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PROPERTIES OF HIGH STRENGTH LIGHTWEIGHT AGGREGATE CONCRETE PAVING BRICKS

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ABSTRACT: - This investigation aims to study the properties of paving brick products made from high strength lightweight aggregate concrete (HSLWAC). The mix proportion is 1: 1.35: 0.87 (cement: sand: coarse aggregate) by weight with 520 kg/m^3 cement. Local porcelinate coarse aggregate, with maximum size of 9.5 mm, 5% silica fume as partial replacement by weight of cement, 1% by weight of cement superplasticizer, and w/c ratio of 0.29, was used in the mix. Fibers are used including macro hooked steel fiber with aspect ratio 100, micro polypropylene fiber (pp), and micro carbon fiber (CF). Concrete paving brick was produced from three different HSLWAC mixes including, concrete mix without fibers (reference mix), hybrid fibers reinforced concrete mix containing 0.75% volume fraction of steel fiber and 0.25% volume fraction of polypropylene fiber, and hybrid fibers reinforced HSLWAC mix with 0.75% volume fraction of steel fiber and 0.25% volume fraction of carbon fiber. Experimental tests including, compressive strength, absorption, abrasion resistance as well as the appearance were carried out for the produced paving bricks.

The results indicated that the produced HSLWAC paving bricks can be classified as medium loading type according to Iraqi Specification No. 1606-2009. This type is used for paving low loaded roads and service areas.
Keywords: Lightweight Concrete, Hybrid, Fibers, Macro, Micro, Steel Fiber, Carbon Fiber, Polypropylene Fiber, Paving Bricks.

INTRODUCTION

Structural lightweight aggregate concrete (SLWAC) had been successfully used for structural purposes for many years. The decrease in density for the same strength level permits a saving in dead load for structural design and foundation. Also, lightweight concrete (LWC) is more resistant to fire, and has better heat and sound insulation properties than normal weight concrete [(1)]. Structural lightweight aggregate concrete contributes to sustainable development by conserving energy, maximizing structural efficiency, increasing concrete service life, and lowering transportation requirements [(2)]. Adding lightweight aggregate (LWA) to concrete minimizes crack formation which has become an essential element in sustainability. This is due to the higher aggregate / matrix adhesion as well as the reduction of internal stress due to elastic matching of coarse aggregate and matrix phases [(3)]. At the same strength, lightweight concrete (LWC) products are up to 40% lighter than traditional concrete products. Lower weight reduces the physical demands on labor and equipment, which results in fewer injuries and works compensation claims, as well as extending equipment life. Repeatedly, lifting less weight extends a worker's career [(4)].

Incorporation of fibers in cement – based material shows a great interest to increase the toughness, impact, fatigue endurance, energy absorption capacity, tensile proportion, and abrasion resistance of basic matrix. As a result of above advantages, fibers reinforced concrete is used in tunnel linings, hydraulic structures, and high way pavement [(5)]. The use of

hybrid fibers in concrete has become more common. The performance of hybrid fiber system exceeds that included by each fiber type alone. The main advantage of using hybrid fiber in concrete is the ability to restrain cracking at different scales of the cracking process. The micro-cracks are bridged by short fiber, while the formation of macro- cracks is restrained by long fiber [6]. Concrete paving brick is a system of individual shaped blocks arranged to form a continuous hard wearing surface overlay. It becomes a feature of the towns and cities. There is a growth in the concrete paving brick market because of its greater acceptance not only for roads, driveways and parking areas, but also for other applications such as mines, harbor, etc. [7]. In Iraq, there is no detailed study on properties of paving brick products made from hybrid fiber lightweight aggregate concrete. This research aims to study the properties of paving brick produced from high strength lightweight aggregate concrete and the effect of incorporation hybrid fibers on these properties.

EXPERIMENTAL PROGRAM

Materials

Cement

The cement used through this work is ordinary Portland cement (Type I). It is produced by United Cement Company (MAS) Al-Sulaymaniyah / Iraq. Chemical composition and physical properties of cement used throughout this research are shown in tables (1) and (2) respectively. Test results indicated that the adopted cement satisfies the requirements of the Iraqi Specification No.5/1984.

Fine Aggregate

Al-Ekhaider natural sand of maximum size 4.75mm was used as fine aggregate. It was tested to determine the grading and other physical and chemical properties. Its gradation lies in zone (2). The results showed that sand grading; physical properties, and sulfate content were within the requirements of the Iraqi Specification No.45/1984. The properties of fine aggregate used throughout this investigation are shown in table (3)

Coarse Aggregate

Local natural Porcelinate stone was used as a coarse aggregate. It was a large white lump occurs in Wadi-Mallusa (Rutba) at Western Desert of AL –Anbar Governorate. The lumps were crushed manually to small pieces then screened on standard sieve series (12.5mm, 9.5 mm and 4.75mm). The maximum size of aggregate was 9.5mm. The aggregate prepared with grading that conforms ASTM C330-05 Specifications. The grading of porcelinate LWA is shown in table (4). The aggregate was washed with water in order to remove the dust associated with crushing process of porcelinate stone, then, it was spread inside the laboratory to have saturated surface dry condition.

Admixtures

Two types of concrete admixtures were used in this work:

1) Superplasticizer

A superplasticizer, commercially known as **GLENIUM 51**, [8] was used throughout this work as a high range water reducing agent (sulphonated melamine and naphthalene formaldehyde type F). The dosage recommended by the manufacturer was 0.5-1.6 liters/100kg of cementations material. This type of admixture conforms to the ASTM C494-05 type F. Table (5) shows the properties of the superplasticizer used.

2) Silica Fume

Silica fume used in this investigation is commercially known as **MEYCO** from the Chemical Company **BASF** [9]. The recommended dosage of silica fume is 5-15% as partial replacement of cement weight. The chemical composition and physical requirements show that the silica fume conforms to the chemical and physical requirements of ASTM C1240 Specifications. The chemical composition of silica fume is shown in table (6), while the typical properties, physical requirements and pozzolanic activity index are shown in tables (7) and (8) respectively.

Fibers

Three types of fibers were used in this work

a) Macro hooked steel fiber with 50 mm long and 0.5 mm diameter (aspect ratio, l/d = 100), with ultimate tensile strength for individual fibers of 1180 MPa. The density of the steel fibers is 7800kg/m^3 [10].

b) Polypropylene fiber (PP) with 12mm length and 18 micron diameter (aspect ratio l/d= 677) and minimum tensile strength of 350 MPa [11].

c) Carbon (5mm length and 7µm in diameter) with tensile strength 4300 N/mm^2 [12].

Figure (1) shows types of fibers used in this investigation.

Concrete Mixes

Three HSLWAC mixes were used to produce the paving bricks including:

- Plain HSLWAC mix without fiber (mix BP).
- Hybrid fiber reinforced HSLWAC mix containing the combination of macro steel fiber with volume fraction of 0.75%, and micro polypropylene (pp) fiber with volume fraction of 0.25% (mix BSPPF).
- Hybrid fiber reinforced HSLWAC mix containing the combination of macro steel fiber with volume fraction of 0.75%, and micro carbon fiber with volume fraction of 0.25% (mix BSCF).

Mixing and Casting

Special molds were manufactured to produce this type of bricks as shown in Figure (2). All the internal surfaces of these molds were lightly oiled to avoid the adhesion of hardened concrete with them. Mixing was performed using 0.1m^3 capacity mixer. Silica fume and cement were mixed in dry state for about three minutes to disperse the silica fume particles throughout the cement particles, and then the sand and aggregates were added and mixed for two minutes. Thirty percent of the mixing water was added to the HRWRA, the solution was well stirred before using and then added gradually to the dry constituents (cement, silica fume, sand, and aggregate). The whole constituents were mixed for further two minutes. For Fibers reinforced concrete mixes, the fibers were uniformly distributed into the mix in three minutes, and then the mixing process continued for additional two minutes. The mix was immediately poured into molds. The samples were compacted by table vibration in three layers. The top surface of the specimens were leveled and then covered with nylon sheets to prevent the loss of moisture.

Curing

After 24 hours from casting, the specimens were demoulded carefully and stored in water tanks until the time of testing.

Specimens

Paving brick specimens were prepared from the selected HSLWAC mixes with the dimensions shown in Figure (2). The numbers of specimens prepared from each mix were as follows:

1- Ten brick specimens for dimensional measurement and for compressive strength test.

2- Five brick specimens for water absorption test.

3- Five brick specimens for the abrasion resistance test with surface area 50 cm^2 and with the same thickness of the brick specimens.

Figure (3) shows the paving brick specimens prepared in this investigation.

Experimental Tests

A number of experimental tests were carried out to study some properties of concrete paving bricks. These tests are as follows:

- Appearance test, compressive strength and absorption test according to Iraq Specification No. 1606, 2009[13] and the Guidance Document No. 969, 2001 [14].
- Abrasion resistant test, which was carried out according to EN 1342-2000 [15] and EN 1339-2003 [16] using wearing machine, as shown in figure (4).

RESULTS AND DISCUSSIONS

Compressive Strength of Concrete Paving Bricks

High strength lightweight aggregate concrete mixes prepared in previous research [17] including, plain mix [without fiber (BP)], concrete mix reinforced with hybrid fiber [a combination of 0.75% steel fiber and 0.25% polypropylene fiber (BSPPF)], and concrete mix reinforced with a combination of 0.75% steel fiber and 0.25% carbon fiber (BSCF), as well as the properties (Compressive strength, oven dry density, splitting tensile strength, and modulus of rupture) of these mixes are shown in table (9). Iraqi Specification No.1606-2009 for concrete paving bricks classified the concrete paving brick according to its strength and absorption into three categories, high loading type, medium loading type, and light loading type, as shown in table (10).

The results of the compressive strength at 28 days for different concrete paving bricks prepared in this investigation are shown in table (11) and figure (5). The results show that the compressive strength of concrete paving bricks for different types range from 40.32-48.76 MPa, and the highest compressive strength was recorded for specimens reinforced with 0.75% volume fraction of steel fiber and 0.25% volume fraction of carbon fiber. This is because, in comparison with longer and higher specific gravity fibers, shorter and lower specific gravity are more efficient in delaying cracks owing to the high specific contact surface of non metallic fibers [18].

Water Absorption of Concrete Paving Bricks

Absorption is the process by which a liquid is drawn into and tends to fill permeable voids in a porous solid body. In other words, absorption is the increase in mass of a porous solid body resulting from the penetration of a liquid into its permeable voids [19]. The rate of water absorption by capillary suction is a good measure of the quality of a concrete and its potential durability when exposed to aggressive environments. Low values of absorption indicate that aggressive ions will have difficulty in penetrating the concrete [20]. The Iraqi Specification No. 1606 -2009 specified the percentage of absorption for concrete paving bricks according to the degree of loading, as shown in table (10). The water absorption results for concrete paving bricks are shown in table (11) and figure (6). The results show that the absorption of concrete pavement brick products ranged from 4.0-6.5%, which it is less than 10% and indicate that it is a good quality concrete.

Abrasion Resistance of Concrete Paving Bricks

The abrasion resistance of concrete is defined as the ability of a surface to resist being worn away by rubbing and friction. Abrasion of floors and pavements can result from production operations, foot or vehicular traffic. Therefore, abrasion resistance is of concern in industrial floors. The compressive strength is proportional to the abrasion resistance of concrete. Because abrasion occurs at the surface, it is critical that the surface strength be maximized. Resistance can be increased by the use of shakes and toppings, finishing techniques, and curing procedures [21].

The results in table (11) and figure (7) indicate that the abrasion resistance results from the produced paving bricks ranged from 23.25-24.50 mm. These results are within the limits which is less than 26 mm according to Iraqi Specifications No.1606. The results also show that concrete paving bricks, reinforced with hybrid fiber, have good abrasion resistance in comparison with paving bricks without fibers.

Appearance Test (Difference in Dimensions) of Concrete Paving Bricks

The results listed in table (11) show that the differences in dimensions are within the limits of Iraqi Specification No. 1606-2009. From the results of all tests for concrete paving bricks, it can be concluded that all the specimens of concrete paving bricks produced in this investigation can be classified as medium loading type which can be used for paving roads and service areas

CONECLUSIONS

1. High strength LWAC paving bricks can be produced with compressive strength in the range of 40.23-48.76 MPa.
2. The water absorption of the produced HSLWAC paving bricks is in the range of 4%-6.5%.
3. The abrasion resistance of the produced HSLWAC paving bricks is in the range of 23.25-24.5 mm, which is within the limits of Specifications (not more than 26mm).
4. The produced concrete paving bricks can be classified as medium loading type according to Iraqi Specification No. 1606-2009. This type is used for paving low loaded roads and service areas.

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Table (1): Chemical composition and main compounds of the cement used throughout this investigation *.

Oxide Composition	Abbreviation	% By weight	Limits of I.Q.S No.5 1984
Lime	CaO	61.90	……
Silica Dioxide	SiO_2	21.77	…….
Alumina Trioxide	AL_2O_3	4.76	…….
Iron Oxide	Fe_2O_3	3.33	…….
Sulphate	SO_3	2.5	≤ 2.8%
Magnesia Oxide	MgO	3.91	≤ 5%
Loss on Ignition	L.O.I	2.24	≤ 4%
Lime Saturation factor	L.S.F	0.78	0.66- 1.02
Insoluble Residue	I.R	0.88	≤ 1.5
Main Compounds (Bouge′s equation)			
Tricalcium silicate	C_3S	43.9	……
Dicalcium silicate	C_2S	29.43	……
Tricalcium aluminate	C_3A	6.59	……
Tetacalcium alumno-Ferrite	C_4AF	10.19	…….

*Tests were carried out in the Central Organization for Standardization and Quality Control.

Table (2): Physical properties of ordinary Portland cement*.

Physical properties	Test Result	Limits of I.Q.S No.5
Specific surface area, Blain method m^2/kg	**390**	**> 230**
Setting time ,vicat's method)		
-Initial setting (hrs: min)	**2:10**	**≥ 45 min**
-Final setting (hrs: min)	**4:30**	**≤ 10 hrs**
Compressive Strength of Mortar		
(MPa)	**18.23**	**≥ 15**
-3days	**27.03**	**≥ 23**
-7days		
Soundness (Autoclave) %	**0.01**	**≤ 0.8**

*Tests were carried out in the Central Organization for Standardization and Quality Control.

Table (3): Grading and physical properties of fine aggregate*.

Sieve Size (mm)	Cumulative Passing (%)	Limits of Iraqi Specification No.45/1984/ Zone 2
4.75	100	90-100
2.36	90.15	75-100
1.18	74.20	55-90
0.60	52.10	35-59
0.30	18.33	8-30
0.15	3.90	0-10
Sulphate content = 0.40% Fine material passing from sieve (75 µm) = 4.2% Specific gravity = 2.65 Fineness modulus = 2.61 Absorption = 1.75%		max.= 0.5% max. = 5.0%

*Tests were carried out in the Central Organization for Standardization And Quality Control.

Table (4): Grading of coarse porcelinate.

Sieve size (mm)	Cumulative passing (%)	Cumulative passing (%) ASTM C 330
12.5	100	100
9.5	97.22	80-100
4.75	24.95	5-40

Table (5): Technical Description of Superplasticizer Used in this Investigation *.

Form	Viscous liquid
Color	Light brown
Relative density	1.1 @ 20°C
PH	6.6
Viscosity	128+/ -30cps @ 20°C
Transport	Not classified as dangerous
Labeling	No hazard label required

*According to manufacturer (The Chemical Company BASF).

Table (6): Chemical Composition for Silica Fume *.

Oxides	Content %	ASTM C-1240-05 Limitation
SiO_2	90.2	≥85
AL_2O_3	0.24	---------
Fe_2O_3	2.4	----------
Na_2O_3	0.16	----------
CaO	0.65	----------
MgO	0.41	----------
TiO_2	0.02	----------
K_2O	1.26	----------
P_2O_5	0.1	---------
SO_3	0.4	≤4
L.O.I	3.33	≤6

*Test was carried out by the National Center for Geological Survey and Mines.

Table (7): Typical Properties of Silica Fume*.

Form	Powder
Color	Grey
Bulk density	550-700 kg/m^3
Chloride content	< 0.1%

*According to manufacturer (BASF The Chemical Company).

Table (8): Physical Requirements and Pozzolanic Activity Index for Silica Fume (SF) used in this Investigation *.

Physical properties	SF	ASTM C-1240-05 Limitations
Specific surface area, min, (m^2/g)	21	≥ 15
Strength activity Index with Portland cement at 7days, min. percent of control	123	≥ 105
Percent retained on 45μm (No.325), max, %	8.5	≤ 10

*According to manufacturer (BASF The Chemical Company).

Table (9): Some properties of HSLWAC mixes [21].

Mix Symbol	Type of Fiber	Compressive Strength at 28 day age (MPa)	Oven dry Density at 28 day age (kg/m^3)	Splitting Tensile Strength at 28 day age (MPa)	Modulus of Rupture at 28 day age (MPa)
BP	0	41.30	1930	0.90	3.84
BSPPF	0.75%S1 + 0.25%PP	43.00	1998	4.30	4.86
BSCF	0.75%S1 + 0.25%CF	45.60	2009	4.80	6.32

Table (10):The classification of concrete pavement brick.

The Type of Brick	**Minimum Compressive Strength (MPa)**		**Maximum Percentage Absorption (%)**	
	For the mean	**For one brick**	**For the mean**	**For one brick**
High loading type	**55**	**50**	**6**	**8**
Medium loading type	**35**	**30**	**7**	**9**
Light loading type	**30**	**25**	**10**	**12**

Table (11):Properties of concrete pavement bricks.

Mix symbol	**Type of Fibers**	**Compressive Strength (MPa)**	**Absorption (%)**	**Abrasion Resistance (mm)**	**Difference in Thickness (mm)**	**Difference in Length & Width (mm)**
BP	**0**	**40.32**	**4.0**	**24.50**	**2.00**	**-1.20**
BSPPF	**0.75%S1 + 0.25%PP**	**47.12**	**6.5**	**23.25**	**-1.25**	**1.50**
BSCF	**0.75%S1 + 0.25%CF**	**48.76**	**6.0**	**24.00**	**1.25**	**1.25**

Figure (1) Types of fibers used in this work.

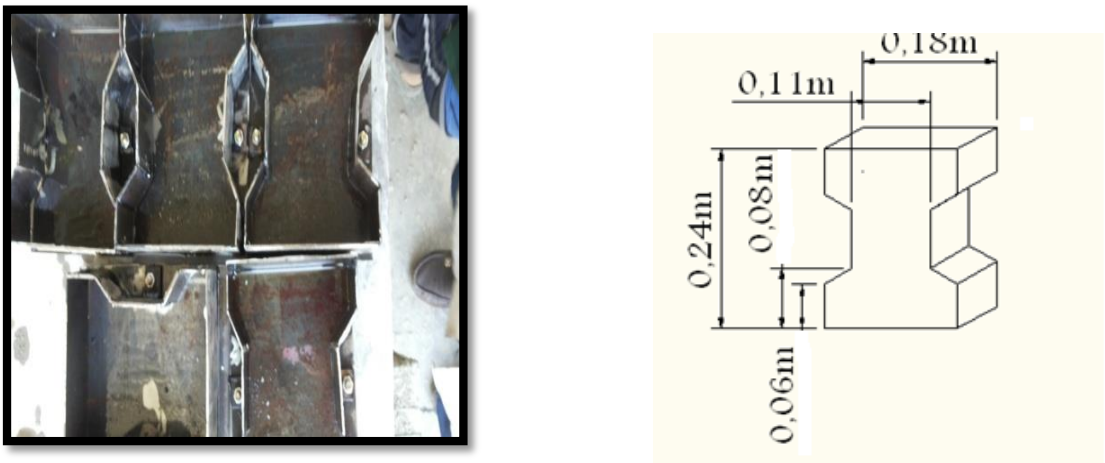

Figure (2) Molds and dimensions of concrete paving bricks.

Figure (3) Concrete paving bricks specimens prepared in this investigation.

Figure (4) Abrasion resistance test for for concrete paving bricks.

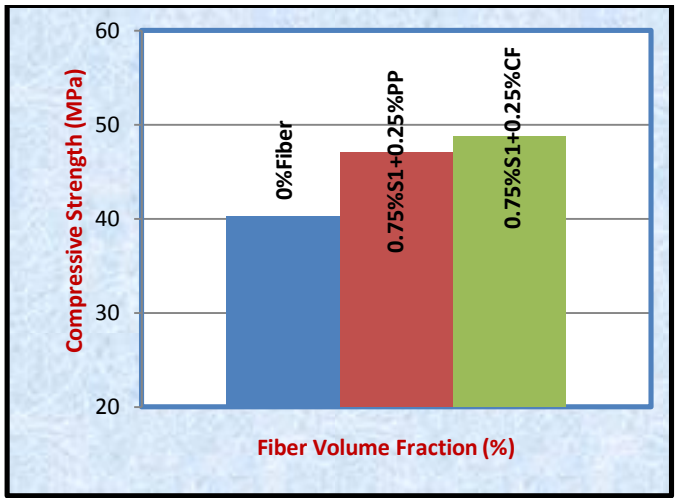

Figure (5) The Compressive strength of concrete paving bricks.

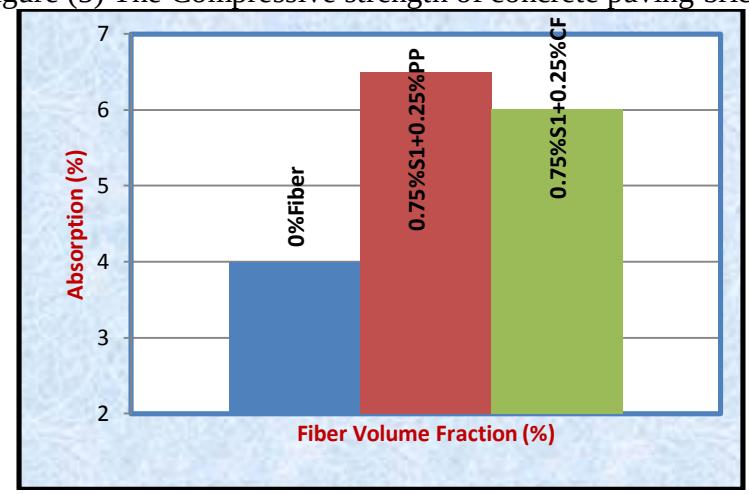

Figure (6) Absorption values of concrete paving bricks.

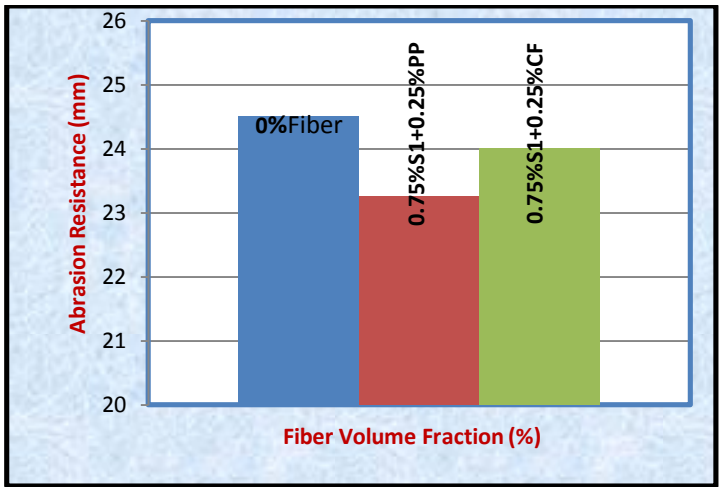

Figure (7) The Abrasion resistance of concrete paving bricks.

خواص طابوق الرصف من خرسانة الركام خفيف الوزن عالية الاداء

أ. د. وسن اسماعيل خليل **المهندسة سهاد عبد الجبار موزان**

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الخلاصة

يهدف هذا البحث دراسة خواص طابوق الرصف الخرساني المنتج من خرسانة عالية المقاومة ذات ركام خفيف الوزن وبنسبة خلط وزنية :0.87:1.35:1 (سمنت: رمل :ركام) بمحتوى سمنت 520 كغم/م^3 سمنت. تم استخدام البورسيلنايت المحلي كركام خشن وبمقاس اقصى 9.5 مم ، 5% ابخرة السليكا المكثفة كأستبدال جزئي من وزن الأسمنت ، 1% من وزن الاسمنت ملدن متفوق و 0.29 نسبة الماء/ الاسمنت . الالياف المستخدمة تضمنت الياف فولاذية طويلة معقوفة النهايات وبنسبة باعية 100، ألياف البولي بروبلين الدقيقة والياف الكاربون الدقيقة . تم انتاج هذا الطابوق من ثلاث خلطات خرسانية عالية المقاومة خفيفة الوزن شملت خلطة خرسانية بدون الياف (الخلطة المرجعية) ، خلطة خرسانية حاوية على 0.75% الياف فولاذية +0.25% الياف البولي بروبلين ، خلطة خرسانية حاوية على 0.75% الياف فولاذية + 0.25% الياف الكاربون . تم اجراء فحوصات مختبرية لطابوق الرصف الخرساني المنتج تضمنت فحص مقاومة الانضغاط ، فحص الامتصاص ، فحص مقاومة البري ،وفحص المظهر.

أظهرت النتائج ان الطابوق المنتج يصنف وحسب المواصفة العراقية 1606 كطابوق رصف خرساني من النوع متوسط التحميل والذي يستخدم لرصف الطرق والمناطق الخدمية.

الكلمات الدالة: الخرسانة خفيفة الوزن, الهجينة, الالياف, الماكرو, المايكرو, الالياف الفولاذية, الياف الكاربون, الياف البولي بروبلين, طابوق الرصف.