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PROPERTIES OF SUSTAINABLE HIGH PERFORMANCE LIGHTWEIGHT AGGREGATE CONCRETE REINFORCED WITH FIBERS

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ABSTRACT: - In this investigation, sustainable High Performance Lightweight Aggregate Concrete (HPLWAC) containing recycled crushed clay brick from construction and demolition waste as coarse lightweight aggregate (LWA) and reinforced with mono fiber, double and triple hybrid fibers in different types and aspect ratios were produced. High Performance crushed brick lightweight aggregate concrete mix with compressive strength of 41.2MPa, oven dry density of 1930 kg/m^3 at 28 days were prepared. The Fibers used including, macro hooked steel fiber with aspect ratio 60 (type S_1), macro crimped plastic fiber (P) with aspect ratio 63, micro steel fiber with aspect ratio 65 (type S), and micro polypropylene fiber (PP) with aspect ratio 667. Six HPLWAC mixes were prepared including, one plain concrete mix (without fiber), two mono fiber reinforced concrete mixes (reinforced with either steel fiber type S or plastic fiber with 0.75% volume fraction), two double hybrid fiber reinforced concrete mixes (0.5% steel fiber type S +0.25% polypropylene fiber and 0.5% plastic fiber + 0.25% steel fiber type S), and one mix with triple hybrid fiber (0.25% steel fiber type S_1+0.25% polypropylene fiber +0.25% steel fiber type S). Fresh (workability and fresh density) and hardened concrete properties (oven dry density, compressive strength, splitting tensile strength, flexural strength and absorption) were studied. In general mono and hybrid (double and triple) fiber reinforced HPLWAC specimens give significant increases in splitting tensile strength and flexural strength compared with plain HPLWAC specimens. The percentages increase in splitting tensile strength for specimens with mono steel fiber are 55.8%, 65.9%, 82% and 91.9%, while for specimens with mono plastic fiber the percentages increase are 34%, 45.5%, 61.5% and 71.2% at 7, 28, 60, 90 days age respectively relative to the plain concrete. The maximum splitting tensile and flexure strengths were recorded for triple hybrid fiber reinforced HPLWAC specimens. The percentages increase in splitting tensile strength for triple hybrid fiber reinforced specimens are 57.2%, 68.6%, 87.5% and 101.8%, while the percentages increase in flexure strength are 48%, 59.6%, 66.9% and 70.7% at 7, 28, 60 and 90 days age respectively relative to the plain concrete specimens.

Keywords: Sustainable lightweight aggregate, Mono Fiber, Hybrid Fiber, Crushed brick

INTRODUCTION

High performance structural lightweight concrete (HPLWC) is a new advance in concrete technology which has the properties of HPC and LWC such as high strength, low permeability, low density and high thermal insulation properties which are appropriate for many applications. High strength lightweight concrete typically has a compressive strength from 34 - 69 MPa and an air dry density not exceeding 2000 kg/m^3 [1, 2].

Lightweight Concrete (LWC) is one of the most significant topics for researchers due to its many advantages. Lightweight Aggregate (LWA) used in concrete reduces the weight of different structural members which leads to a decrease in the load transmitted to the foundations, and less work and efforts are required to transport these members. The occurrence of voids and pores in LWA provides good thermal and acoustic insulating properties and a good fire resistance to concrete [(3)]. So, structural lightweight concrete (SLWC) offers advantages of higher strength / weight ratio, higher tensile strain capacity, lower coefficient of thermal expansions and heat/sound insulation characteristics in comparison with normal strength concrete [(4)]. Fibers provide a mechanism that reduces unstable crack propagation; effective crack bridging is provided while imparting strength, toughness and resistance to shrinkage cracking [(5)]. Generally the inclusion of single (mono) typed fibers into concrete has limited functions. Combination of two or more different types of fibers (different fiber types and geometries) becoming more common in NWC. The performance of these hybrid systems would exceed that caused by each single fiber type. There will be a synergy between the fibers.

The sustainable construction concept was introduced due to the growing concern about the future of our planet because construction industry is a great consumer of natural resources and, at the same time, waste producer [(6, 7)]. Consequently, alternative materials like construction or demolition waste as well as other industries by-products are increasingly being tested and used as environmental sustainable natural aggregates substitutes in concrete [(8)]. Large quantities of brick waste are produced simultaneously as construction and demolition waste and by the construction industry [(9)]. Local natural LWA in Iraq is very limited, such as porcelinte aggregate. The use of natural coarse LWA leads to the consumption of natural lightweight aggregate. Thus it is important to use another types of LWA in concrete, such as crushed clay brick from construction and demolition waste. The use of crushed clay brick from construction and demolition waste causes reduction in environmental pollution and reduces the total cost of buildings thus developed the structural application of sustainable LWAC in Iraq.

Several investigations have been carried out to study the influence of, mono steel fiber, polypropylene, and plastic fiber on properties of artificial lightweight aggregate concrete [(10, 11)]. Very little work was carried out on properties of concrete containing crushed clay brick as coarse LWA and reinforced with mono fibers. Zinkaah [(12)] investigated the influence of straight steel fibers with volume fraction of 0.25%, 0.5%, 0.75% and 1%, 15mm length, and aspect ratio of 75 on the properties of normal strength lightweight concrete containing crushed clay brick as coarse lightweight aggregate. The reference lightweight concrete (without fiber) has equilibrium density of 1842 kg/m^3 and compressive strength at 28 days of 29.77 MPa. The results indicated that, the compressive strength of LWC reinforced with steel fiber up to 0.75% volume fraction increases compared with the reference concrete. The percentage increase in splitting tensile strength, flexural strength and static modules of elasticity with the addition of steel fiber was in range of 5.93% - 62.62 %, 20.91% -54.24% and 4% -12% respectively.

There are limited investigations on properties of LWAC reinforced with hybrid fibers [(13, 14)]. No detailed work was carried out to investigate the properties of high performance LWAC with recycled crushed clay brick as coarse LWA and reinforced with hybrid fibers.

EXPERIMENTAL PROGRAM

Materials

Cement

Ordinary Portland cement (Type I) from Bazian Company in Iraq was used. Test results show that the adopted cement satisfies to the Iraqi Specifications No. 5/1984[(15)].

Fine Aggregate

Normal weight natural sand with maximum size of 4.75 mm was used in this investigation. It was brought from AL-Ukaider region and its gradation is in zone (2). The results demonstrate that the grading of the sand, physical properties and sulfate content are within the requirements of the Iraqi Specifications No. 45/1984[16].

Coarse Crushed Brick Lightweight Aggregate

The clay bricks were brought from demolition of buildings from expansion and development work around AL-Kadhimain shrine. The recycled crushed clay brick was used as a sustainable lightweight aggregate. The large pieces were cleaned from the mortar and dust then crushed to small sizes manually by a hammer in order to facilitate the insert of broken clay brick through the feed hole of the crusher machine. The Jaw crusher has been prepared to give crushed clay brick with maximum aggregate size of 12.5 mm. The crushed clay brick was screened on standard sieves complying with ASTM C 136 -01[17] Specification. An electrical sieve shaker performed the screening for about 5 minutes. The grading of coarse crushed clay brick aggregate is conforms to ASTM C330-03[18] Specification. The required quantity of the crushed clay brick LWA for each concrete batch was washed with water in order to remove the dust produced from the crushing process. Then, the crushed clay bricks were submerged in water for about 24 hours, and then spread in the laboratory to be in saturated surface dry condition, as recommended by ACI committee 211-2[19].

The physical and chemical properties of the crushed clay brick aggregate were determined. Table (1) lists these properties and their corresponding adequate Specifications.

Admixtures

Two types of concrete admixtures were use in this investigation:

High Range Water Reducing Admixture (HRWRA)

Chemical admixture based on modified Polycarboxylic ether (Sika-Viscocrete-5930) was used. It is a third generation superplasticizer meets the requirements of ASTM C494M/04[20] types F.

Silica Fume

Silica fume used in this investigation is produced by Sika Company. The results indicate that the silica fume used satisfy the physical and chemical requirements of the ASTM C1240[21].

Fibers

Four types of fiber were used in this work including:

a- Macro hooked steel fibers (type S_1) with 30 mm length and 0.5 mm diameter (aspect ratio l/d = 60), the ultimate tensile strength for individual fibers of 1180 MPa and density of 7800kg/m^3.

b- Straight steel fibers (type S) with 13 mm in length and 0.2 mm in diameter (aspect ratio l/d = 60), the ultimate tensile strength for individual fibers is 1180 MPa and the density is 7800kg/m^3.

c- Crimped plastic fiber (P) with 50 mm length, 0.8 mm diameter, and aspect ratio l/d = 63, and minimum tensile strength between 250- 350 MPa.

d- Micro polypropylene fiber (PP) with 12mm length, 18 micron diameter (aspect ratio l/d= 677), and minimum tensile strength of 350 MPa.

Mixing of Concrete

Mixing procedure of concrete is significant to obtain the required workability and homogeneous mixes. Mixing was performed in rotary mixer with capacity of 0.1 m^3. The specified amount of micro silica fume was mixed with a desired quantity of cement for 10 minutes in the mixer. The coarse lightweight aggregate was used in a saturated surface dry state. The designated weight of cementation materials, fine and coarse aggregate were then placed in mixing pan and mixed for three minutes. About seventy percent of the required amount of mixing water was added to the dry mixture and mixed for one minute, while thirty percent of the mixing water was added to the HRWRA. The solution was well stirred and then added to the mixture gradually; all constituents were mixed for further two minutes. Finally, specific amount of fiber were added to the fresh concrete slowly with small portions and mixed for two minutes in order to prevent the collection which lead to balling of fiber.

Concrete Mixes

Plain LWAC mix and several LWAC mixes reinforced with mono and hybrid fiber were prepared in this investigation. Table (2) demonstrates the details of concrete mixes studied in this investigation.

Preparation, Casting and Curing of Specimens

After conducting workability test (slump and inverted slump cone tests), the concrete specimens were prepared by casting the concrete in different standard molds (150 × 300 mm and 100 × 200 mm cylindrical molds, 100 mm cube molds, and 100 × 100 × 400 mm prism molds). The molds were well cleaned and oiled before casting of concrete to avoid the adhesion of hardened concrete to the internal surfaces of the molds. The fresh concrete was placed in the molds with layers according to the standard specifications for each test and compaction by means of vibration table. The top layers of concrete specimens had been smoothed by steel trowel, and then the specimens were covered with nylon sheets for 24 hours to prevent the evaporation of water. After that the concrete specimens were demoulded and fully immersed in tap water until the time of testing.

EXPERIMENTAL TESTS

The following experimental tests were carried out to investigate the effect of sustainable aggregate on some properties of HPLWAC reinforced with fiber:

- Slump test according of ASTM C-143[22].
- Fresh density test according ASTM C 567-05a [23].
- Inverted slump cone test according to ASTM C995-01[24].
- Oven dry density test according to ASTM C 567-05a [23] (using150×300 mm cylindrical specimens).
- Compressive strength test according to B.S. 1881[25] (using 100 mm cube specimens).
- Splitting tensile strength test according to ASTM C496–04[26] (using 100×200 mm cylindrical specimens).
- Flexural tensile strength test according to ASTM C 78 [27] (using 100×100×400 mm prism specimens).
- Water absorption test according to ASTM C642 [28] (using 100mm cube specimens).

RESULTS AND DISCUSSION

Selection of Mix Proportions for High performance LWAC

Reference lightweight aggregate concrete mix was design in accordance with ACI 211.2 [19] without any admixtures with compressive strength of 20 MPa at age 28 days. The mix proportion of this mix is 1:1.37:0.73 (cement: sand: LWA) by weight, w/c ratio of 0.43 to have slump value of 100 ± 5mm, and cement content of 550 kg/m^3. Several trial mixes were achieved in order to select the optimum silica fume content and the optimum dosage of superplasticizer, while w/c ratio was modified to have the same slump value of the plain mix (without fiber). The results demonstrate that the optimum dosage of superplasticizer was 2.5 Liter per 100 kg of cement. The oven dry density and the compressive strength at 28 days age for the selected reference mix with crushed clay brick are 1912 kg/m^3 and 36.5 MPa respectively. The details of the trial concrete mixes with different dosages of superplasticizer are shown in Table (3). Different dosages of silica fume as partial replacement by weight of cement (5%, 8%, and 10 %) were used with the selected mix containing the optimum dosage of superplasticizer. Table (4) shows the effect of silica fume content on workability, compressive strength and density of LWAC mixes. It can be noticed that the workability of the concrete mix is slightly decreased with the increase of silica fume content. This is because of the high surface area of very fine particles of silica fume which leads to absorbed water. The compressive strength and oven dry density of the selected mix containing 10% silica fume as a replacement by weight of cement and 2.5 liter of superplasticizer /100 kg of cement are 41.2 N/mm^2 and 1930 kg/m^3 respectively at 28 days age.

Fresh Properties

Workability

The workability test results including slump test and inverted slump cone test are shown in Table (5). The slump test did not give accurate results for workability of fiber reinforced concrete mixes **[14]**; hence inverted slump cone test is recommended for this type of mixes. Generally, the results indicate that the inclusion of fibers reduces the workability of the plain HPLWAC. This is due to the large surface area of fibers that increases the viscosity of the mixtures **[29]**. All HPLWAC mixes reinforced with fibers were produced without any fibers balling. Despite of the reduction in workability, visible inspections detects that the addition of fibers to HPLWAC enhances the uniformity and stability for fresh mixes. This is because of that fibers can make network structure in fresh concrete that can effectively restrain the segregation of LWA; this was also indicated **by Libre et al. [30].**

Fresh Density

The fresh densities of HPLWAC are listed in Table (5). Results show that plastic fiber reduces the fresh density of HPLWAC, while steel fibers increases the density of the HPLWAC containing crushed clay brick compared with the corresponding plain concrete. This is because of the low specific gravity of plastic fiber and the high specific gravity of steel fiber. The fresh density of hybrid fiber reinforced HPLWAC mixes is higher than those reinforced with plastic fiber but lower than concrete mixes reinforced with steel fiber.

Oven Dry Density

The oven dry and equilibrium densities of HPLWAC mixes prepared in this investigation are listed in Table (5). It can be noticed that the addition of steel fiber to LWAC increases its density; because of the high specific gravity of this fiber, while the addition of plastic fiber reduces its density compared with the plain mix. Therefore in SLWAC instead of using only mono steel fibers it is suggested to use a combination of low volume fraction of steel fiber with synthetic or non-metallic fiber (hybrid fiber) to have the same total volume fraction of mono steel fiber in concrete mixtures **[31]**. The results of HPLWAC mixes containing crushed clay brick aggregate and reinforced with double hybrid fiber (mix MBH_1 and mix MBH_2) and triple hybrid fiber (mix MBH_3) show densities less than that containing mono steel fibers (MBS_1) with the same total fiber volume fraction.

Compressive strength

The compressive strength development with age for all HPLWAC mixes is presented in Table (6). Generally, the compressive strength increases with age for all concrete specimens. It can be noticed that the inclusion of mono steel fiber in HPLWAC containing crushed clay brick slightly increases the compressive strength at 7, 28, 60 and 90 days age. The percentages increase were about 2.5%, 5.78%, 6.35% and 6.9% respectively compared with the plain concrete (without fiber). This is due to the capability of steel fiber to delay and limit the propagation of the micro cracks **[32]**. These results are agreed with the pervious findings, by Zinkaah [12] and Hassanpaur et al. [32]. Plastic fiber causes reduction in concrete compressive strength of about 10%, 8.3%, 4.2% and 5.3% of age 7, 28, 60 and 90 days respectively compared with the reference specimens. This may be attributed to the high air content and large volume of voids presence in these mixes which reduce the compressive strength. The same results were reported by Abdul Fatah [33]. Concrete mixes reinforced with hybrid fibers (mix MBH_1, MBH_2 and MBH_3) show lower compressive strength than that reinforced with mono steel fiber (MBS_1), while these compressive strengths are higher than that for concrete mix reinforced with mono plastic fiber (MBP). The highest compressive strength is obtained for LWAC mix reinforced with mono steel fiber type S_1 (MBS_1).

Splitting Tensile Strength

The results of splitting tensile strength for all HPLWAC mixes were demonstrated in Table (7). It can be noticed that the inclusion of fibers in HPLWAC significantly improves the splitting tensile strength for both mono and hybrid fiber mixes compared with the plain mix (without fiber). The percentages increase in splitting tensile strength for HPLWAC containing crushed clay brick and reinforced with mono steel fiber are 55.8%, 65.9%, 82% and 91.9, while the percentages increase for specimens reinforced with mono plastic fiber are 34%, 45.5%, 61.5% and 71.22 at 7, 28, 60 and 90 days age respectively compared with the plain specimens. This is due to the ability of fiber in arresting cracks propagation [34] and the high tensile strength of steel fiber compared with plastic fiber. Plain HPLWAC specimens failed suddenly once the concrete cracked, while fiber reinforced concrete specimens were still intact together. All Double hybrid fiber specimens reinforced (MBH1 and MBH2) shows lower splitting tensile strength, while the triple hybrid fiber reinforced specimens with a combination of 0.25% steel fiber type S1+0.25% steel fiber type S + 0.25% PP (MBH_3) shows higher splitting tensile strength at all ages in comparison with concrete specimens reinforced with mono steel fiber type S_1 (MBS_1). The decrease in splitting tensile strength for the double hybrid fiber mix is attributed to the low tensile strength of polypropylene and plastic fibers compared with steel fiber. The improvement in splitting tensile strength for triple fiber reinforced concrete mix (MBH_3) is attributed to the synergy phenomenon of hybrid fibers. Short fibers can bridge micro-cracks more efficiently, because they are very thin. Considering that micro-crack forms and crack bridging by fibers, occur in the first stages of tensile loading, the short fibers can have a considerable effect to increase the tensile strength. As the micro-cracks grow and join into larger macro-cracks, the long fibers become more and more effective in crack bridging [35]. Similar findings were obtained by Daneti and Wee [36]. All hybrid fiber reinforced HPLWAC (MBH_1, MBH_2 and MBH_3) show higher splitting tensile strength than that for concrete specimens reinforced with mono plastic fiber (MBP). This is attributed to the high tensile strength of steel fiber relative to plastic fiber. The maximum splitting tensile strength is recorded for concrete mix reinforced with triple hybrid fiber (MBH_3). The percentages increase in splitting tensile strength for this mix are 57.2%, 68.6%, 87.5% and 101.8% at 7, 28, 60 and 90 days age respectively relative to the plain concrete mix.

Flexural Tensile Strength (Modulus of Rupture)

The influence of fiber on flexural strength is illustrated in Table (8). The results show that the addition of fibers to HPLWAC increases the flexural strength for both mono and hybrid (double and triple) fiber reinforced concrete specimens relative to plain concrete specimens. The percentages increase in flexural strength for HPLWAC with crushed brick aggregate reinforced with mono steel fiber (MBS_1) are 43.09%, 55.32%, 62.63% and 68.35%, while the percentages increase for concrete mix reinforced with mono plastic fiber (MBP) are 22.82%, 29.15%, 34.34% and 36.5% at 7, 28, 60 and 90 days age respectively compared with the plain concrete. This behavior is due to the increase in crack strength of the composite and the ability of fiber to resist forces after; the concrete matrix has been cracked [37]. The results also show that the percentages increase in flexural strength for concrete mix reinforced with mono plastic fiber are lower than that reinforced with mono steel fiber HPLWAC. This is because of the high tensile strength of steel fiber with the higher bonding strength between steel fibers and cement matrix [38]. The comparison between flexural values for HPLWAC mix reinforced with mono steel fiber (MBS_1) and double hybrid fiber mix (MBH_1) with a combination of steel fiber typeS_1 (0.5%) and polypropylene fiber (0.25%), shows that the flexural strength of the double hybrid fiber reinforced concrete mix is slightly decreased by about 7%, 9.3%, 8.3% and 10.7% at ages 7, 28, 60 and 90 days respectively. This can be attributed to the less tensile strength of polypropylene fibers and the weak bond between polypropylene fibers and cement matrix [30]. Double hybrid fiber reinforce concrete mix (MBH_2) with a combination of plastic fiber (0.5%) and steel fiber type S (0.25%) shows that the flexural strength is higher than that reinforced with mono plastic fiber (MBP). It can be attributed to the high tensile strength of steel fiber in double hybrid fiber reinforced mix relative to tensile strength of plastic fiber in mono plastic fiber reinforced mix. Triple hybrid fiber reinforced concrete mix (MBH_3) shows the highest value of flexural strength. This is because blending of different fibers together in a matrix play a role at two different levels, material and structural, according to the, length, type and diameters of fibers [39].

Water Absorption

The results of water absorption for HPLWAC specimens are shown in Table (9). The water absorption of all HPLWAC specimens is below 10 percent by weight. This conforms to the good quality of HPLWAC prepared in this investigation and satisfies the requirements of ASTM C208 [40]. The results indicate that HPLWAC with crushed clay brick LWA reinforced with mono (steel or plastic) and hybrid (double and triple) fibers have lower water absorption compared with plain concrete. This is attributed to fibers role by effectively increasing crack resistance that reduces the permeability of concrete.

CONCLUSIONS

From the experimental results presented in this investigation, the following conclusions can be drawn:

1. High performance sustainable lightweight aggregate concrete containing recycle crushed clay brick with 41.2 MPa compressive strength, oven dry density of 1930 kg/m^3, and equilibrium density of 1980 kg/m^3 at 28 days age can be produced.
2. The addition of mono steel fiber to HPLWAC increases the oven dry density, while mono plastic fiber causes a decrease in oven dry density. Double hybrid fiber HPLWAC mixes with a combination of (0.5% steel fiber type S_1+0.25% polypropylene fiber) or (0.5%, plastic fiber + 0.25% steel fiber type S) and triples hybrid fiber with (0.25% (steel fiber type S1+polyproplen fiber +steel fiber type S)), show densities less than that for mono steel fiber with 0.75% volume fraction.
3. The compressive strength slightly increasers for HPLWAC reinforced with mono steel fiber, while concrete specimens containing mono plastic fiber show slight reduction in compressive strength of about 10% at 7, 28, 60 and 90 days age compared with the plain specimens. Hybrid double fiber reinforced HPLWAC specimens slight reduction while the hybrid triple fiber slightly increases in compressive strength than for concrete specimens without fiber.
4. The splitting tensile strength of HPLWAC reinforced with fibers significantly improves for mono and hybrid fiber relative to plain specimens (without fiber). The percentages increase for specimens reinforced with mono steel fiber are 55.8%, 65.9%, 82% and 91.9, while the percentages increase for specimens with mono plastic fiber are 34% ,45.5%, 61.5 and 71.2 at 7, 28, 60 and 90 days age respectively. Double hybrid fiber reinforced HPLWAC specimens show higher splitting tensile strength than that for concrete specimens reinforced with mono plastic fiber, but lower than specimens reinforced with mono steel fiber. The maximum splitting tensile strength was recorded for triple hybrid fiber concrete specimens.
5. The addition of fibers to HPLWAC specimens increases the flexural strength for mono and hybrid fiber reinforced specimens. The percentage increases for specimens with mono steel fiber are 43%, 55.3%, 62.6% and 68.3% , while concrete specimens reinforced with plastic fiber are 22.8%, 29.19%, 34.34% and 36.5% at 7, 28, 60 and 90 days age respectively relative to plain specimens. All hybrid fiber reinforced specimens show increases in flexural strength relative to concrete mix reinforced with plastic fiber. Triple hybrid fiber reinforced show the highest value of flexural strength.
6. The water absorption of all HPLWAC specimens reinforced with mono and hybrid fibers decreases compared with the plain specimens.

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Table (1): Properties of Coarse Crushed Brick Lightweight Aggregate

Properties	Specifications	Test Results
Specific gravity	ASTM C127-01	1.89
Absorption (%)	ASTM C127-01	19.1
Dry loose unit weight, kg/m^3	ASTM C330	636**
Dry rodded unit weight, kg/m^3	ASTM 29/C29M/97	729
Aggregate crushing value (%)	BS 812-part 110-1990	65.6
Sulfate content (as SO_3), (%)	BS 3797-part 2-1981	0.89***
Staining Materials ****		
Stain intensity	ASTM 641-98	No stain
Stain index		0

* Physical analysis was conducted by National Center for Construction Laboratories and Researches (NCCLR).

* * Within the limit of ASTM C330 ≤ 880 kg/m^3.

*** Within the limit of BS 3797 part 2 ≤1.0%.

**** Staining material test was done in National Center for Construction Laboratories and Researches (NCCLR).

Table (2): Details of Lightweight Aggregate Concrete Mixes

Symbol of Mix	Fiber Volume (%)				
	S_1	P	S	PP	Mix proportion 1:1.37:0.73 by weight (Cement: Sand :LWA), Cement content 550 kg/m^3 w/c =0.26, HRWRA= 2.5 L/ 100kg of cement silica fume 10% as a replacement by weight of cement
MBR	0	0	0	0	
MBS_1	0.75	0	0	0	
MBP	0	0.75	0	0	
MBH_1	0.50	0	0	0.25	
MBH_2	0	0.5	0.25	0	
MBH_3	0.25	0	0.25	0.25	

Table (3): Details of the Trial Mixes with Different Dosages of HRWRA

Mix Proportions By Weight	w/c Ratio	HRWRA (L/100kg of cement)	Slump (mm)	Oven Dry Density (kg/m^3)	Compressive Strength (MPa)	
					7 Days	28 Days
1:1.37:0.73 Cement: Sand: LWA With cement content of 550 kg/m^3	0.43	0	100	1870	15.2	20.3
	0.40	1.0	105	1887	21	27.5
	0.35	1.5	102	1897	23.5	29.3
	0.30	2.0	100	1903	24	32.4
	0.26	2.5	100	1912	27.8	36.5
	0.25	3.0	110	1927	26.3	35.2

Table (4): Details of Trial Mixes with Various Dosages of Silica Fume as a Replacement by Weight of Cement

Mix Proportions By Weight	HRWRA (L/100kg of cement)	Silica Fume (% by Weight of Cement)	w/c Ratio	Slump (mm)	Oven Dry Density (kg/m^3)	Compressive Strength (MPa)	
						7 Days	28 Days
1:1.37:0.73 Cement: Sand: LWA With cement content of 550 kg/m^3	2.5	0	0.26	100	1912	27.8	36.5
	2.5	5	0.26	99	1915	28.6	36.8
	2.5	8	0.26	98	1924	29.8	38.7
	2.5	10	0.26	97	1930	31.7	41.2

Table (5): Workability and Density for HPLWAC Mixes

Mix Symbol	Slump Cone (mm)	Inverted Slump Cone		Fresh Density (kg/m^3)	Oven Dry Density (kg/m^3)	Equilibrium Density (kg/m^3) **
		Sec.	cm*			
MBR	97	30	--	2018	1930	1980
MBS_1	70	120	6	2030	1940	1990
MBP	80	110	---	1995	1922	1972
MBH_1	75	120	5	2023	1934	1984
MBH_2	75	120	2	2005	1925	1975
MBH_3	60	120	7	2027	1938	1988

* The distance from top of concrete level to the top of cone is recorded when the elapsed time is more than 120sec.

** Equilibrium density is equal to oven dry density pulse 50 kg/m^3 according to ASTM C567-05a.

Table (6) Compressive Strength for HPLWAC Mixes

Mix Symbol	Compressive Strength (MPa)			
	7 Days	28 Days	60 Days	90 Days
MBR	31.7	41.2	42.5	43.8
MBS_1	32.5	42.1	45.2	46.5
MBP	28.5	37.8	40.7	41.5
MBH_1	31.0	40.5	43.8	44.6
MBH_2	29.7	39.3	41.5	42.9
MBH_3	32.0	42.5	44.0	45.2

Table (7) Splitting Tensile Strength for HPLWAC Mixes

Mix Symbol	Splitting Tensile Strength (MPa)			
	7 Days	28 Days	60 Days	90 Days
MBR	2.15	2.58	2.65	2.71
MBS_1	3.35	4.28	4.85	5.20
MBP	2.88	3.75	4.28	4.64
MBH_1	3.23	4.20	4.65	5.08
MBH_2	3.05	3.96	4.47	4.73
MBH_3	3.38	4.35	4.97	5.47

Table (8): Flexural Strength for Different Fibrous HPLWAC

Mix Symbol	Flexural Strength (MPa)			
	7 Days	28 Days	60 Days	90 Days
MBR	3.90	4.70	4.95	5.15
MBS_1	5.58	7.30	8.05	8.67
MBP	4.79	6.07	6.65	7.03
MBH_1	5.19	6.68	7.43	7.83
MBH_2	4.96	6.30	6.80	7.18
MBH_3	5.77	7.50	8.26	8.79

Table (9) Water Absorption for HPLWAC Specimens

Mix Symbol	Water Absorption of 28 Days, %
MBR	7.35
MBS_1	6.12
MBP	6.95
MBH_1	6.75
MBH_2	6.62
MBH_3	6.05

خواص خرسانة الركام الخفيف الوزن عالية الاداء والمستدامة المسلحة بالالياف

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الخلاصة

يهدف هذا البحث الى انتاج خرسانة الركام خفيف الوزن عالية الاداء والمستدامة تحتوي على مكسر الطابوق الطيني المعاد تدويره من مخلفات البناء كركام خشن خفيف الوزن ومسلحة بالالياف الاحادية والهجينة المزدوجة والثلاثية بانواع ونسب باعية مختلفة. تم تحضير خرسانة عالية الاداء من مكسر الطابوق الطيني الخفيف الوزن بمقاومة انضغاط 41.2 نيوتن\مم^2 و كثافة جافة 1930 كغم\م^3 بعمر 28 يوم. الالياف المستخدمة تتضمن, الياف فولاذية معقوفة النهاية بنسبة باعية 60 (نوع S_1), الياف بلاستك بنسبة باعية63, الياف فولاذية دقيقة معقوفة النهاية بنسبة باعية65 (نوع S), والياف البولي بروبلين الدقيقة بنسبة باعية667. تم اعداد ست خلطات خرسانية تتضمن على, الخلطة المرجعية بدون الياف , خلطتان مسلحة بنوع واحد من الالياف (الالياف الفولاذية نوع S_1 أو الياف البلاستك وبنسبة حجمية 0.75%), اثنان من الخلطات المسلحة بالالياف الهجينة المزدوجة (الالياف الفولاذية نوع S 0.5%+ الياف بولي بروبلين0.25% وخلطة الياف البلاستك 0.5% + الالياف الفولاذية نوع S 0.25 %) والخلطة الخرسانية الهجينة ثلاثية الالياف (0.25 % (الياف فولاذية نوع S_1 +الياف البولي بروبلين + الياف فولاذية نوع S). تم دراسة الخواص الطرية للخرسانة (قابلية التشغيل والكثافة الطرية) وخواص الخرسانة المتصلبة (الكثافة الجافة, مقاومة الانضغاط, مقاومة شد الانثناء, مقاومة الشد الانشطاري و الامتصاص للماء). بصورة فان نماذج الخرسانة العالية الاداء الخفيفة الوزن والمسلحة بالالياف الاحادية والهجينة (الثنائية والثلاثية) أظهرت زيادة مهمة في مقاومة الشد الانشطاري مقاومة شد الانثناء مقارنة بالنماذج الخرسانية المرجعية (بدون الالياف). ان نسب الزيادة في مقاومة الشد الانشطاري للنماذج المسلحة بالالياف الفولاذية الاحادية هي 55.8%, ,65.9%, 82% و 91.9%, بينما نسب الزيادة للنماذج المسلحة بالالياف البلاستكية الاحادية هي 34%, 45.5%, 61.5% و71.2% للاعمار 7, 28, 60 و 90 يوماً على التوالي بالمقارنة مع النماذج غيرالمسلحة بالالياف. ان اعلى مقاومة شد انشطاري و ومقاومة شد انثناء سُجلت للنماذج المسلحة بالالياف الهجينة ثلاثية الالياف. ان نسب الزيادة لمقاومة الشد الانشطاري للنماذج المسلحة بالالياف الهجينة ثلاثية الالياف هي 57.2%, 68.6 %, 87.5%, 101.8%, بينما نسب الزيادة لمقاومة شد انثناء هي 48 %, 59.6 %, 66.9%, 70.7%, للاعمار 7, 28, 60 و 90 يوماً على التوالي بالمقارنة مع النماذج غيرالمسلحة بالالياف.