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Mechanical Properties of Fiberous High Performance Lightweight Aggregate Concrete

Abstract- *Structural lightweight aggregate concrete solves weight and durability problems in buildings and structures. Recent advanced in material technology have accelerated the development of high performance concrete using lightweight aggregate. The main objective of this research is to produce high performance lightweight aggregate concrete reinforced with polypropylene and to study the mechanical properties of this type. The effect of various factors such as type of fiber and volume fraction of fibers also has been investigated. The experimental work included the use of pumice as coarse and fine lightweight aggregate, superplasticizer and silica fume to produce high performance lightweight concrete. Several trial mixes were examined to determine the proper proportion of the concrete constituent. Three types of polypropylene with different volume fraction were used. The procedure also includes studying the compressive strength, splitting tensile strength, flexural strength and static modulus of elasticity. The test results shows that the addition of all types of polypropylene fiber results in significant improvement in most mechanical properties compared with reference concrete specimens at different ages except compressive strength it was improved at* V_f *=0.25% and decrease at* V_f*=0.75%.*

Keywords- *High performance concrete, lightweight concrete, compressive strength, splitting tensile strength, flexural strength, pumice.*

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1. Introduction

Recently with rapid development of very tall buildings, large size and long span concrete structure, the requirements for better concrete performance are higher strength, higher toughness, and lightweight. Therefore, for lightweight concrete has been used for structural purpose for several years. The unit weight of lightweight concrete (LWC) ranges from 1440 to 1840 kg/m^3 compared with that of 2400 kg/m^3 for normal concrete [1,2]. Replacing structural normal weight-aggregate with lightweight aggregate reduces dead load by (25-30) % [3]. The use of these types of concrete is usually predicted and the reduction of project cost, improved functionality or combination both. Cost reduction may come from smaller size foundation elements and less steel reinforcement [4,5]. The reduction in dead loads may results in smaller supporting members resulting in a major reduction in cost and at the same time this will mean reduced internal seismic forces exposed to those structures. However, LWC can be considered as brittle material. The higher compressive strength, the higher is the brittleness. Therefore, improving the brittleness is the key point to popularize the application of LWC [3]. It is well known that the normal concrete reinforced with fibers provides better properties compared to normal concrete, especially the improvement of toughness. Several investigations have been made on the effect of steel fiber addition on the behavior of the lightweight concrete [6-8]. This information about lightweight high performance concrete reinforced with polypropylene is scarce Widodo et al. [9] Nevertheless, in spite of the advantage that have been reported in this area, much more research is still needed. Hence, the investigation focus of this study is the effects of different polypropylene fiber type and volume fraction on the mechanical properties of high performance lightweight aggregate concrete (HPLWAC).

2. Experimental Program

I. Materials

●Cement

Ordinary Portland cement type I has been used in this study manufactured by United Cement Company commercially known (Mass-Bazian).The physical and chemical properties of this cement are presented in Table 1. The test results indicate that the cement conforms to the provisions of Iraqi specification No.5/1984 [10].

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Table 1: Chemical composition analysis and Physical properties results of cement used

Chemical composition			**Limits of (I.Q.S.) No.5/1984**	**Physical properties**		**Limits of (I.Q.S.) No.5/1984**
Oxides		**Content %**		**Properties**	**Test results**	
Silica	SiO_2	20.31	-----	Specific surface area (m^2/kg)	263	≥230
Alumina	Al_2O_3	5.3	-----			
Iron Oxide	Fe_2O_3	3.37	-----			
Lime	CaO	61.89	-----			
Magnesia	MgO	1.99	<5.00	Initial setting	2 h:40 min	≥00:45
Sulfate	SO_3	2.61	<2.80	Final setting	3 h:20 min	≤10:00
Lime Saturation Factor	L.S.F	0.91	0.66-1.02	Compressive Strength (MPa)	3 days 26	≥15.00
					7 days 29	≥23.00
Loss on Ignition	L.O.I	2.97	<4.00	Soundness (mm)	1.0	≤10
Insoluble residue	(I.R)	0.51	<1.5			
Main compounds						
C_3S	49.66	C_3A	8.34	C_2S	20.84	C_4AF 10.24

* Chemical analysis was conducted by National Center for Construction Laboratories and Researches.

●Normal-weight Sand

AL-Ukhaider natural sand of maximum size 4.75 mm was used. Its gradation lies in zone (2). The gradation, Physical and chemical properties results are shown in Table 2 of fine aggregate were within the requirements of the Iraqi specification No. 45/1984 [11].

●Light-weight Sand (Pumice Sand)

The pumice stone was received as large lumps so it crushed into smaller size manually by means of hummer. The required sizes were separated by screening the aggregate through a standard sieve series. The grading of fine lightweight aggregate (pumice sand) which was adopted throughout this work conforms to the requirement of the ASTM C330-04 [12]. Table 3 shows the physical properties of sand used.

●Light-weight Gravel (Pumice)

Crushed Pumice stone was used as coarse lightweight aggregate of nominal size (12.5 - 4.75) mm in this work as shown in Figure 1. Pumice pieces were broken manually mixed and graded as per the requirement of ASTM C 330-04 [12]. Table 4 illustrates the physical properties.

Table 2: Chemical and physical properties of sand

Properties	**Test results**	**Limit of Specification I.Q.S No.45/1984 Zone (2)**
Specific gravity	2.60	-
Absorption %	0.75	-
Dry loose-unit weight (kg/m^3)	1595	-
Sulfate content as SO_3 %	0.08	≤0.5
Materials finer than 75µm%	1.18	≤ 5
Fineness modulus	2.81	

Table 3: Physical properties of lightweight sand (pumice)

Physical properties	**Test Results**	**Limits**
Loose bulk density (kg/m^3)	964	Max=1120 ASTM C330-04
Specific gravity	2.3	-----
Fineness modulus	2.56	-----
Absorption %	3.75	-----

Figure 1: Particles of pumice

●Mineral Admixture (Silica fume)

Silica fume used in this investigation is commercially known as MEYCO from the Chemical Company BASF [13].was brought from Arwqat Baghdad Company. It is complies with ASTM C 1240-05 [14]. The strength activity

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index was measured, the value was 126%. Table 5 shows the Technical Specification of micro silica.

●Chemical Admixture (Superplastisizer)

Table 4: Physical properties of lightweight coarse aggregate (pumice)

Physical properties	Test Results	Limits
Loose bulk density (kg/m^3)	571	880 (max)
Oven dry bulk specific gravity	1.86	
Particle specific gravity	2.53	
Absorption % (1 Hours)	2.8	
Absorption % (24 Hours)	6	

Table 5: Technical specification of micro silica

Property	Test Results
Color	gray
Density	550 – 700 kg/m^3
Specific weight	2300 kg/m^3
Chlorine amount	< 0.1 %
Blain (fineness)	> 15000 m^2/kg
Activity index	> 95 %

Throughout this investigation as a (HRWRA). It is a third generation of superplasticizers and it complies with ASTM 494-05 [15] type F.

●Polypropylene Fibers

High performance monofilament polypropylene fibers of different lengths and waste polypropylene were used in this work as shown in Figure 2. Table 6 indicates the typical properties of the used polypropylene fibers and its geometrical characteristics.

●Water

High performance concrete superplasticizer which is known commercially (GLENIUM 54) used

Ordinary potable water was used for mixing and curing all concrete mixes in this investigation.

II. Mix design

Mix design is made in accordance with volumetric method ACI 211.2 [16]. The reference concrete mixture is designed to give at 28 days age a compressive strength 50 MPa. Eleven trial mixes were conducted to find the proper weight of materials ensuring homogeneity and workability of the mixture and having a dry unit weight not exceeding the specification of structural lightweight aggregate concrete. The final mix had the following constituents: cement content 520 kg/m^3 , silica fume 52 kg/m^3 , natural sand 610 kg/m^3 , fine pumice 133 kg/m^3 , coarse pumice 450 kg/m^3 and w/c = 0.32.

III. Curing

After demolding the specimens, they were continuously cured by water. The specimens were cured until the time of testing.

Table 6: Properties of polypropylene fibers

Specific gravity	**0.91 g/cm^3**
Constituent	Polymerized polypropylene
Fiber length	18mm and 6 mm
Fiber diameter	12 micron for 6mm fiber length 18-30 micron for 18mm fiber length
Surface area	230m^2/kg min.
Young Modulus	3500-3900 MPa
Tensile Strength	350 MPa min.

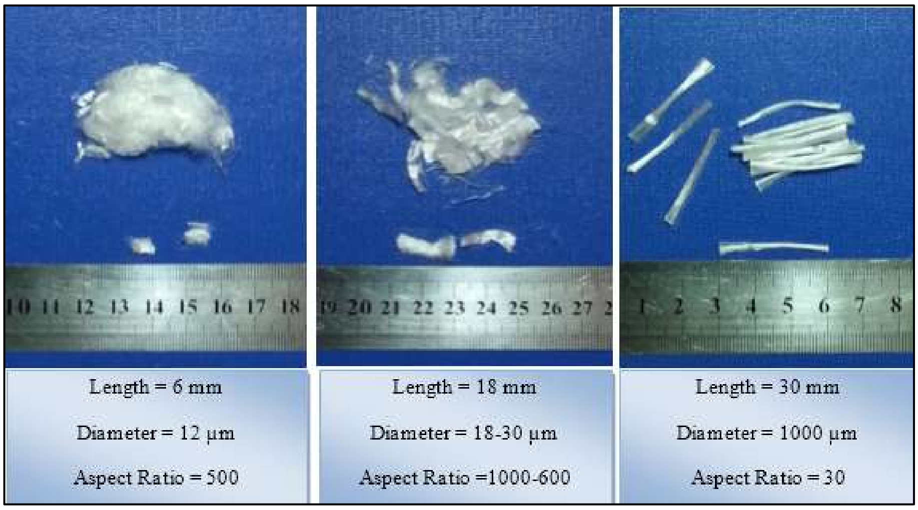

Figure 2: Types of polypropylene fibers used

IV. Experimental Tests

●Workability (Slump)

The workability of all concrete mixes (with and without fibers) was measured immediately after mixing using slump test according to the procedure described in ASTM C143–03 [17]. The w/c or w/cm was adjusted to give medium workability within (120–50) ± 5 mm for all concrete mixes.

●Compressive Strength

This test was conducted on 100 mm using a digital compression-testing machine of 2000 kN capacity at fixed load according to B.S. 1881: part 116:1989 [18]. The average compressive strength of three specimens was recorded. The test was conducted at ages of 7, 28, 60 and 90 days.

●Splitting Tensile Strength

The splitting tensile strength test was performed according to ASTM C496 -04 [19**]**. (100×200) mm cylindrical concrete specimens were used. The specimens were tested using an electrical testing machine with a capacity of 2000 kN. This test was conducted at ages of (7, 28, 60 and 90) days. The average splitting tensile strength of three cylinders was calculated.

●Modulus of Rupture (Flexural Strength)

Flexural strength was carried out by using (400 x 100 x 100) mm prism specimens in conformity with ASTMC78-03 [20]. The prisms were subjected to two points loading at a rate of 0.02 MPa/sec. Since fracture occurs within the central of the beam for all specimens. The specimens were tested at age of (7, 28, 60 and 90) days and the average value of three specimens in each age were taken.

●Static Modulus of Elasticity

The static modulus of elasticity determine from compression test according to the ASTM C469-02 [21]. The test was performed at age of 28 and 90 days using capped cylinders of 100x200 mm and using the chord modulus.

●Dry Unit Weight (28-Air Dry Density)

This test was conducted according to ASTM C567-00 [22]. Cylindrical specimens of (100x200) mm were used in this test and the average of three specimens was adopted at each mix.

3. Results and Discussion

●Compressive Strength

Figures 3 to 6 and Table 8 show the compressive strength results of fiber reinforced high performance lightweight aggregate concrete containing different types of polypropylene fibers and volume fractions at various ages. It can be observed that the inclusion of mono polypropylene fiber of 6 mm length with volume fraction 0.25% improves the compressive strength of specimens by about 5.9 %, 17.3% and 9.5% at 28, 60 and 90 day respectively compared with reference specimens. while with volume fraction of 0.5% there is slightly increment and with volume fraction of 0.75% compressive strength decrease by about 9.8 %, 6.5%, 11.1% and 14.7% at 7, 28, 60 and 90 day respectively.

The inclusion of mono polypropylene fiber of 18 mm length with volume fraction 0.25% improves the compressive strength by about 12.2 %, 6.1% and 2% at 28, 60 and 90 day respectively. While with volume fraction of 0.5% there is slight reduction and with volume fraction of 0.75% the compressive strength tends to decrease, the average percent of decrease was 4.7%.

The reduction in compressive strength with volume fraction 0.75% for both mono polypropylene (6, 18)mm may be due to the fact that the polypropylene is compressible material causing debonding and micro cracking, then the failure occurs at a lower strength compared with the reference specimens [23]. These results are in agreement with other investigators [24,25].

The effect of using waste polypropylene fiber of 30mm length is shown in Fig. 5, which shows that the compressive strength tend to a little increase by addition 0.25% by volume fibers, the average percentage increase was 7.7%. While at V_f =0.5% and 0.75% the compressive strength approximately the same at V_f=0.25%.

●Splitting Tensile Strength

The relationship between the splitting tensile strength and volume fraction of different types of polypropylene fibers of high performance lightweight concrete specimens are shown in Figures 7-9 and Table 9. Generally, it can be seen that there is a noticeable increase in splitting tensile strength for all mixes as the polypropylene fibers content increases from 0.25% to 0.75%. The average percent of increase in splitting tensile strength of HPLWAC specimens reinforced with mono polypropylene 6 mm length is 15%, 19% and 25% over that of reference specimens for percentage (0.25%, 0.5% and 0.75%) respectively. It can be also noted that the average percentage increase of specimens reinforced with mono polypropylene of 18mm length was 17.9%, 22.3% and 32% for volume fraction fiber 0.25%, 0.5% and 0.75% respectively. On other hand, the use of waste polypropylene of 30mm length shows a considerable increase in splitting tensile strength of specimens, the average percentage increase of splitting tensile strength of specimens was 23.5%, 26% and 33% for volume fraction of 0.25%, 0.5% and 0.75% respectively. This may be because the increase in length of fibers bridging the cracks in the matrix can provide resistance to crack propagation and crack opening before being pullout at failure [6].

●Modulus of Rupture

The relationship between the modulus of rupture (ultimate flexural strength) and volume fraction of different types of polypropylene fibers of high performance lightweight concrete specimens are shown in Figures 10-12 and Table 10. Generally, it can be seen that there is a noticeable increase in splitting tensile strength for all mixes as the polypropylene fibers content increases from 0.25% to 0.75%. The average percent of increase in splitting tensile strength of HPLWAC specimens reinforced with mono polypropylene 6 mm length is 5.7%, 16.1% and 28.7% over that of reference specimens for percentage (0.25%, 0.5% and 0.75%) respectively. It can be also noted that the average percentage increase of specimens reinforced with mono polypropylene of 18mm length was 19.4%, 19.6% and 27.5% for volume fraction fiber 0.25%, 0.5% and 0.75% respectively. On other hand, the use of waste polypropylene of 30mm length shows a considerable increase in flexural strength of specimens, the average percentage increase of splitting tensile strength of specimens was 19%, 26.3% and 28.2% for volume fraction of 0.25%, 0.5% and 0.75% respectively. The same reason about increase in splitting strength can be applied to modulus of rupture.

●Static Modulus of Elasticity

Table 11 show the modulus of elasticity results of fiber reinforced high performance lightweight aggregate concrete containing different fiber volume fractions at various ages. Generally it can be observed that the modulus of elasticity increased with addition of fiber with volume fraction 0.25% and decrease with volume fraction 0.5% and 0.75 for all types of polypropylene used These results are in agreement with investigator [26].

●Dry Unit Weight (28-Air Dry Density)

Air-dry density results of reference high performance lightweight aggregate concrete equal to 1958.7 and generally it can be observed that the density decreases with adding polypropylene fiber as shown in Table 12.

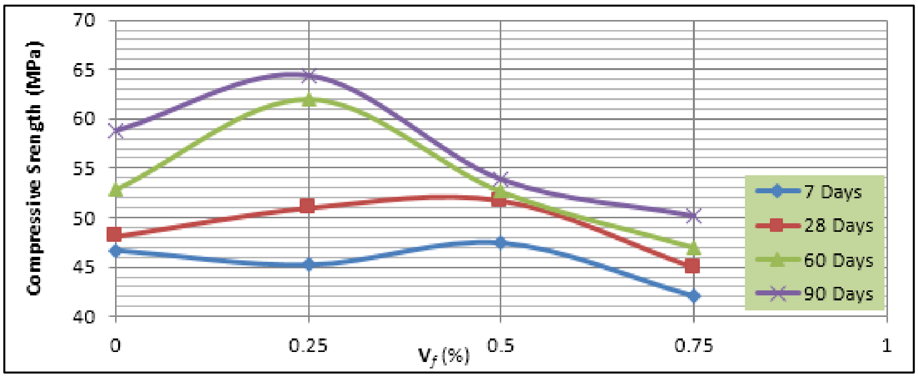

Figure 3: Effect of mono polypropylene (6mm) content % by volume on compression strength of HPLWC at different ages

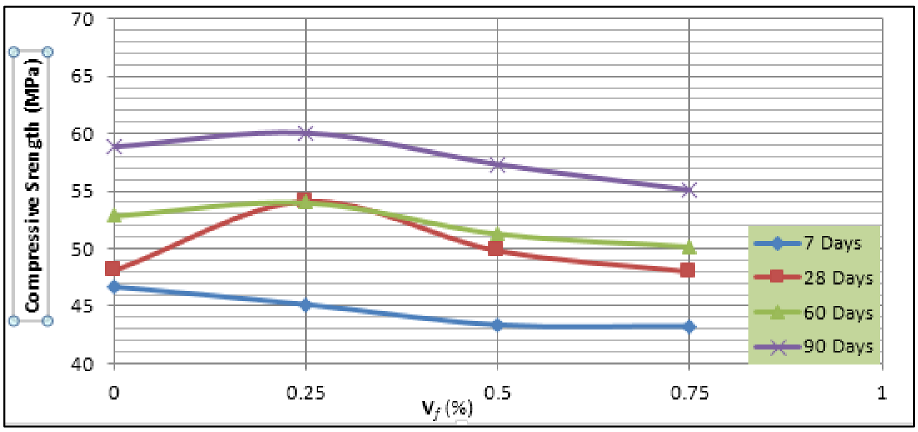

Figure 4: Effect of mono polypropylene (18mm) content % by volume on compression strength of HPLWC at different ages

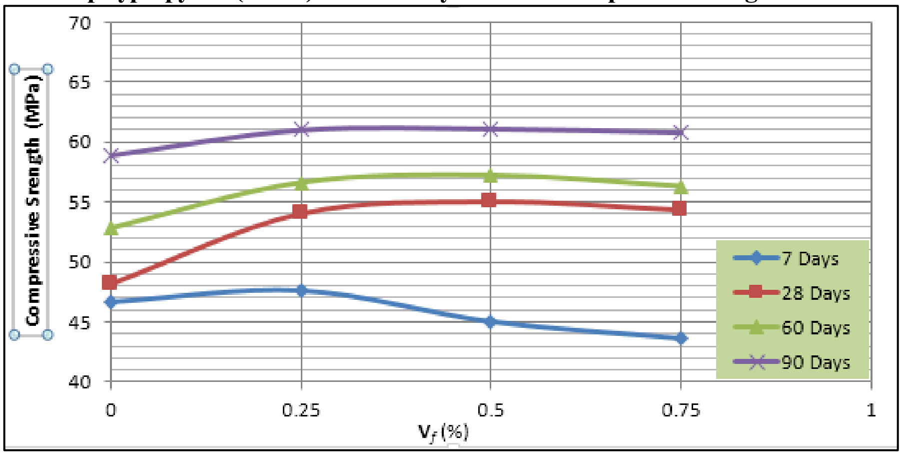

Figure 5: Effect of waste polypropylene (30mm) content % by volume on compression strength of HPLWC at different ages

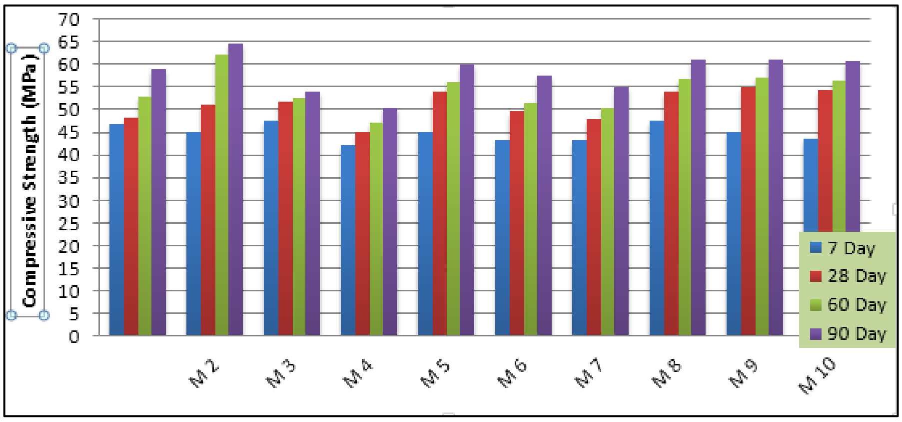

Figure 6: Effect of V_f and fiber length on the compressive strength at different ages

Table 7: Effect of Fiber reinforcement on the Workability of high performance lightweight concrete mixes

Mix	Type of Fiber (mm)		Percent of fiber by volume (%)	Slump (mm)
M 1 Reference	-----		0	120
M 2	Mono polypropylene	6	0.25	110
M 3			0.5	95
M 4			0.75	80
M 5		18	0.25	115
M 6			0.5	75
M 7			0.75	55
M 8	waste	30	0.25	65
M 9			0.5	55
M 10			0.75	50

Table 8: Effect of fiber reinforcement on the compressive strength of HPLWC at different ages

Mix	Type of Fiber (mm)		Volume fraction (%)	Compressive strength (MPa) 7 Day	28 Day	60 Day	90 Day
M 1 (Ref)	-----		0	46.65	48.1	52.85	58.8
M 2	Mono polypropylene	6	0.25	45.2	50.95	62	64.4
M 3			0.5	47.4	51.7	52.65	53.9
M 4			0.75	42.1	45	47	50.2
M 5		18	0.25	45.1	54	56.1	60
M 6			0.5	43.3	49.8	51.3	57.3
M 7			0.75	43.2	48	50.2	55.1
M 8	was te	30	0.25	47.6	54	56.6	61
M 9			0.5	45	55	57.2	61.1

M 10	0.75	43.6	54.3	56.3	60.8

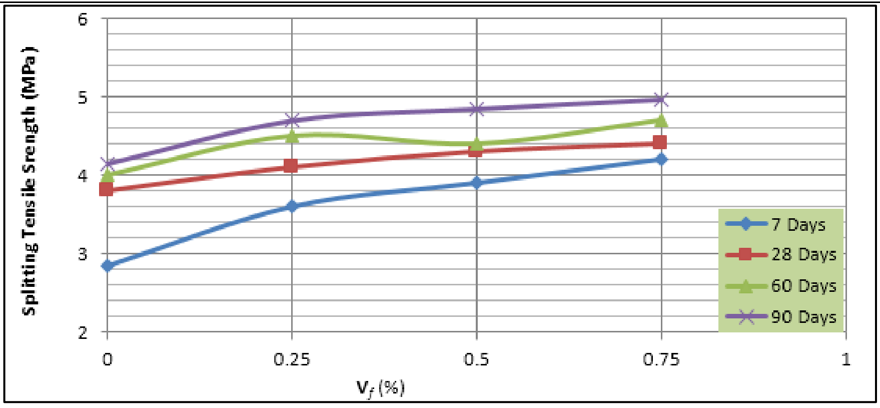

Figure 7: Relationship between splitting tensile strength of HPLWC specimens and volume fraction of mono polypropylene (6mm) at different ages

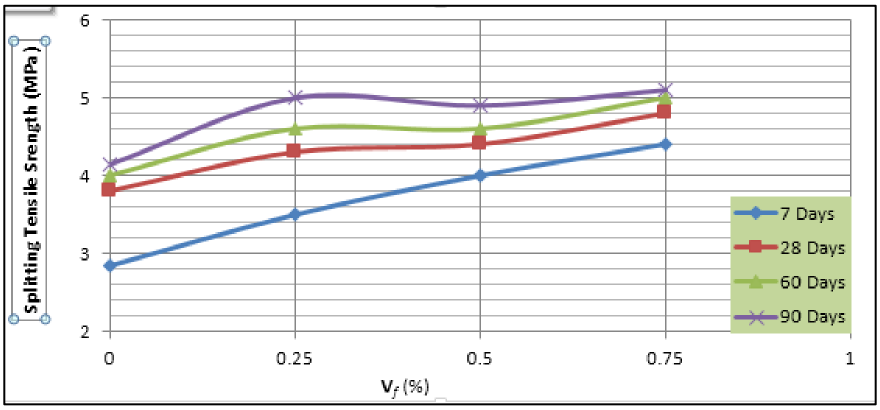

Figure 8: Relationship between splitting tensile strength of HPLWC specimens and volume fraction of mono polypropylene (18mm) at different ages

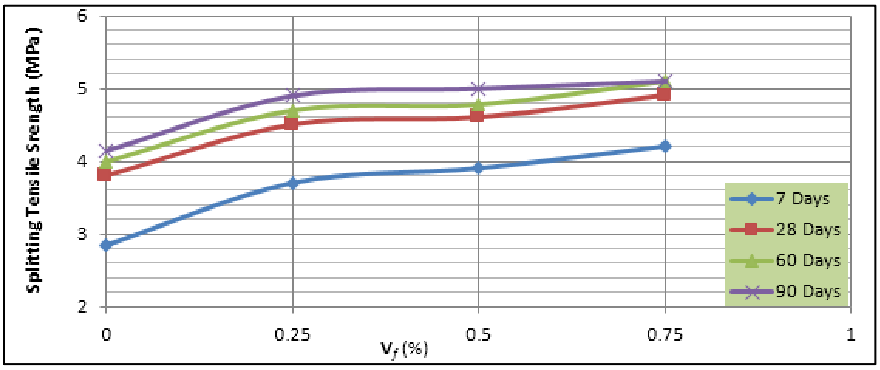

Figure 9: Relationship between splitting tensile strength of HPLWC specimens and volume fraction of waste polypropylene (30mm) at different ages

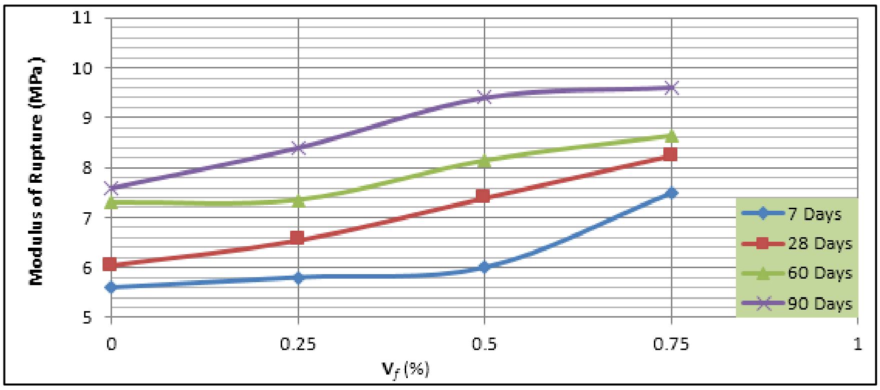

Figure 10: Relationship between modulus of rupture of HPLWC specimens and volume fraction of mono polypropylene (6mm) at different ages

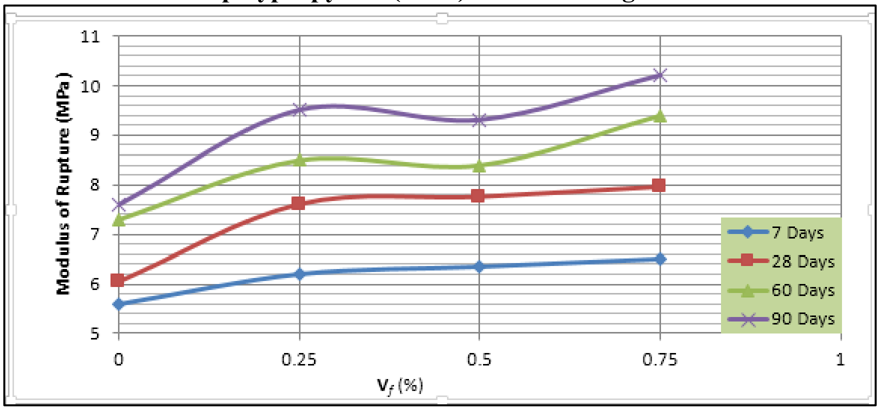

Figure 11: Relationship between modulus of rupture of HPLWC specimens and volume fraction of mono polypropylene (18mm) at different ages

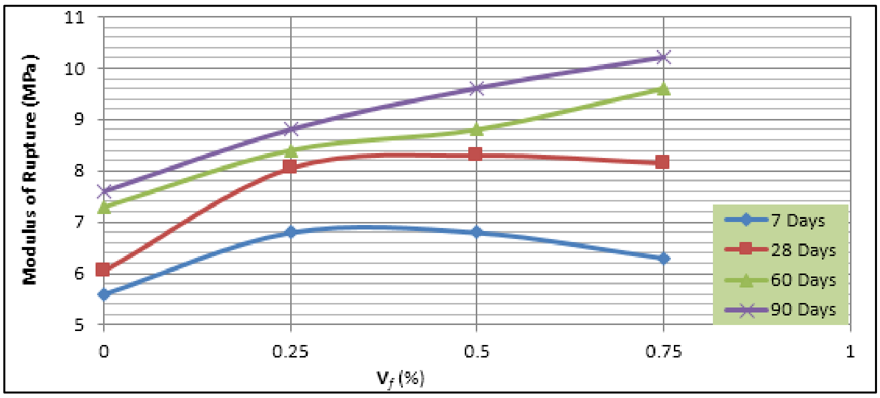

Figure 12: Relationship between modulus of rupture of HPLWC specimens and volume fraction of waste polypropylene (30mm) at different ages

Table 9: Effect of fiber reinforcement on the splitting tensile strength of HPLWC at different ages

Mix	Type of Fiber (mm)		Volume fraction (%)	Splitting tensile strength (MPa) 7 Day	28 Day	60 Day	90 Day
M 1 (Ref)	-----		0	2.85	3.8	4	4.15
M 2	Mono polypropylene	6	0.25	3.6	4.1	4.5	4.7
M 3			0.5	3.9	4.3	4.4	4.85
M 4			0.75	4.2	4.4	4.7	4.97
M 5		18	0.25	3.5	4.3	4.6	5
M 6			0.5	4	4.4	4.6	4.9
M 7			0.75	4.4	4.8	5	5.1
M 8	waste	30	0.25	3.7	4.5	4.7	4.9
M 9			0.5	3.9	4.6	4.78	5
M 10			0.75	4.2	4.9	5.1	5.3

Table 10: Effect of fiber reinforcement on the flexural strength of HPLWC at different ages

Mix	Type of Fiber (mm)		Volume fraction (%)	Flexural strength (MPa) 7 Day	28 Day	60 Day	90 Day
M 1 (Ref)	-----		0	5.6	6.05	7.3	7.6
M 2	Mono polypropylene	6	0.25	5.8	6.55	7.35	8.4
M 3			0.5	6	7.4	8.15	9.4
M 4			0.75	7.5	8.25	8.65	9.6
M 5		18	0.25	6.2	7.6	8.5	9.5
M 6			0.5	6.35	7.75	8.4	9.3
M 7			0.75	6.5	7.95	9.4	10.2
M 8	was te	30	0.25	6.3	8.05	8.4	8.8
M 9			0.5	6.8	8.3	8.8	9.6

M 10	0.75	6.3	8.15	9.6	10.2

Table 11: Static Modulus of HPLWC reinforced with different types of polypropylene

Mix	Type of Fiber (mm)		Volume fraction (%)	Modulus of Elasticity (GPa) 28 Day	90 Day
M 1 (Ref)	-----		0	25.89	27.44
M 2	Mono polypropylene	6	0.25	28.81	29.13
M 3			0.5	28.32	30.52
M 4			0.75	25.5	26.44
M 5		18	0.25	28.05	30.13
M 6			0.5	25.21	29.41
M 7			0.75	24.12	25.83
M 8	waste	30	0.25	27.65	29.85
M 9			0.5	27.44	28.60
M 10			0.75	25.56	27.31

Table 12: 28-Day air-dry density of mixes

Mix	Volume Fraction %	Fiber Length mm	Air Dry Density Kg/m^3	Variation from Reference mix %
M 1	-----	-----	1958.7	-----
M 2	0.25	6	1968.8	+ 0.5 %
M 3	0.5	6	1967.1	+ 0.4 %
M 4	0.75	6	1916.6	- 2.1 %
M 5	0.25	18	1918.9	- 2 %
M 6	0.5	18	1910.1	- 2.4 %
M 7	0.75	18	1887.2	- 3.6 %
M 8	0.25	30	1891.7	- 3.4 %
M 9	0.5	30	1899.5	- 3 %
M 10	0.75	30	1867.1	- 4.6 %

4. Conclusions

From the results of this investigation, the following conclusions can be drawn:

1. The addition of mono polypropylene fiber (6 and18) mm with V_f = 0.25% to lightweight concrete mixes have a little effect on the compressive strength at age 90 days. The average percentage of increase was 9.5% and 2% respectively. While with volume fraction of 0.5% and 0.75% the compressive strength tend to decrease, the average decrease was 11.5% and 4.35 % respectively.

2. Using waste polypropylene of 30 mm length appears to have a slight increase in compressive strength for V_f = 0.25% - 0.75%, the average percentage increase at 90 days was 3.6%.

3. The splitting tensile strength of high performance lightweight concrete improved by inclusion of different types of polypropylene with V_f = 0.25% , 0.5% , 0.75% , the percentage increase at 90 days was 21% , 19% and 24% respectively in comparison to reference specimens.

4. The results show that the modulus of rupture increases, as the volume fraction of polypropylene fiber increases (V_f = 0.25 % – 0.75%) and with volume fraction 0.75% fibers, there is a substantial increase in modulus of rapture compared with that of plain specimen.

5. The addition of different types of polypropylene fibers (mono-short (6mm) and long (18mm)) and waste (30mm) has a little effect on the static modulus of elasticity of fiber-reinforced lightweight concrete.

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