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Efficiency Development of Light Weight High Strength Concrete by using Carbon Fibers.

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ABSTRACT
This study aims to progress brittleness of the high strength lightweight aggregate concrete (HSLWAC) by using Porcelinite stone as light weight aggregates and silica fume with water cement ratio 0.28 to give 41.34 MPa compressive strength at 28-days and reinforced with carbon fibers. Fifteen mixtures using in this work with three various lengths of (5mm, 10mm, and 20mm), five mixes for every length with volume fractions (0.25%, 0.5%, 1.0%, 1.5%, and 2%) of carbon fibers. The slump test, compression strength, flexural strength, splitting tensile strength, and modulus of elasticity were investigated to determine the mechanical properties of (HSLWAC). The density of reference (HSLWAC) that was get through the experimental work was (1835 Kg/m^3) at (28) days. The results shown that at general, the brittleness of (HSLWAC) improved with increased the content and length of carbon fibers, The optimum properties was for mix (L5) of 20mm length and 2% of carbon fibers of 45.44 MPa, 3.21MPa ,and 6.97MPa for compression strength, flexural strength, splitting tensile strength respectively.

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Introduction

The use of high-strength Lightweight concrete (HSLWAC) can reduce the self-weight of structures and cross-sectional areas of structural elements. Both can increase the effective usable space for high-rise buildings and increase the span length for bridges [1]. The requirement for structural high strength lightweight aggregate concrete (HSLWAC) in many contemporary construction is increasing, owing to the benefit of higher strength/weight ratio, better capacity of tensile strain, minimum coefficient of thermal expansion because of the voids existing in the lightweight aggregates (L.W.A) and minimum density that is suitable for a decrease of load-bearing elements and the foundation size [2]. The lightweight high strength concrete has densities from 1000 to 2000 kg/m^3 and compressive strength more than 40 MPa [3]. Lightweight aggregates are normally available (volcanic cinders, pumice, diatomite, etc.) or unnaturally made (expanded shale, PFA, perlite, slate, etc.) [4].

(HSLWAC) is considered as a relatively brittle material as the concrete is strong under compression and weak under tension or flexure. Carbon fibers are inert, medically safe, chemically stable, low in density, and their strength-to-density ratio is one of the highest among all fiber types. Carbon fiber has a very high tensile strength (2110 to 2815 N/mm^2) and young's modulus. Patodi, and Rarhod, have concluded that, cement composites made with carbon fiber, as reinforcement will have very high modulus of elasticity and flexural strength [2].

Literature Review

There are many studies have dealt with improved (HSLWAC) characteristics:

Abdul kader Ismail A. et al. in (2013) [7]. Studied the mechanical properties of lightweight aggregate concrete (LWAC) using chopped carbon fibers 5mm length, 10μm diameter with different ratios of volume (0.5%, 1%, and 1.5%) results showed that the addition of carbon fiber increases the compressive strength is about 30%, splitting tensile strength about 58% and flexural strength about 35%.

Xiang Shu et al. in (2014) [6] carried out to investigate the effects of carbon fiber with different sizes on the mechanical properties of Portland cement mortar. The laboratory test results show that the hybrid fiber mix exhibited superior tensile performance to the microfiber mix.

Wasan Ismail Khalil, et al. in (2015) [7] studied some properties of high strength lightweight aggregate concrete (HSLWAC) reinforced with mono and hybrid fibers in different dimensions and types. High strength porcelinite lightweight aggregate concrete mix. The results shown that mono and hybrid fiber reinforced HSLWAC specimens show significant increase in splitting tensile strength and flexural strength in comparison with plain HSLWAC specimen.

Akar Abdulrazaqet al. in (2011) [8]. Studied the influence of high performance carbon fiber concrete using superplasticizer and condensed silica fume reinforced with different volume fractions (0%, 0.2%, 0.3%, 0.4% and 0.5%) of carbon fibers the results show that the addition of carbon fibers improves the mechanical properties of high performance concrete the addition of carbon fibers causes a slight increase in compressive strength and modulus of elasticity of high performance concrete when the fiber volume fraction increases, while the splitting tensile and flexural strengths shows a significant increase relative to the reference high performance concrete (without fiber). The percentage increase in splitting tensile and flexural strengths for high performance concrete with fiber volume fraction 0.5% at 28 days is about 45% and 46% respectively.

Materials

1. Cement

Type I, ordinary Portland cement used in this study from Al- Douh refectory. Test results shown the cement identified with Iraqi specifications No. 5/1984 [9] .The properties of cement shown in the table (1) and (2).

Table (1). Chemical properties of cement

Oxide Percentage	Cement	Limit of Iraqi Spec. No.5/1984
CaO	63.2	-
SiO2	18.9	-
Al2O3	3.8	-
Fe2O3	4.6	-
SO3	1.5	≤ 2.5
Mg O	1.7	5.0
L.O.I	1.9	4.0
L.S.F	0.9	0.66-1.02
I.R	0.4	≤ 1.5

Table (2). Physical properties of cement

Physical Properties	Test results	Limit of Iraqi Spec. No.5/1984
Initial setting time (vicat)	65 min.	≥ 45 min.
Final setting time (vicat)	170 min.	≤ 375
Compressive strength of mortar (MPa) 3-days	19.0	≥ 15
Compressive strength of mortar (MPa) 7-days	30.5	≥ 21
Specific gravity	3.1	-
Specific surface	3000	-

2. Aggregate.

2.1. Coarse Aggregate.

Porcelinite stone was used as coarse aggregate. The quarry of this stone is located in Rutba at the western desert in Anbar. It was received in medium lumps from the State Company of Geological Survey and Mining. The physical, chemical and mineral analysis tests were done by the State Company of Geological Survey and Mining (SCGSM). The stone was crushed by crushing machine. The maximum aggregate size was 12.5 mm. Porcelinite was graduated to the grading which was presented in table (3). Due to the porcelinite cellular structure, lightweight aggregate (LWA) absorbs more water than normal weight aggregate. In order to avoid the continuous absorption of porcelinite LWA which caused rapid slump loss, the aggregate was washed with water for sufficient time to attain saturation. Then , the water was dripped off and the aggregate spreads inside the laboratory for suitable time to bring the aggregate particles to saturated surface dry condition (SSD), which is recommended by ACI committee 211[9] respectively.

Table (3): Grading of Porcelinite Aggregate.

Sieve Size (mm)	Passing %	ASTM C330-04[16]
12.5	100	90-100
9.5	96	85-100
4.75	21	10-30
2.36	4	0-10
1.8	2	0-5

Table (4): Physical Properties of Fine Aggregate

Proprty	Results	Specification	Limit of Iraq Spec. No45/1984[17]
Bulk pecific gravity	2.55	ASTM C128-7[18]	
Absorption %	2.1	ASTM 128-97	
Dry loose unit weight (kg\m3)	1600	ASTM C29-97[14]	
Sulphate content SO3	0.09	I.O.S N 45-84	0.5(max)
Material finer than 0.075mm	0.7	BS-882-1965[19]	5.0(max)

2.2. Fine aggregate.

The grading of fine aggregate are listed in Table (4). A (4.75) mm maximum size of clean sand is used as fine aggregate. and compatible to the requirement of Iraqi specifications No. 45/1984 [10].

Table (5). Sieve analysis of fine aggregate.

Sieve size	Passing ratio (%)	Limit of ASTMC33-03
9.5mm	100.00	100
4.75mm	94.56	95-100
2.36mm	72.45	80-100
1.18mm	68.40	50-85
600µm	53.32	25-60
300µm	16.60	5-30
150µm	2.12	0-10

3. Superplasticizer.

Superplasticizer is high range water reducing additives, It meet the requirements of super plasticizer according to ASTM-C494 Type B, D and G [13].Table (6) shows the typical properties of superplasticizer. High range water reducing (HRWRA) added to decrease the water demand of the concrete, when Silica fume added and reducing w/c.

Table 6. Typical properties of superplasticizer

properties	Specifications
Specific gravity	1.2
Form	Liquid
PH	7-9

4. Silica Fume (SF)

Table (7) shown the properties of silica fume according to ASTM C-1240-05[14], which shown in Fig. (1-b), the silica fume added in a dry state to the cement and thoroughly mixed with it in order to provide a homogenous mixture. Silica fume have a very high water demand.

Table (7) shown the chemical and physical properties of silica fume.

Oxide composition	Oxide Content%	Physical Properties	ASTM C-1240 Limitations
SiO_2	91.4	-	≥ %85
L.O.I	0.53	-	≤ 6.0
SO_3	0.13	-	
MgO	1.03	-	-
Na2O	0.16	-	-
Percent retained on 45µm(No. 325) sieve ,max ,%	8	-	≤ 10
Specific gravity	-	2.21	-
Bulk density	-	310 kg/m^3	-
Specific Surface	-	20 m^2/gm.	≥ 15
form	-	Amorphous	-

5. Carbon Fiber (C.F.)

A High execution of carbon fiber used in this study shown in Fig. (1-a). Carbon fiber complied with requirements of ASTM C1116-02 [12].Table (8) indicated the characteristics of carbon fiber High performance high strength chopped carbon fiber brought form waste factory as filaments was used in this investigation. Table (8) indicates the mechanical properties of chopped carbon fiber used in this investigation.

Table (8): Physical and Technical Properties of carbon Fiber (C.F.)

Properties	Results
Filament Diameter, µm	8
Bulk Density (min.), g/L	427
Elongation, %	1.53
Tensile Strength, MPa	1635
Flexural Strength, MPa	260

(a) (b)

Figure (1): (a) Carbon fibers (b) Silica fume.

Mix Proportions

The reference mixture is made by (ACI 211.2-02) [16], after several trial mixes were carried out in order to select the optimum dosage of (HRWRA) and silica fume. The (HRWRA) has been used to reduce the w/c ratio and maintain the same workability of the reference mix (100±5 mm slump according to ASTM C-143) which causes increase in the strength of LWAC. The selected HSLWAC has mix proportion of 1:1.35:1.87 (cement: sand: aggregate.) by weight with cement content 520 kg/m^3 and w/c ratio of 0.28, HRWRA 2.5 liter per 100 kg and 5% SF as replacement by weight of cement. The compressive strength and oven dry density of the selected mix are 62.3 N/mm^2 and 1955 kg/m^3 respectively at 28 day age. The carbon fiber is used in varying length 5 mm, 10 mm, and 20 mm with (0.25%, 0.5%, 1.0%, 1.5%, and 2%) in volume fraction. Table (8) shows the proportions of mixes of (HSLWAC) with coarse aggregate. for all mixtures the aggregates was used in saturated surface dry case (S.S.D.) Specific surface area of (S.F.) is greater than the cement, therefore the concrete performance is reduced fundamentally and more water is needed to fix it, because the concrete Performance should not be changed; the amount of superplasticizer is increased. [17].

Casting and Curing of (HSLWAC).

The samples cast in three layers by rodding 25 times with applying a vibration for (10) seconds. After mixing, the specimens disposed of the molds and maintained in the water until they will arrive the test age of (7) and (28) days when they are ready to do the experimental tests.

Concrete testing.

(HSLWAC) specimens prepared at general according to ASTM C192-02.[21].For each mix, six (150 mm) standard cubic steel molds used for casting specimens and for Compression strength in (7) and (28) days in agreement with ASTM C39-98 [22], the splitting tensile strength used two molds of (100X200) mm cylindrical concrete samples measured conformity to the ASTM C 496- 86[23], two (100X100X400mm) prisms for flexural strength at (28) day, correspond with ASTM(C293–02).[24].

Table 9: Mix Proportion for cubic meter of concrete.

Ingredients	Quantity (kg/m^3)
Cement content	520
Fine aggregate	700
Coarse aggregate	995
water	146
Superplasticizer	11.3
Silica fume	5

Table 10: Mix Designation for fiber content in volume fraction.

Fiber Volume friction (%)	Length of carbon fiber (mm) 5	10	20
0	CF0	CF0	CF0
0.25	M1	N1	L1
0.5	M2	N2	L2
1.0	M3	N3	L3
1.5	M4	N4	L4
2.0	M5	N5	L5

Results and Discussion

Workability (slump)

In this study, the quantity of water and SP were kept constant for all mixes in order to evaluate the effects of different CF fibers on the workability of OPC. Slump tests were carried out to determine the consistency of fresh concrete. The use of carbon fibers is well known to affect the workability and flowability of plain concrete intrinsically [26]. From Fig. 2, it can be seen that the slump value of fresh (HSLWAC) decreases due to an increase in CF fiber volume fraction. The addition of carbon fibres from 0.25% to 2% of volume fraction for length 5mm reduces the range of slump values by approximately 6.3%–36.8%. The results also indicate that, the carbon fibers of long length produced a lower slump, for length 10 mm the reduction in slump values was 9.5%-38.9% and length 25 mm the reduction in slump values was 15.8%-40%. Mehta and Montero [26] reported that a slump value for structural lightweight concrete in the range of 50–75 mm is comparable to an equivalent value of slump of 100–125 mm for normal concrete. This phenomenon might be attributed to the long length of fibres have higher effective surface area for the cement paste to wrap around due to the high fiber content and long of fibres, which in turn, increases the viscosity of the development of a fiber–matrix bond compared to shorter fibres. The bond increases the viscosity which restrains the mixture from segregation and flow. The fibres have the tendency to absorb admixture [27].

Table 11: Fresh and hardened properties of (HSLWAC) with carbon fibers

Length of Carbon Fibers (mm)	% of Carbon Fibers	Slump (mm)	Compressive Strength MPa 7-days	Compressive Strength MPa 28-days	Split Tensile Strength MPa	Flexural Strength MPa	Modulus of Elasticity MPa
5	0	95	35.14	41.34	2.12	3.74	27722
	0.25	89	35.43	41.68	2.33	4.54	27903
	0.5	81	35.83	42.15	2.48	4.88	28098
	1.0	73	36.19	42.58	2.69	5.25	29256
	1.5	66	36.75	43.23	3.01	5.89	31510
	2.0	60	36.91	43.42	3.15	6.01	32617
10	0	95	35.14	41.34	2.12	3.74	27722
	0.25	86	35.57	41.85	2.45	4.68	28120
	0.5	78	36.11	42.48	2.88	5.34	28311
	1.0	70	36.52	42.97	3.01	5.48	33709
	1.5	64	37.10	43.65	3.07	6.32	36952
	2.0	58	37.60	44.23	3.18	6.57	39400
15	0	95	35.14	41.34	2.12	3.74	27722
	0.25	80	35.90	42.23	2.56	4.95	28406
	0.5	72	36.70	43.18	2.78	5.74	33792
	1.0	65	37.58	44.21	3.02	5.89	36433
	1.5	59	38.15	44.88	3.12	6.65	39800
	2.0	57	38.62	45.44	3.21	6.97	40413

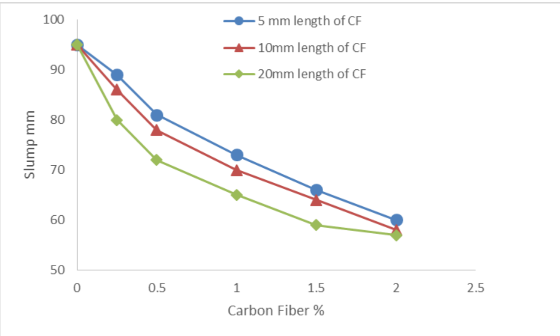

Figure (2) slump mm of all mixes with deferent length of carbon fibers.

Results of Compression strength.

As it is seen in table (11) presents the Compression strength test results and figure (3) at (7) and (28) day, it can be found that (HSLWAC) made with Carbon Fibers (C.F.) in addition silica fume had more Compression strength than control mix, the raise in the Compression strength at 28 days was more than their conformable Compression strength at (7) days due to the condensation of product of hydration process with silica fume about the Carbon fiber and loss the transition zone porous and further improves the mechanical properties of the concrete [29]. Figure 3 presents the variation of compressive strength with carbon fiber content, it is observed that, compressive strength increases with fiber length and fiber content. The increase in strength is more predominant for 20 mm length fibers. For the given fiber content, 20 mm length fibers show higher compressive strength compare to 5 mm and 10 mm length fibers. At 2% fiber content 20 mm length fiber shows 10% increase in compressive strength whereas the increase is by compressive strength whereas the increase is by 5.03% and 7% for 5 mm and 10 mm length of fibers respectively, compared with the strength of high strength concrete with 0% carbon fiber. This condition can be attributed to the improvement in the mechanical bond strength when the fibers both have the ability to delay the micro- crack formation and arrest their propagation afterward up to a certain extent [14, 15]. The maximum Compression strength of (HSLWAC) was (45.44) MPa at (28) days of age founded in the mix (L5) with 2% of carbon fibers.

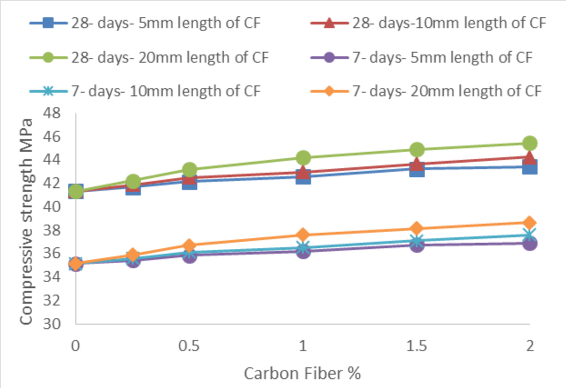

Figure (3) compressive strength with carbon fibers percentage at (7) and (28) days for different lengths.

Splitting Tensile Strength

The test results on split tensile strength of (HSLWAC) with carbon fibers is shown in Table 11 and plotted in Fig 4. It is observed from the Fig. 4, that the split tensile strength shows increase in strength with increasing fiber content relative to the plain specimens (without fiber). The percentage increase in splitting tensile strength for 5mm length HSLWAC mixes (M1, M2, M3, M4, and M5) containing of volume fraction 0.25%, 0.5 %, 1%, 1.5% and 2% carbon fiber is 10%, 17%, 26.9%, 41.5% and 48.6% respectively relative to the CF0 specimens. This is attributed to the mechanism of fibers in arresting crack progression and the improvement of bond between fibers and matrix due to the extra dense calcium silicate hydrate gel obtained from silica fume addition [18].

Also Fig. (4) indicate that the 20 mm length fibers show higher split tensile strength compare to 10 mm length fibers. The percentage increase in splitting tensile strength for HSLWAC mixes containing 20mm fiber type (L1, L2, L3, L4, and L5) with volume fraction 0.5%, 1% and 0.25% carbon fiber is 4.5%, 3.6%, 0.3%, 1.6% and 0.9% respectively relative to 10mm length fibers . This is attributed to the mechanism of fibers in arresting crack progression and the improvement of bond between fibers and matrix due to the extra dense calcium silicate hydrate gel obtained from silica fume addition [18].

Splitting failure characteristics of HSLWAC completely change with presents of fibers. Non fibrous concrete specimens suddenly failed in a brittle manner and separated into two parts; all samples of mono and hybrid fibrous HSLWAC consist of two parts still connected by fibers bridging the major crack. A reduction in crack width was observed in hybrid fibers HSLWAC which significantly contributed to the reduction in overall crack area.

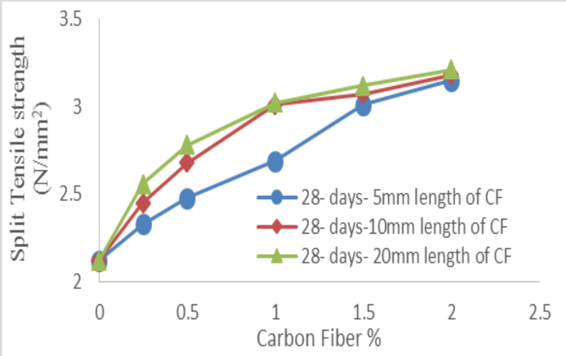

Figure. (4) Splitting tensile strength with carbon fibers percentage at (28) days with different lengths.

Flexural Strength

Flexural strength test results are given in Table (11) and plotted in Fig 5, show significant improvement in flexural strength with the addition of carbon fibers. The increase in flexural strength is more sensitive with fiber content compared to compressive and split tensile strength, for a given fiber length. Maximum increase of 86.4% in flexural strength is observed at mix (M5) content for 5 mm length fiber compared to a flexural strength of high strength concrete with 0% fibers.

The comparison between flexural strength values for HSLWAC specimens of 20 mm length mixes (L1, L2, L3, L4, and L5) and 10mm length mix specimens (N1, N2, N3, N4, and N5) shows that the percentage of increase in flexural strength is 6.88%, 5.8%, 11.7%, 7.5%, 5.2% and 6.1% respectively. This is because carbon fibers are strong and stiff and they can blunt and arrest microcracks before they coalesce into macro cracks leading to fracture [23].Plain HSLWAC exhibited brittle failure under flexural with the specimen being separated into two pieces. Fibrous high strength lightweight aggregate concrete mix with carbon fiber content 0.25% shows the same behavior. This is due to the lower elastic modulus of the carbon fiber.

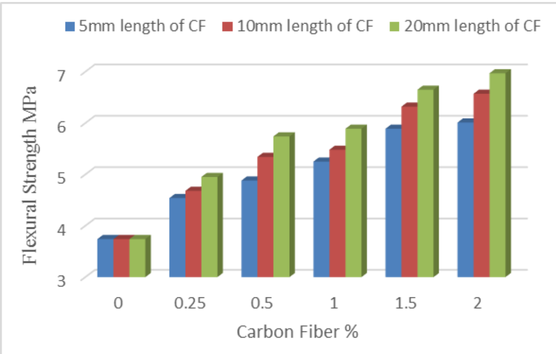

Figure. (5) Flexural strength with carbon fibers percentage for different lengths.

Modulus of elasticity

Test results for Modulus of elasticity indicate that in table (11) and figure (6). The addition of carbon fibers show branching raise in the elasticity. Like to strength properties the modulus of elasticity also shows increased values at higher fiber content. For example at 5 mm length the modulus of elasticity shows increase with increasing fiber content relative to the plain specimens (without fiber). The percentage increase in modulus of elasticity HSLWAC mixes (M1, M2, M3, M4, and M5) containing of volume fraction form 0.25% to 2% carbon fiber is in the range 0.7% - 17.7% respectively relative to the (CF0) reference mix. Also the increasing length of carbon fibers shown raises the modulus of elasticity as in the other strength factors.

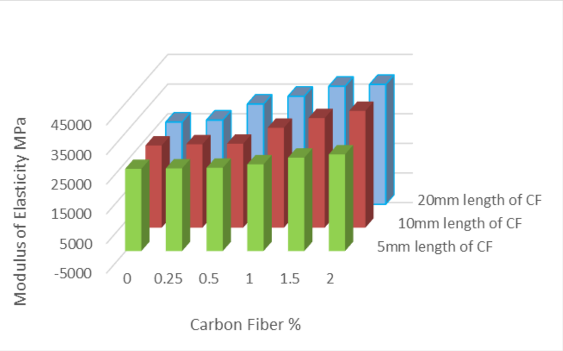

Figure (6). Modulus of elasticity for all mixes.

CONCLUSIONS

The control (HSLWAC) has a density of (1835) kg/m^3, and the voids content was reducing with increasing the percentage of silica fume, the lowest density of (1746.72) kg/m^3 was from the mix (PC5) at 28-days. It permeability coefficient (K) and voids content was (0.324) cm/s, and (30.21%) respectively.

(1) Carbon fibres reduce the slump value of concrete. The reduction in slump value is within the range of 11%–64% for different length of carbon fibres. However.

(2) The compressive strength of (HSLWAC) increases with an increase in carbon fibres content. Plain (HSLWAC) concrete has a 28-day compressive strength of 41.34 MPa, and this value increases to 43.42 MPa when the concrete is reinforced with 2% volume fraction for mix (M5) of 5 mm length carbon fibers, also the compressive strength of (HSLWAC) increases with longer the length of carbon fibres to 10mm and 20mm were 45.44 MPa and 44.23MPa for mixes (N5) and (L5) of 2% volume fraction.

(3) The excess the content of carbon fibers in HSLWAC with 5mm length significantly improves the splitting tensile strength of mix (M5) reinforced specimens was 48.6% relative to the reference specimens. HSLWAC specimens show significant increase in splitting tensile strength with increasing content. The percentage increase in splitting tensile strength for HSLWAC mixes containing 20mm fiber type (L1, L2, L3, L4, and L5) with volume fraction 0.5%, 1% and 0.25% carbon fiber is 4.5%, 3.6%, 0.3%, 1.6% and 0.9% respectively relative to 10mm length fibers.

(4) The effect of incorporating of carbon fibres in improving the flexural strength with increased content of carbon fibers is more pronounced compared to its effect on splitting tensile strength. The higher percentage increase in flexural strength for (L5) mix was 6.97 MPa compared with reference concrete mix (CF0).

(5) For Modulus of elasticity indicate that the addition of carbon fibers show marginal increase in the elasticity. Similar to strength properties the modulus of elasticity also shows increased values at higher fiber length and fiber content.

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