37.7% respectively at 28 days without steel fiber according to reference mix, these ratios decreased to 4.5, 18.5 and 35.6% when steel fiber increased to 1%, and decreased to 3.5, 16.46 and 33.6 %when steel fiber 2% .

5.4 Unit weight.

The unit weight of hardened concrete was measured according to ASTM C29/M-97 and ASTM C567 [13].The results shown in Fig.(7), obviously indicate that an increase in Perlite will affect and reduce the density. The results show that increasing Perlite material to 2.5,5 and 10% the unit weight of hardened concrete reduced about 4.5, 15.5 and 19.3 % respectively at 28 days for all concrete specimens with or without steel fiber as shown in Fig.(8).

5.5 Absorption.

The absorption of hardened concrete was measured according to ASTM- C642-82[14]. The results are shown in Fig.(9). Obviously an increase in Perlite increases the absorption of hardened concrete. The results show that increasing Perlite material to 2.5,5 and 10% the absorption significantly increases to about 63, 109 and 193 % respectively at 28 days for mixes without steel fiber as shown in Fig.(10).

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Table (1) Physical properties of cement

Physical properties		Test results	Limits of Iraqi standard specifications No.5/1986[6]
Specific surface area (Blaine method) cm^2/gm		3650	≥ 2300
Soundness (autoclave method)		0.25%	≤ 0.8%
Setting time hrs: min.	Initial setting	1:15	≥ 0:45
	Final setting	2:45	≤ 10:0
Compressive strength MPa	3 days	25	≥ 15
	7 days	32.5	≥ 23

Table (2) Chemical properties of cement

Oxide composition	**Abbreviates**	**contents**	**Limits of Iraqi standard specifications No.5/1986[6]**
Lime	CaO	60.5	--------
Silica	SiO_2	21.4	------------
Alumina	Al_2O_3	5.98	--------
Iron Oxide	Fe_2O_3	3.9	--------
Magnesia	MgO	1.36	≤ 5.0%
Sulfate	SO_3	1.82	≤2.5%
Loss on ignition	L.O.I	1.8	≤ 4%
Insoluble residue	I.R	1.04	≤ 1.5%
Lime saturation factor	L.S.F	0.92	0.66-1.02

Table (3) Distribution of sand particles

Sieve Size(mm)	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**	**Pan**
% passing	**100**	**100**	**32.56**	**6.41**	**3.13**	**0.32**

Table (4) Chemical properties of Perlit[7]

Oxides	**SiO_2**	**Al_2O_3**	**K_2O**	**Na_2O**	**CaO**	**Fe_2O_3**	**MgO**
Contents%	**72-76%**	**11-17%**	**4-5%**	**3-4%**	**0.5-2%**	**0.5-1.5%**	**0.1-0.5%**

Table (5) Properties of Top Flow 703[8]

Properties	Appearance	Specific gravity	Chloride contents	Flash point
Contents	**Dark brown/ black liquid**	**1.235 @ 25+2 ^oC**	**Nil**	**N/A**

Table (6) chemical properties of SBR[9]

PH	Specific gravity	Compressive strength	Tensile strength	Flexural strength	Water vapor permeability	Service temperature	Solid content
9-10.5	1.01	40 MPa dependant on cement used and workability	Up to 6.5 MPa dependant on cement used and workability	Up to 13 MPa	4 $mg/m^2/24$ hrs through on 1.1 mm^2 thick test piece	- 20 ^oC to + 60 ^oC	47%

Table(7) Concrete Mixes

Type of concrete	Mix No.	Cement (kg)	Sand (kg)	Metakaolin (% by weight of cement)	Super Plasticizer (L/100 kg C)	SBR (% by weight of cement)	W/C	Perlite (%by wt. of cement)	Steel fiber (%)by volume
Ordinary concrete	1	950	1040	7.5%	2.5	10%	0.268	0	0
	2	950	1040	7.5%	2.5	10%	0.268	0	1
	3	950	1040	7.5%	2.5	10%	0.268	0	2
Light weight concrete	4	950	1040	7.5%	2.6	10%	0.28	2.5	0
	5	950	1040	7.5%	2.6	10%	0.28	2.5	1
	6	950	1040	7.5%	2.6	10%	0.28	2.5	2
	7	950	1040	7.5%	2.7	10%	0.3	5	0
	8	950	1040	7.5%	2.7	10%	0.3	5	1
	9	950	1040	7.5%	2.7	10%	0.3	5	2
	10	950	1040	7.5%	2.8	10%	0.32	10	0
	11	950	1040	7.5%	2.8	10%	0.32	10	1
	12	950	1040	7.5%	2.8	10%	0.32	10	2

Table (8) Tests Results

Mix No.	Compressive strength MPa			modulus of rupture MPa			Modulus of elasticity GPa			Density Kg/m^3			Absorption%		
	3	7	28	3	7	28	3	7	28	3	7	28	3	7	28
Mix1	47.34	67.91	99.8	9.8	12.0	13.97	29.08	36.31	44.71	2400	2432	2485	1.43	1.21	0.95
Mix2	50.38	72.9	110	10.78	14.1	15.52	31.34	38.12	48.29	2415	2455	2495	1.35	1.12	0.9
Mix3	61.4	84.2	120.3	12.42	14.6	16.39	33.33	40.26	49.77	2471	2501	2532	1.24	1.093	0.88
Mix4	38.89	56.98	82.55	8.7	10.9	12.7	28.32	37.25	43.11	1715	1736	1769	2.21	1.91	1.51
Mix5	41.99	62.2	89.5	9.266	12.2	13.11	30.56	38.06	45.46	1732	1753	1784	2.09	1.8	1.4
Mix6	56.59	68.17	97.6	10.6	12.89	13.86	32.47	40.1	47.6	1766	1794	1800	2.02	1.077	1.39
Mix7	28.11	47.19	63.55	6.349	8.2	9.46	22.2	29.99	37.35	1481	1518	1552.5	2.931	2.53	1.99
Mix8	32.8	50.22	69.5	7.1	9.31	10.25	22.91	31.3	38.18	1508	1552	1581	2.71	2.41	1.9
Mix9	44.7	54.32	76.06	8.1	9.87	10.86	24.59	32.24	38.88	1523	1575	1605	2.7	2.361	1.853
Mix10	22.88	32.105	53.91	3.6	6.4	7.21	19.09	24.05	31.03	1410	1444	1477	3.712	3.38	2.78
Mix11	23.2	34.45	58.8	5.12	7.1	8.24	20.6	25.97	31.11	1419	1459	1484	3.44	3.21	2.55
Mix12	27.07	39.38	63.51	5.37	7.8	8.77	22.28	26.98	33.04	1436	1484	1512	3.42	3.137	2.548

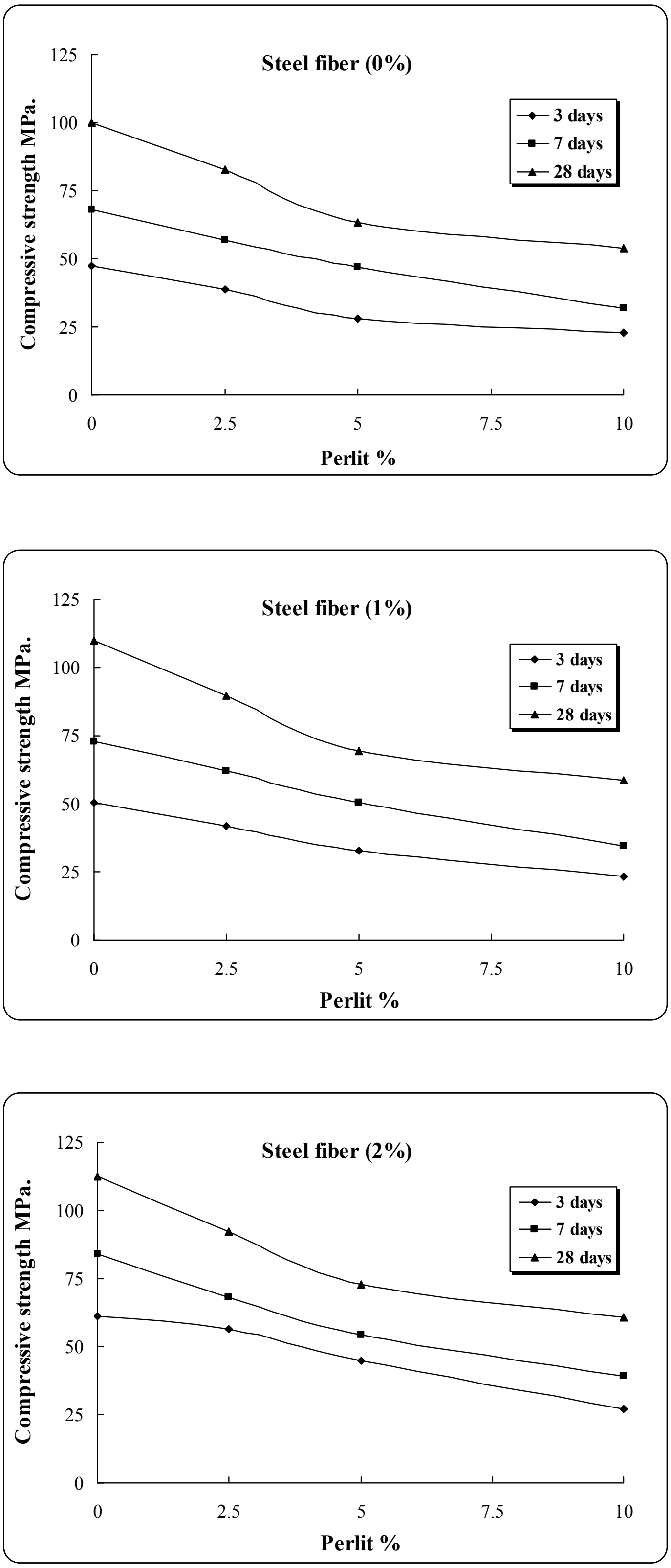

Figure (1): Effect of Perlite content on compressive strength of concrete for different steel fiber volume fracture.

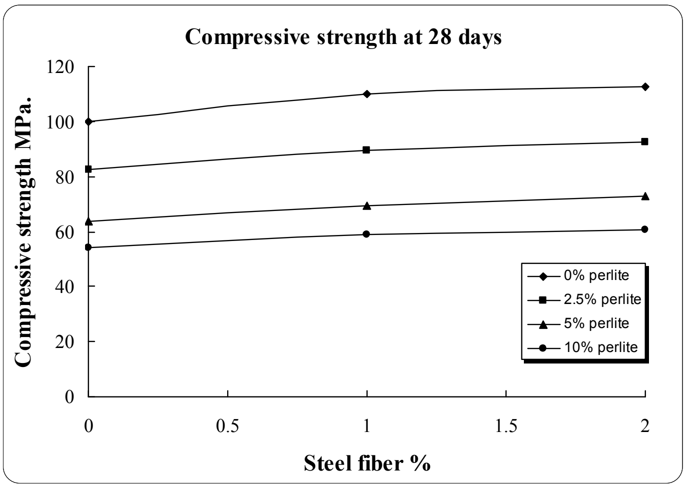

Figure (2): Effect of steel fiber volume fracture content on compressive strength of concrete at 28 days

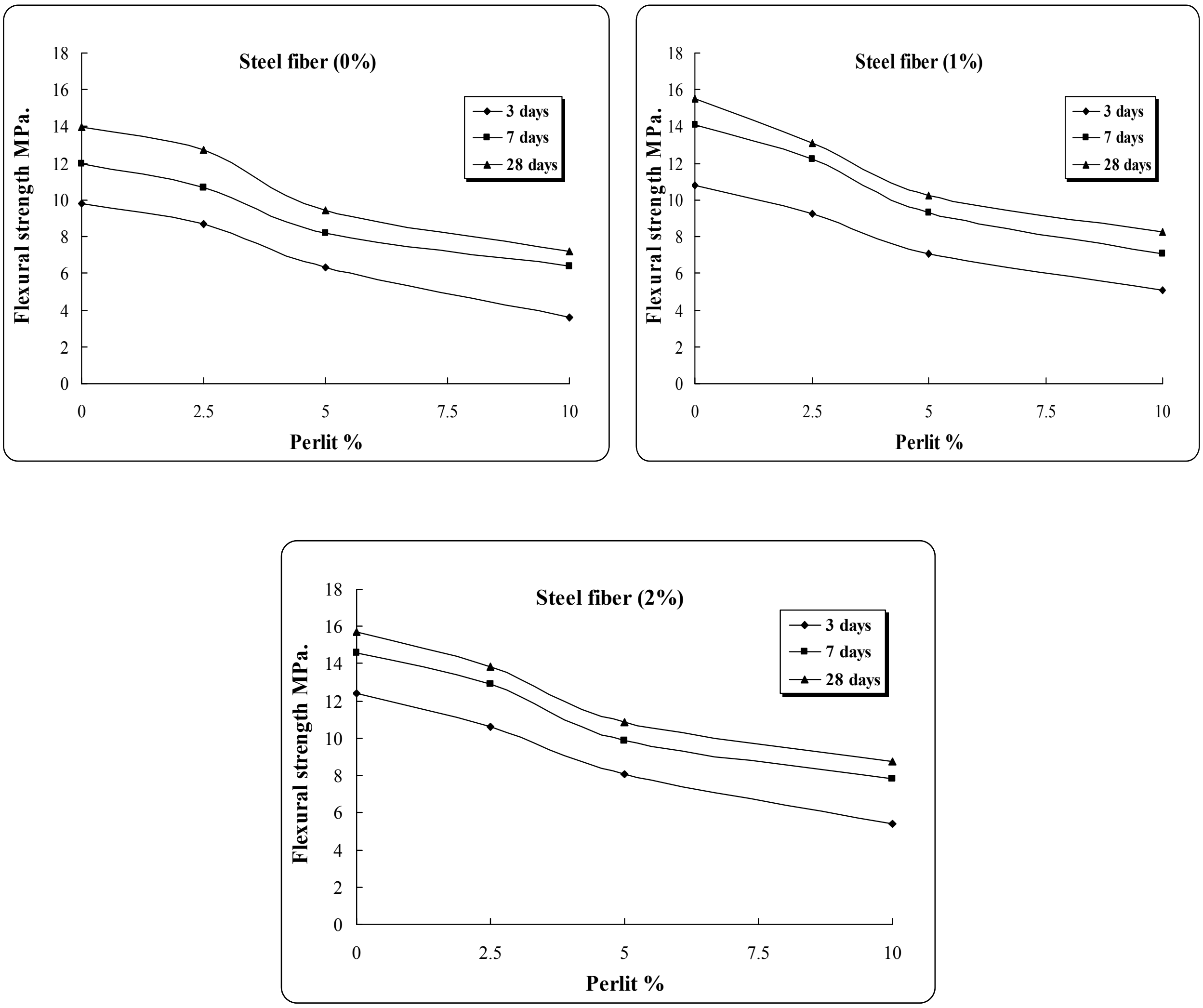

Figure (3): Effect of Perlite content on modulus of rupture of concrete for different steel fiber volume fracture**.**

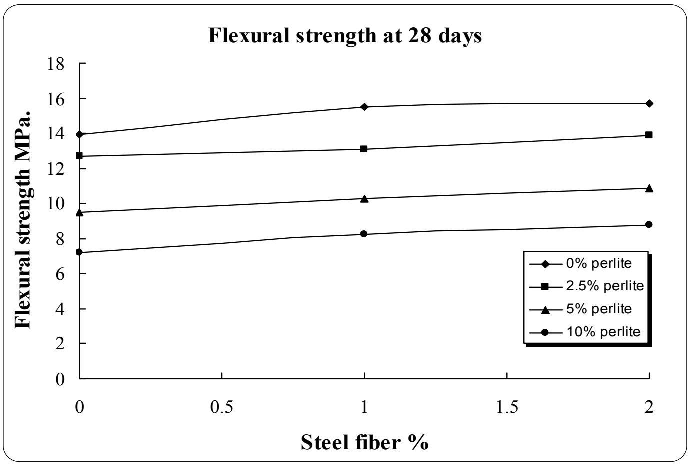

Figure (4): Effect of steel fiber volume fracture content on modulus of rupture of concrete at 28 days.

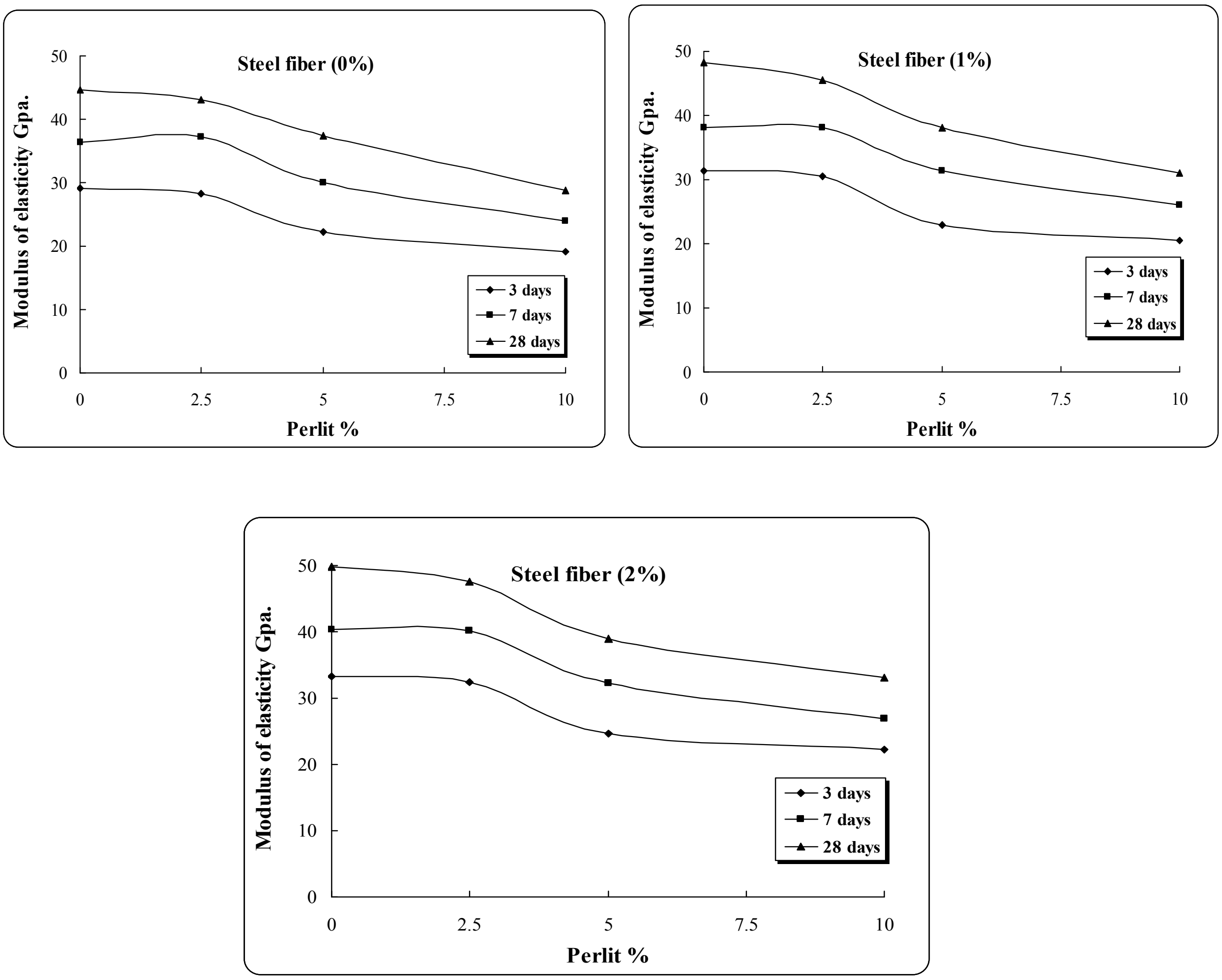

Figure (5): Effect of Perlite content on modulus of elasticity of concrete for different steel fiber volume fracture ratios.

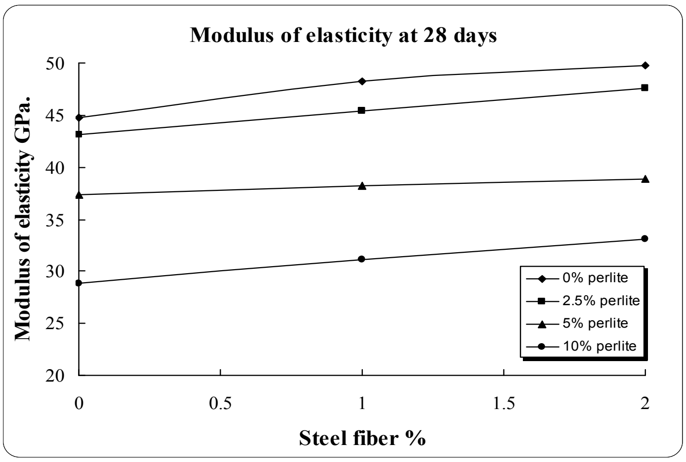

Figure (6): Effect of steel fiber volume fracture content on modulus of elasticity of concrete at 28 days.

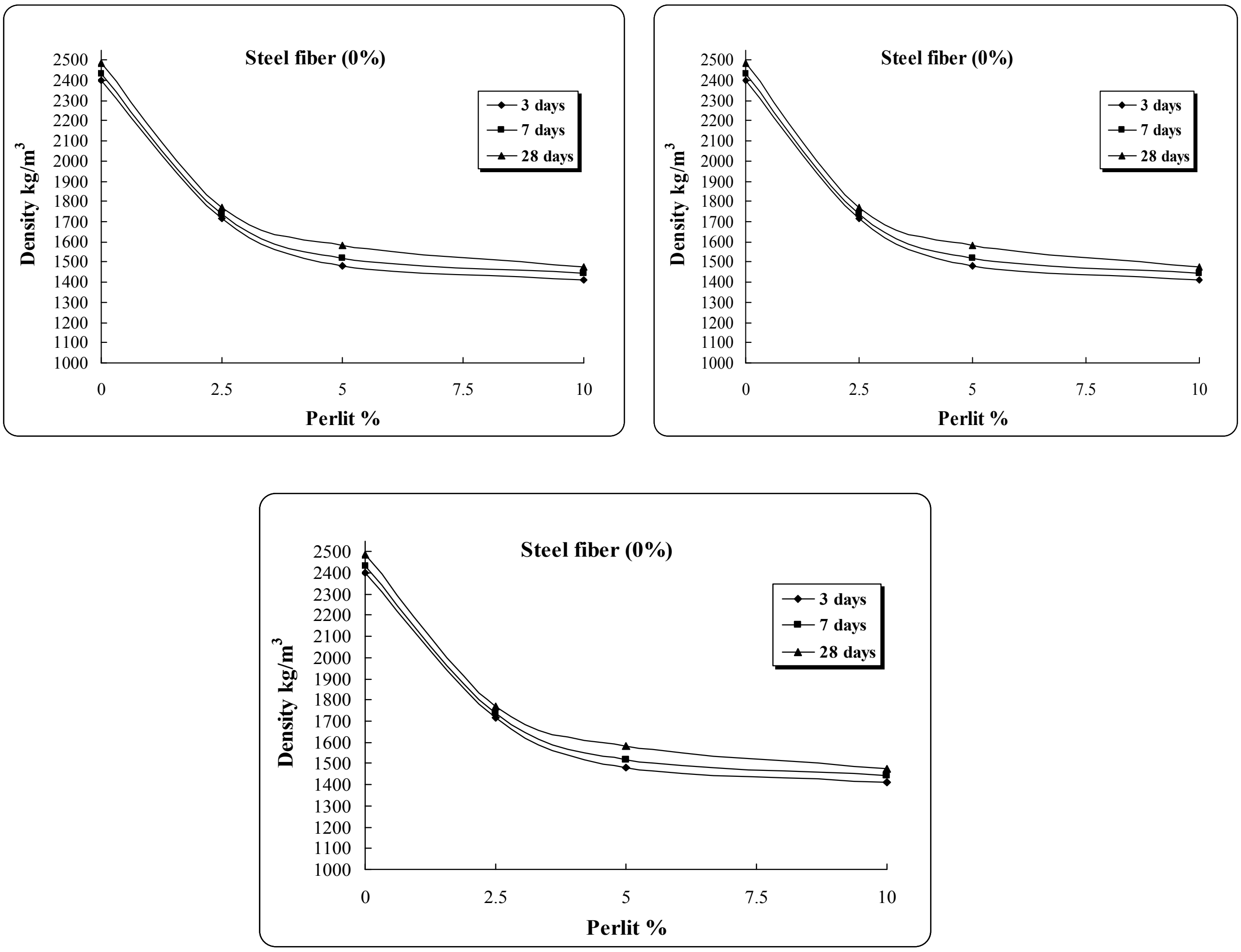

Figure (7): Effect of various Perlite content ratios on unit weight of concrete for different steel fiber volume fracture.

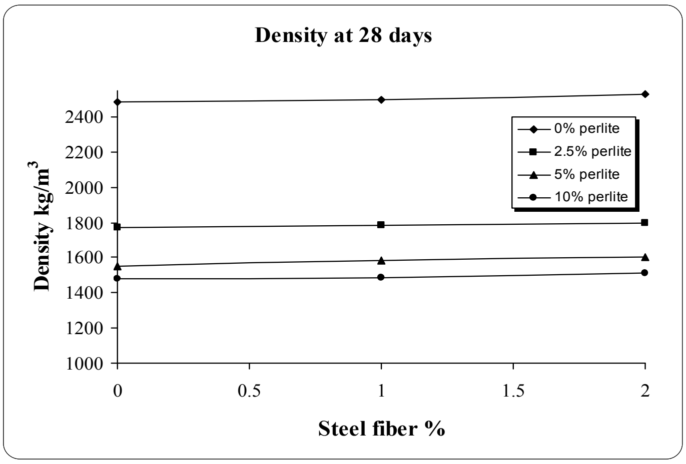

Figure (8): Effect of steel fiber volume fracture content on unit weight of concrete at 28 days

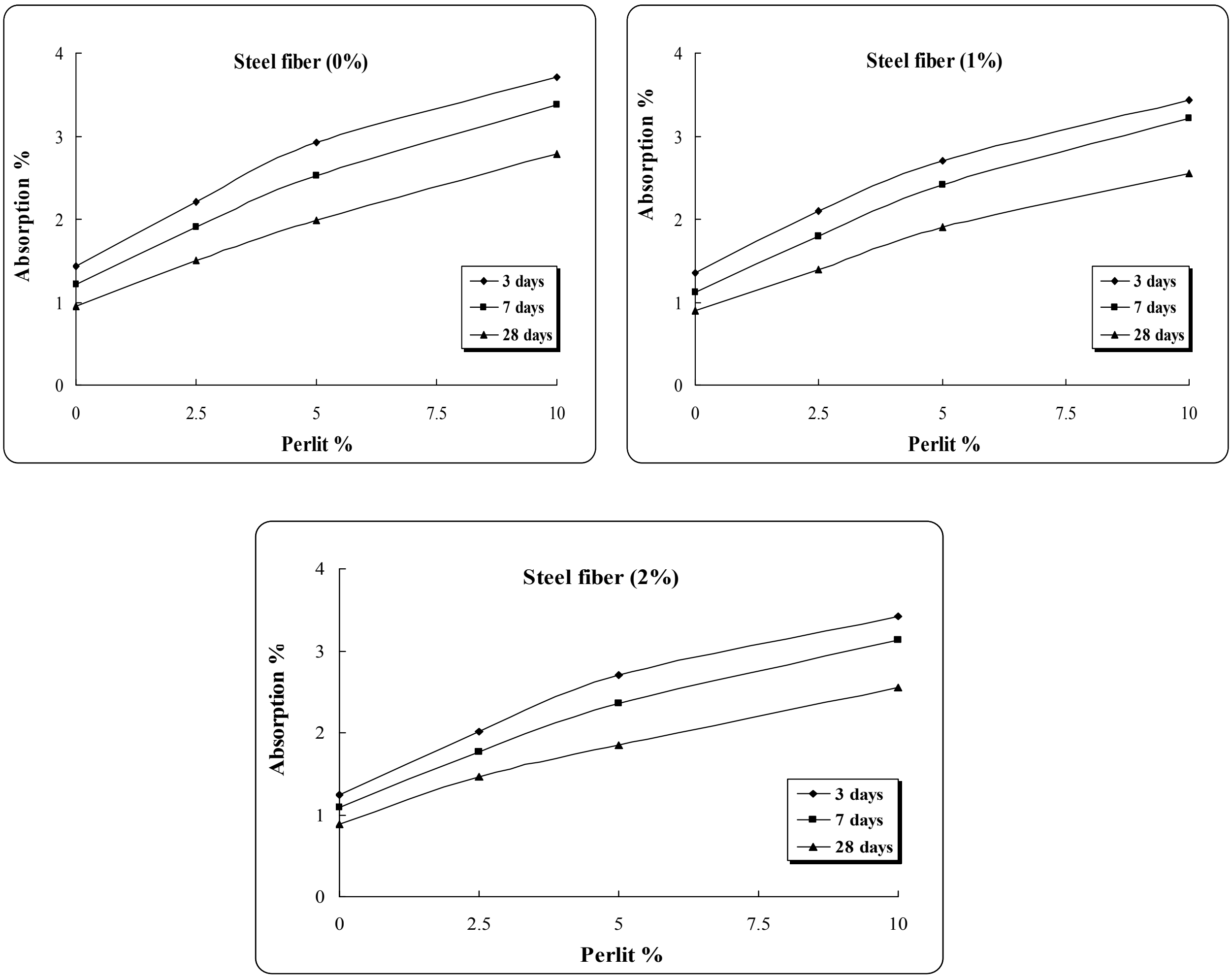

Figure (9): Effect of Perlite content on absorption of hardened concrete for different steel fiber volume fracture ratios

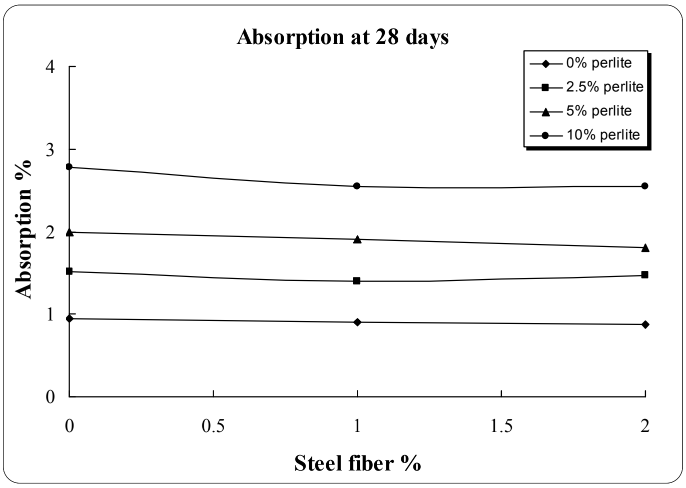

Figure (10): Effect of steel fiber volume fracture content on absorption of hardened concrete at 28 days**.**

دراسة بعض الخواص الميكانيكية لخرسانة المساحيق الفعالة خفيفة الوزن

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الخلاصة.

بصورة عامة، تتكون خرسانة المساحيق الفعالة الأصلية من خليط السمنت وملدن متفوق مع المايكرو سليكا (بخار السليكا)، ألياف الحديد والركام الطبيعي فائق النعومة بمقاس (150-600 مايكرومتر). إن الغرض الرئيسي من العمل إنتاج ودراسة بعض الخواص الميكانيكية للخرسانة خفيفة الوزن ذات المساحيق الفعالة باستخدام خليط الاسمنت مع الميتاكؤلين عالي الفعالية بدلا" من بخار السليكا ، ملدن فائق الفعالية ، ألياف الحديد بنسب مختلفة والركام الطبيعي فائق النعومة بمقاس (150- 600 مايكرومتر) ومادة البرلايت خفيفة الوزن بنسب مختلفة أيضا".

لغرض دراسة الخواص الميكانيكية لهذا النوع من الخرسانة تم اعتماد عدة فحوصات مختبرية شملت مقاومة الانضغاط ، معايير الكسر ، معامل المرونة، الكثافة والامتصاص ولأعمار ٣، ٧، ٢٨ يوم. تم اعتماد خلطة مرجعية بدون استعمال مادة البرلايت أو ألياف الحديد (خلطة رقم١) لغرض مقارنة النتائج العملية. بينت النتائج العملية (لنسبة برلايت ثابتة تتراوح بين ٠% - ١٠%) إن إضافة ألياف الحديد بنسبة ١% يؤدي إلى تحسن الخواص الميكانيكية بنسب (٨.٣ – ١٠%، ٣.٢ – ١١% و ٠.٢٥%-٨%) لمقاومة الانضغاط، معايير الكسر ومعامل المرونة على التوالي وتزيد بحوالي(٠.٨ - ١.٨%) للكثافة وكذلك للامتصاص بحوالي(٤.٥ - ٨.٢%). كذلك فان زيادة هذه النسبة إلى ٢% فان تلك الخواص تتحسن بنسب (١٦.٥%-٢٠.٣% و ٩-١٧% و ١.٧-١١.٥%) لمقاومة الانضغاط، معايير الكسر ومعامل المرونة وتزيد بحوالي(١.٧%-٢.٣%) للكثافة وكذلك للامتصاص بحوالي (٧.٨%-٨.٣%). كذلك بينت النتائج العملية (لنسبة ألياف حديد ثابتة تتراوح بين ٠%-٢%) إن زيادة نسبة البرلايت بنسبة ٢.٥% تتأثر الخواص الميكانيكية بنسب متفاوتة حيث تقل بنسب تتراوح بين (١٧.٣-١٨.٨% ، ٩.٥-١٥.٥%، ٤.٤-١٦.٦% و ٤.٩٨-٦.٩%) لمقاومة الانضغاط، معايير الكسر، معامل المرونة والكثافة على التوالي، والامتصاص يزداد بنسبة (٥٥.٥-٦٦.٥%). كذلك فان زيادة هذه النسبة إلى ٥% فان تلك الخواص تتأثر بصورة واضحة حيث تقل بنسب تتراوح بين (٣٦%- ٣٦.٧٧%، ٣٣.٧%-٣٧%، ١٦.٥%-٢١.٨٨% و ١٥.٩١%-١٩.٧٤%) لمقاومة الانضغاط، معايير الكسر، معامل المرونة والكثافة على التوالي أما الامتصاص فيزداد بنسبة (١٠٦%-١١٠.٥%)، ويزداد التأثير في الخواص الميكانيكية عند زيادة نسبة البرلايت إلى ١٠% حيث تزداد بنسب تتراوح بين (٤٥.٩٨%-٤٧.٢%، ٤٦.٥%-٥٤.٢% ، ٣٠.٦%-٣٥.٥٧% و ١٩.٤%-٢٣.٣٦%) لمقاومة الانضغاط، معايير الكسر، معامل المرونة والكثافة على التوالي أما الامتصاص فيزداد بنسبة (١٨٣-١٩٢.٦%). ولغرض الحصول على خرسانة خفيفة الوزن إنشائية ذات مقاومة جيدة بينت الدراسة إن النسب المثلى لألياف الحديد هي ١% ونسبة البرلايت ٢.٥%.

الكلمات الدالة:المواد البوزلانية الفعالة، خرسانة خفيفة الوزن، الألياف الحديدية، الخواص الميكانيكية.