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Original Research

MECHANICAL PROPERTIES OF SUSTAINABLE FIBER-REINFORCED LIGHTWEIGHT AGGREGATE CONCRETE

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Abstract: With the rapid growth of high-rise buildings and large-scale structures, there is a need to preserve natural resources and reduce loads on buildings by using lightweight concrete to achieve better performance for structures. In the study, four groups were prepared; the first group included one mix containing natural aggregate, and the second mix replaced all the natural aggregates with lightweight pumice aggregates. These mixes are reinforced with carbon fiber with a 0.5% volume fraction. In the second group, a variable volume fraction of carbon fiber of (0.0 and 1%) of mixes. In the third group, the mixes have different lengths of carbon fiber (20mm, 30mm) and a volume fraction of carbon fibers 0.5%. Finally, the fourth group partially replaces sand as a variable with a percentage of lightweight fine aggregates (10% and 30%) reinforced with fibers. Adding carbon fibers to the concrete specimens by 0.5% and 1% improved splitting tensile strength and flexural strength compared to the specimens containing carbon fibers with a length of 5mm. Also, enhanced samples containing fibers by 0.5% and lengths of 20 mm or 30 mm, compared to the sample containing carbon fibers with a length of 5 mm. Also, the specimens containing lightweight fine aggregates as a replacement with a percentage of sand have a lower splitting tensile strength and flexural strength than the reference mix.

Keywords: *Chopped carbon fiber; natural lightweight aggregates; pumice aggregate; sustainable concrete*

1. Introduction

With the rapid development of tall buildings, large-scale concrete structures, and long-span concrete structures, increased strength, toughness, and Lightweight Concrete (LWC) have become needed for better substantial performance. The use of natural volcanic materials (like pumice and ash) in construction is thus on the rise. Their usage as building materials can help keep construction costs down. The modern use of lightweight aggregate (LWA) in concrete helps to reduce the load transmitted to the foundations by lightening the weight of various structural members. Good thermal and acoustic insulating characteristics and fire resistance are provided by the existence of voids and pores in LWA. Therefore, compared to normal-strength concrete, lightweight structural concrete (SLWC) has improved qualities such as a better strength-to-weight ratio, stronger tensile strain capacity, a lower coefficient of thermal expansion, and heat-to-sound insulation [1]. Pumice stone is one of the earliest LWAs used in construction.

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The discharge of gases from cooling magma during volcanic activity creates small hollow holes, resulting in the porous structure of pumice. The brittle nature of (LWA) as pumice Lightweight aggregate concrete (LWAC). Decreases in the tensile strength and flexural strength of the brittleness of LWAC can be overcome by using fibers. The technological development of a wide variety of fibers has been developing new possibilities for advancing fiber-reinforced composite cementation materials [2].

Numerous researchers studied the properties of LWAC containing pumice aggregate reinforced with steel or polypropylene fibers with different volume fractions [3-5].

Mohammed et al. [6] studied the mechanical properties of LWAC by using the natural pumice stone as coarse and fine LWA, superplasticizer admixture, and silica fume to produce high-performance LWC. Sand LWA had a replacement ratio of 18% by weight of sand and a w/c ratio of 0.32 and Polypropylene fibers in different lengths (6mm and 18mm, and 30 mm length of polypropylene fibers, and the fiber volume ratio was (0.25%, 0.5%, and 0.75%) were used. It was concluded that adding polypropylene fibers to LWC by 0.75% and a length of 30mm increases the compressive strength by 12.8% at age 28 days compared with reference specimens (which was with no fiber). Adding these fibers improved the splitting tensile strength and flexural strength as they were added to the mixtures with a volume fraction of 0.75% and length of 30mm by 32.85% and 32.8% compared with the plain specimens. The fresh, oven-dry, and air-dry densities were reduced using polypropylene fibers.

To produce high-performance, lightweight concrete, Ahmed et al. [7] studied the use of pumice as both coarse and fine lightweight aggregate in combination with silica fume and superplasticizer. Three different polypropylene variants with different lengths and volume fractions were utilized. The study found that while polypropylene fiber (6 and 18 mm in length) with Vf = 0.25% was added to lightweight concrete mixes, the average percentage increase in compressive strength was only 2% and 9.5%, respectively. On the other hand, the compressive strength showed a tendency to decline as the volume fractions rose to 0.5% and 0.75%, with average percentage decreases of 11.5% and 4.35%, respectively. Furthermore, it was observed that adding 30 mm of waste polypropylene could slightly improve compressive strength for Vf = 0.25%–0.75%, with an average percentage increase of 3.6%. The study also found that the high-performance, lightweight concrete's splitting tensile strength and modulus of rupture were better than those of the plain specimens when different kinds of polypropylene with varying volume fractions were added. While adding different lengths of polypropylene fibers has little effect on the static modulus of elasticity of fiber-reinforced lightweight concrete. Very few studies are found on the properties of chopped carbon fiber reinforced structural LWAC, including local pumice (Coarse and fine) as lightweight.

Sheelan et al. [8] explain the uses of chopped carbon fibers with different volume fractions (0.5%, 1%, 1,5%2%, and 2.5%) lengths of 6 mm to enhance the tensile strength of Porcelanite lightweight aggregate concrete. High-range water superplasticizers and silica fumes were used in the investigation. Results showed that adding carbon fibers to porcelanite lightweight aggregate concrete increased its modulus of elasticity, splitting tensile strength, and compressive strength. In comparison to the reference Porcelanite lightweight aggregate concrete without fibers, the addition of carbon fibers increased these properties by as much as 2%. For compressive strength, splitting tensile strength, and modulus of elasticity, the corresponding percentage increases were 14.40%, 68.00%, and 10.66%, respectively. The escalation of fibers also increased flexural strength. As the percentage of fibers increased, the dry unit weight of mixtures containing chopped fiber decreased.

The purpose of this study was to investigate the particular mechanical properties of lightweight aggregate concrete (LWAC) reinforced with carbon fiber and made with local pumice as the fine and coarse lightweight aggregate.

2. Materials

2.1. Cement

Ordinary Portland Cement (OPC) (Type I) was used in this research. Lafarge Company in Sulaymaniyah governorate, Iraq, produced the cement. These types of findings of (chemical and physical) cement characteristics tests are shown in Tables 1 and 2. Table 3 illustrates the fundamental cement compounds (Bogue's Equation). According to test results, the chosen cement satisfies Iraqi Specification No. 5/1984[9]. Chemical composition and Chemical analysis and Physical Properties were conducted by the building research directorate (BRD).

Table 1. Cement Chemical Composition

Oxides Composition	Abbreviation	Content (% by weight)	Limits of Iraqi Specification No. 5/1984
Lime	CaO	60.74	---
Silica Dioxide	SiO_2	18.14	---
Alumina Trioxide	Al_2O_3	6.71	---
Iron oxide	Fe_2O_3	2.9	---
Magnesia Oxide	MgO	1.28	≤ 5 %.
Sulphate	SO_3	2.09	≤ 2.8 %
Loss on Ignition	L.OI	2.25	≤ 4 %
----	Total	94.11	---
Insoluble material	IR.	1.25	≤ 1.5 %
Lime Saturation Factor	L.SF	0.92	0.66-1.02

Table 2. Cement's Physical Properties

Physical Properties	Test Results	Limit of Iraqi Specification No. 5/1984
Specific surface area (Blaine method), (cm^2 /g)	4678	≥ 2300
Setting time (visits method)		
Initial setting (hrs.: min: sec)	0:1:25	≥ 45 min
The final setting, (hrs.: min)	3:50	≤ 10 hrs.
Compressive strength (MPa)		
For 3-days	25	≥ 15 MPA
For 7-days	43	≥23 MPA

Table 3. Major Compounds Regarding Cement (Bogue's Equation)

Oxides Composition	Abbreviation	Content (% by weight)
Tricalcium Silicate	C3S	49.23
Dicalcium Silicate	C2S	21.5
Tricalcium Aluminate	C3A	12.88
Tetracalcium alumino-Ferrite	C4AF	13.34

2.2. Fine Aggregate

2.2.1 Ordinary fine aggregate (Sand)

This study employed natural Iraqi sand passing through a 4.75 mm sieve as a fine aggregate. The sand was brought in from Al-Ukhaidir /Karbala. Tables 4 and 5 indicate the sand's gradation and chemical and physical characteristics. The grading of fine aggregate and its physical and chemical characteristics meet the requirements of Iraqi Specifications No. 45/1984 [10], according to test results. Chemical composition and Sieve grading for natural sand was conducted by the building research directorate (BRD).

2.2.2 Natural LWFA (pumice)

The pumice stone is located in northern Iraq, specifically in the Sulaymaniyah governorate. The pumice was bought as large pieces, so it was crushed by a crusher and grinding to get very small sizes similar to ordinary sand. The aggregate was screened through a standard sieve series to separate the required sizes. The grading of fine LWA (pumice sand) shown in Table 4 used throughout this study complies with the Iraqi Specifications No. 45/1984 [10] standard. The physical properties of the pumice sand are listed in Table 5. Physical analysis was conducted by the National Center for Construction Laboratories and Research (NCCLR).

Table 4. Fine Aggregate Sieve Analysis

Sieve Size (mm)	Cumulative Passing (% by weight)		Limits of Iraqi Specification No.45/1984 (zone 2)
	sand	Pumice	
4.75	90	100	90 - 100
2.36	75	90	75 - 100
1.18	59.7	80	55 - 90
0.6	39.3	50	35 - 59
0.3	12.4	30	8 - 30
0.15	2.28	10	0 - 10

Table 5. Chemical and Physical Properties of Fine Aggregate

Properties	Test Result		Limits of Specification
	sand	pumice	
Bulk Specific Gravity	2.6	1.32	---
Absorption %	1.92	17.2	---
Dry loose unit weight (kg/m^3)	1620	965	---
Sulphate content (SO^3), %	0.114	0.17	≤ 0.5 %*
Material finer than 0.075 mm sieve, %	3.6	----	≤ 5 %*

***** (I.Q.S.) NO.45-84[10].

2.3 Coarse Aggregate

2.3.1 Normal Coarse Aggregate (Gravel)

Crushed gravel (Angular) from the ALNiba΄ee region near Baghdad was used in this project, with a maximum coarse aggregate size of 20mm. The sieve analysis of coarse aggregates employed throughout this study, which met Iraqi specification No. 45/1984[10], is shown in Table 6. The chemical and physical characteristics of such aggregate are described in Table 7. Chemical composition and Sieve grading for natural gravel was conducted by the building research directorate (BRD).

2.3.2 Lightweight Coarse Aggregate (Pumice)

The crushed pumice stone was prepared as a lightweight, sustainable aggregate in this work, as shown in Fig 1. The pumice stone was crushed at the Materials Laboratory of the Faculty of Engineering Mustansiriyah University in Iraq by a crusher machine with variable size (14-2.36) mm as shown in Fig 2. Based on Iraqi Standard Specifications No45: 1984[10], as shown in Fig. 3, Table 6 shows the sieve analysis of LWA. Table 7 indicates the physical characteristics of lightweight coarse aggregate (LWCA). Physical analysis was conducted by the National Center for Construction Laboratories and Research (NCCLR).

Table 6. Coarse Aggregate Sieve Analysis

Sieve Size (mm)	Cumulative Passing (% by weight)		Limits of Iraqi Specification No. 45/1984 (20-5mm)
	Gravel	Pumice	
20	100	100	95-100
10	60	50	30-60
5	8	10	0-10

Figure 1. Pumice aggregate

Figure 2. Pumice Stone preparation steps.

Table 7. Physical Properties of Coarse Aggregate.

Properties	Test Result		Limits of Specification
	Gravel	pumice	
Bulk Specific Gravity	2.67	0.93	---
Absorption %	1.4	28.6	---
Dry loose unit weight (kg/m^3)		672	---
Sulphate content (SO^3)%	0.04	0.17	0.1 %*
Material finer than 0.075 mm sieve, %	0.08	----	3*

***(I.Q.S.) No.45- 84[10].

Figure 3. Grading of pumice aggregate

2.4. Water

This study used ordinary water to mix and cure all concrete mixes in the present work.

2.5. High Range Water Reducing Admixture (HRWRA)

A Chemical mixture based on modified polycarboxylic ether was used, known commercially as (Sika-Viscocrete-5930). It is a super plasticizer that complies with ASTM C494M/04 type F [11]. According to the manufacturer's document, Table 8 shows the key features of the superplasticizer employed in this study.

Table 8. The key features of Sika-Viscocrete5930

Properties	Value
Color	Light Brownish
Transport	Not designated as dangerous
Form	Turbid Liquid
Viscosity	1281.30cps @20C
Relative Density	1.080 kg/L
PH value	8±1
Labeling	No hazard label needed

2.6. Chopped Carbon Fiber

This study employed carbon fibers (CF) that were unidirectional and bendable (Sika warp-300c) as concrete reinforcement. The carbon fibers were sliced in lengths (5 mm, 20 mm, and 30 mm), as shown in Fig. 4. Based on the manufacturer's information, the characteristics of this fiber are listed in Table 9.

Table 9. The characteristics of Carbon Fiber

Carbon	Dry	Dry fiber	Modulus	Elongat

fiber	density g/ cm^3	Tensile strength (MPa)	of elasticity (MPa)	ion at Break (%)
600 mm width, 0.167mm thickness	1.82	4000	230000	1.7

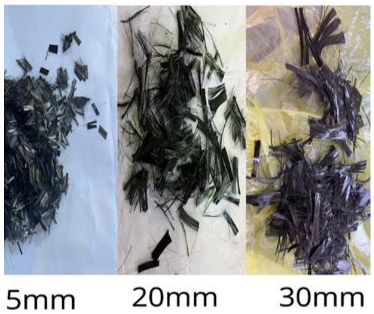

Figure 4. Carbon fibers

3. Mixing of Concrete

The ingredients were mixed in a rotary mixer of 0.1 m^3. Before beginning the mixing process, all of the concrete mix's components were weighed. Gravel and lightweight aggregate were used in a saturated surface dry (SSD) state. In a mixing pan, the appropriate amount of sand, aggregate, and cement was placed and mixed for three minutes. Then, 70% of the required amount of water was introduced to the mixer and mixed for two minutes, while 30% of the mixing water was added to the HRWRA. The solution was thoroughly mixed before being progressively added to the mixture. Again, for two minutes, all of the materials were blended. Finally, the appropriate amount of carbon fiber was carefully added to fresh concrete and blended for two minutes to avoid fiber balling by preventing fiber accumulation.

4. Concrete Mixes

The experiment includes the use of two types of aggregates, normal aggregates (gravels) and LWA (pumice), in which eight concrete mixes were made, divided into four groups with mixing proportions (1:1.8: 0.72) (cement: sand: aggregate) by weight, w/c ratio of 0.28 to have slump value of 100 ± 5mm, and cement content of 550 kg /m3, and the amount of superplasticizer (HRWRA) 1.1L/ 100kg of cement and reinforced with carbon fibers. Group one contains two mixes; the first mix contains ordinary natural aggregate (MRNA) with 0.5% CF, whereas the second mix (MRPA) (reference mix) contains LWA (pumice LWA with 0.5% CF. Group two includes three LWAC mixes. The variable in this group is the volume fraction of carbon fibers (MPAF), as each mix contains a volume fraction of carbon fibers (0.0%, 0.5%, and 1%). Group three also has three LWAC mixes. The variable in this group is the length of fibers (MPAL), as each mix includes a variable length of fibers (5mm, 20 mm, and 30 mm). Finally, Group Four contains three LWAC mixes. The variable in this group is replacing a percentage of the natural sand used with LWFAs (MPARE), as each mix includes a percentage of LWFAs (0.0%, 10%, and 30%) as a replacement with natural sand.

Table 10 depicts the proportions and contents of each concrete mix studied in this investigation.

Table 10. Details of proportions Concrete Mixes

Group No.	Symbol of Mix	Carbon fibers %vol*	length of fiber (mm)	Replacement of sand % by weight
Group 1	MRNA	0.5	5	0
	MRPA	0.5	5	0
Group 2	MPAF-0.0	0	5	0
	MPAF-1.0	1	5	0
Group 3	MPAL-20	0.5	20	0
	MPAL-30	0.5	30	0
Group 4	MPARE-10	0.5	5	10
	MPARE-30	0.5	5	30

*Percent of mix volume

5. Preparation, Casting, and Curing of Specimens

Three (150*150*150 mm) standard cubes were used for compressive test strength for each mix. In addition, three (150*300mm) standard cylinders were used for each mix for splitting tensile strength and modulus of elasticity. Also, three standard prisms were used for the flexural strength test after executing a workability test (slump). Before casting concrete, the molds were thoroughly cleaned and oiled, and then fresh concrete was poured into the molds and compacted using a vibration table. The specimens were then covered with nylon sheets for 24 hours to prevent water from evaporating. The concrete samples were then dismantled and cured in water for 28 days.

6. Experiment Tests

The following experimental tests were conducted to investigate the effect of the pumice aggregate on the mechanical properties of HPLWAC reinforced with CF:

- Slump testing as indicated in ASTM C-143[12].
- Oven dry density testing as indicated in ASTM C-567[13] (using150×300 mm cylindrical specimens).
- Fresh density testing as indicated in ASTM C 567-05a [13].
- Splitting tensile strength testing as indicated in ASTM C496–04[14]. (150×300 mm cylindrical specimens).
- Compressive strength testing as indicated in BS1881[15] (using 150 mm cube specimens).
- Static Modulus of Elasticity testing as indicated in ASTM C469–02[16] (150×300mm cylindrical specimens).
- Flexural tensile strength testing as indicated in ASTM C 78 [17] (100×100×500 mm prism specimens).

7. Results and Discussion

7.1 Fresh Properties

7.1.1 Workability

Table 11 shows the results of the workability test (slump test). The results showed that concrete mix containing gravel (MRNA) had workability higher than mix (MRPA) because the pumice contains pores, which can absorb part of the water mix. Also, the results showed that adding CF to all the mixes lowers their workability. This is because fibers have a more significant surface area, which raises the viscosity of the mixes [18]. Despite the loss of workability, visual examinations reveal that adding fibers to the mixes improves uniformity and stability in fresh mixtures. This is because fibers can form a network structure in the concrete mixes that effectively curtails LWA segregation; Libre et al. also suggested this [19].

7.1.2 Fresh Density

The fresh densities of concrete mixes are listed in Table 11. The results showed that concrete mixes containing gravel (MRNA) had a higher density than those containing LWA (coarse and fine). The results also showed that the addition of CF reduces the fresh density of concrete, and this is due to the low specific gravity of carbon fibers.

7.2 Hardened Properties

7.2.1 Oven Dry Density

The oven dry density test of LWAC and NWC specimens prepared in this investigation is listed in Table 11. LWAC specimens containing crushed pumice aggregate (coarse and fine) showed densities less than the NWC specimen with gravel aggregate because of the high gravity of gravel aggregate compared to the LWA. Also, it can be noticed that adding CF with different proportions to the LWAC specimen slightly decreases its density because of the low specific gravity of this fiber compared to the LWAC specimen without fibers.

Table 11. Workability and Density for Concrete Mixes

Mix Symbol	Slump (mm)	Fresh Density (kg/m^3)	Oven Dry Density(kg/m^3)
MRNA	98	2422	2340
MRPA	80	2010	1920
MPAF-0.0	92	2017	1928
MPAF-1.0	70	2005	1912
MPAL-20	77	2000	1917
MPAL-30	72	2006	1918
MPARE-10	80	1997	1910
MPARE-30	86	1990	1902

7.2.2 Compressive strength (FCU)

Table 12 presents the compressive strength results. From Group One, it can be seen that the compressive strength of the specimen containing gravel (MRNA) increases by about 19% more than the compressive strength of the specimen containing (pumice) (MRPA). Group Two indicates that the LWC specimens reinforced with carbon fibers in different proportions (0.5%, 1%) show higher compressive strength of (7.4%, 16.7%) than LWC without CF, as shown in Fig. 5. Also, Group Three implies that the increasing length of CF from 5mm to 20mm and 30mm resulted in a slight increase in the value compressive strength (by 4.48% and 7.43%, respectively) compared with concrete specimens containing 5 mm fibers. Group Four illustrates that the compressive strength of concrete containing LWFA with ratios (10% and 30%) as a partial replacement by weight of sand and CF by 0.5% and length 5mm is less by (10.3%, 17.2%) respectively than the compressive strength of reference concrete (MRPA).

7.2.3 Splitting Tensile Strength (ft)

Table 12 presents the results of the splitting tensile strength tests for all concrete samples. From group one, the splitting tensile strength of normal-weight concrete is greater than that of LWC by 20.4%. Fig. 6 shows that including CF in different proportions and lengths in LWAC improves the splitting tensile strength compared to LWC, which does not contain CF. Group two indicates that the percentage increase in the splitting tensile strength was 11% and 20% for LWC having CF by 0.5% and 1%, respectively, compared to the specimen without fibers (MPAF0.0). This may be due to the fiber's resistance to cracks and stopping their spread, leading to a delay in the failure of specimens. The increase in the length of the CF can significantly increase the splitting tensile strength because the short fibers can block the micro-cracks.

In contrast, the long fibers effectively bridge the cracks when reaching macro-cracks. Also, Group Three implies that the splitting tensile strength increases by 6% and 9% for the samples containing fibers with lengths of 20 mm and 30 mm, respectively, compared to those containing fibers with a length of 5 mm (MRPA). Group four illustrates that the samples that have LWFA as a replacement with a percentage (10% and 30%) of sand and CF by 0.5% and length 5mm are low density and, therefore, have low compressive strength as well, the splitting tensile strength is directly proportional to the compressive strength. Hence, the splitting tensile strength for those samples decreased by 9% and 16.6%, respectively, compared to the reference sample (MRPA).

7.2.4 Flexural Tensile Strength (fr)

The evolution in the ultimate flexural strength value of LWAC specimens is displayed in Table 12. The results demonstrate that the maximum flexural strength was for a specimen containing normal gravel and CF by 0.5%, while the minimum flexural strength was for a specimen containing LWA (pumice) with LWFA as a replacement with a percentage of 30% of sand and carbon fibers by 0.5% as shown in Fig. 7, the reason for this is that the density of concrete containing gravel is higher, and the porosity is less than LWC.

From group one, it can be seen that the flexural strength of a specimen containing gravel (MRNA) increases by about 29% more than the flexural strength of a specimen containing (pumice) (MRPA). The flexural strength of the CF specimens improved in different proportions and lengths. Group two indicates that the percentage of increased flexural strength of the specimens containing CF at different rates (0.5%,1%) compared to those without CF were (27% and 47.5%) respectively. Also, Group Three implies the percentage of increase in the flexural strength (8%, 13%) for specimens containing CF of different lengths (20 mm, 30 mm), respectively, compared to the sample containing CF by length 5mm (MRPA). This behavior is due to the increased ductility of the specimens with long CF. While group four illustrates that the specimens that contain LWFA as a replacement with a percentage (10% and 30%) of sand and CF by 0.5% and a length of 5mm have a low flexural strength of (28.5% and 46.9%) compared to the reference specimen (MRPA), this is due to the low density of those specimens.

7.2.5 Static Modulus of Elasticity (Ec)

Table 12 displays the values of static modulus of elasticity, accessed from stress-strain relationships performed after 28 days of curing on all the specimens, as shown in the figure. 8. From group one, it can be seen that the modulus of elasticity of a specimen containing gravel (MRNA) increases by about 44% more than the modulus of elasticity of a specimen containing pumice (MRPA). Group two indicates that the percentage of increase in the specimen containing CF at different rates (0.5% and 1%) and lengths of 5mm compared to the specimen without CF (MPAF-0.0) were (3.5% and 8.6%) respectively, and this is because the presence of CF increases the compressive resistance and thus increases the modulus of elasticity. Also, Group three implies that the percentage of the slight increase in the modulus of elasticity was (2% and 4.7%) for specimens containing CF by 0.5% and different lengths (20 mm and 30 mm), respectively, compared to the specimen containing CF by 0.5% and length 5mm (MRPA). Group four illustrates that the specimens have a low modulus of elasticity (6.5% and 11.8%) compared to the specimen (MRPA) due to the lower density due to fine lightweight aggregates.

Table 12. Mechanical Properties of Concrete Specimens

Mix Symbol	FCU (MPa)	ft (MPa)	fr (MPa)	Ec (MPa)
MRNA	69	4.93	7.15	**35006**
MRPA	58	4.1	5.55	**24324**
MPAF-0.0	54	3.73	4.35	**23614**
MPAF-1.0	63	4.45	6.4	**25639**
MPAL-20	60.8	4.33	5.94	**24704**
MPAL-30	62.3	4.46	6.21	**25448**
MPARE-10	52	3.77	4.32	**22932**
MPARE-30	48	3.52	3.78	**21894**

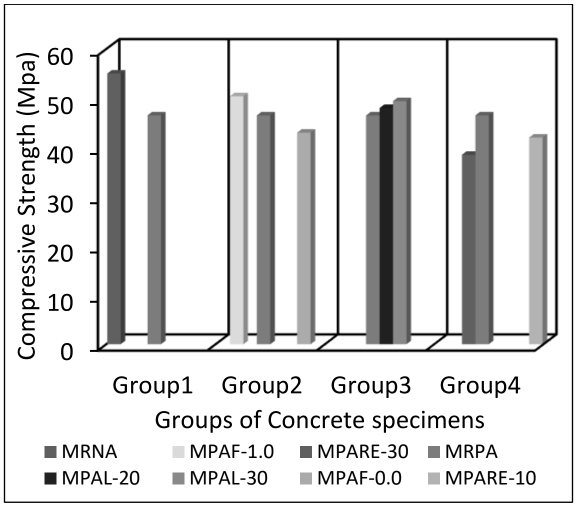

Figure 5. Results of Compressive Strength for All Concrete Specimens

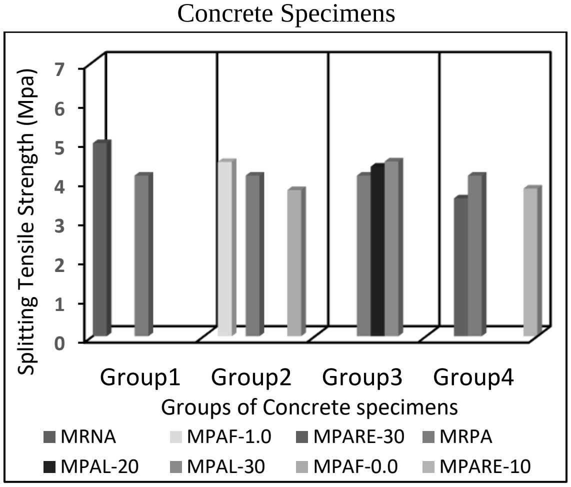

Figure 6. Results of Splitting Tensile Strength for All Concrete Specimens

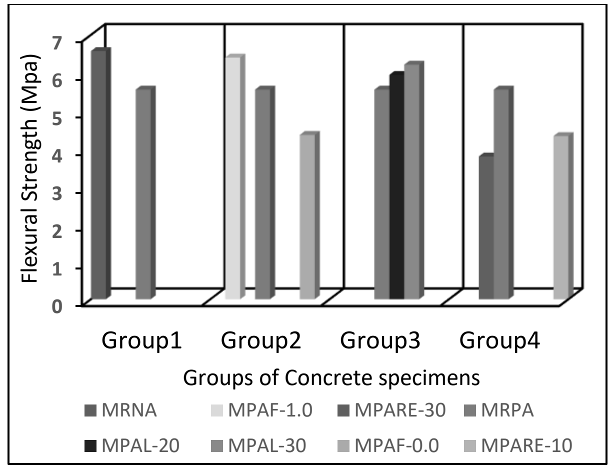

Figure 7. Results of Flexural Strength for All Concrete Specimens.

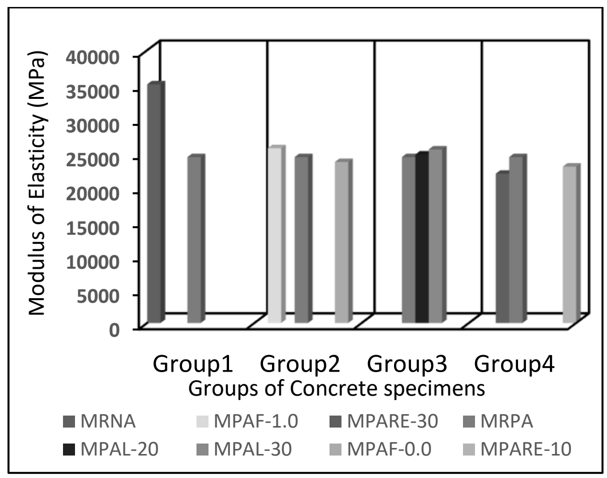

Figure 8. Results of Modulus of Elasticity for All Concrete Specimens

8. Conclusions

Sustainable (LWAC) containing crushed pumice stone has 46.5 MPA compressive strength and an oven-dry density of 1920 kg/m3 at 28 days. Comparison with natural aggregate has 55MPa with 2340 kg/m3. Adding carbon fiber (0.5% and 1%) to LWAC slightly decreases the oven-dry density compared to fiber-free concrete, and the LWFA with ratios (10%, 30%) as a partial replacement by weight of sand reduces the density of concrete specimens compared to the MRPA. The compressive strength slightly increases LWAC specimens reinforced with CF by (0.5% and 1%) compared with concrete specimens without CF. In contrast, the LWFA specimens showed decreased compressive strength compared to the reference concrete specimen (MRPA). The splitting tensile strength of LWAC reinforced with CF significantly improves relative to concrete specimens (without fiber). The tensile strength of splitting increases by (11% and 20%) for the added fibers (0.5% and 1%) compared to concrete specimens (without fiber). The tensile strength increased slightly by 6% and 9% for the samples containing fibers with lengths of 20 mm and 30 mm, respectively, and Specimens containing LWFA showed a reduction in splitting tensile strength by (9% and 17%) respectively, compared to the reference concrete specimen (MRPA). Adding CF with ratios (0.5 %, 1%) to LWAC specimens increases the flexural strength by (27% and 47.5%) respectively. The modulus of elasticity in LWAC specimens increases, while concrete specimens containing LWFA are lower than the (MRPA).

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Conflict of interest

All authors declare that they have no conflicts of interest.

Author contribution

This research is part of a master's thesis in which the two authors, Nagham Tariq and Zainab M. Hussein, proposed the research problem and its aim. The author, Wael Jasim Mohammed, conducted the laboratory experiment and performed the calculations. Both authors Nagham Tariq and Zainab M. Hussein supervised the findings of this work. All the authors discussed the results and contributed to the final manuscript.

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