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Research paper

Enhancement of mechanical properties of lightweight concrete

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Abstract

In this presented paper, Three concrete mixtures were set to produce a Lightweight Aggregate Concrete (LWAC) using Expanded perlite aggregate (EPA) as a replacement of natural gravel. EPA used with replacement fractions of 0%, 30%, and 40% by weight of the coarse aggregate. An additional eight concrete mixtures were arranged to study the influence of using steel fiber (SF) and polypropylene fiber (PP) with various percentages on the mechanical properties of samples with 30% and 40% perlite content. The volumetric ratios of SF and PP fiber were 0%, .5%, 1%. The main objectives of this paper are to produce perlite concrete with a density less than 2000 kg/m3 and with 28-days cube compressive strength not less than 18 MPa, also to enhance perlite concrete properties with two types of fibers. The mechanical properties measured in this experimental work are composed of 28-day cube compressive strength, unit weight, flexural strength, and splitting-tensile strength. From the gained data, the required reduction in unit weight values of perlite concrete has been achieved. Also, steel fibers improved the tensile properties of perlite concrete more than PP fibers.

Keywords: *Expanded Perlite Aggregate; Lightweight Aggregate Concrete; Mechanical Properties; Polypropylene Fiber; Steel Fiber.*

1. Introduction

Lightweight concrete (LWC) has been broadly used in the field of structural engineering in the latest years due to its benefits [1], [2], [3], Such as low density which leads to saving in dead load, cross-section elements and overall cost of the structures, as well as its better fire and seismic resistance, good resistance to thawing and freezing, and better durability [3 -6]. However, there are also some defects of using LWC, for example, its low mechanical properties and higher brittleness nature [3], [6], [7]. We can develop a LWC by three various techniques. First method is by omitting the fine aggregate from the mixture, second method is by using chemical admixtures to obtain stable air bubbles in the concrete mixture, Finally, third way is by replacing a whole or part of natural aggregate (NA) by a natural or artificial lightweight aggregate (LWA), which are available in different parts around the world [4,8]. Expanded clay, expanded glass, perlite, expanded vermiculite and fly ash are most popular types of LWA [9]. Perlite is a natural volcanic rock and it can be expanded by heating above 870°c and as a result of heating its volume expanded up to (4-20) time of its original volume [10]. The porous structure of EPA gives it many advantages such as low density and excellent insulation properties [11 - 13]. Perlite is being used in various scientific branches like engineering, agricultural, medical, and chemical industry [10]. The main purpose of this experimental work is to study the influences of using EPA, SF, and PP fibers with different ratios on the mechanical properties of LWAC. Using EPA as an NA replacement in LWAC decreased the compressive strength with an increase of perlite content [14], also the unit weight of concrete can be reduced significantly by replacing NA with EPA [10]. LWC prepared with more than 20% EPA can be considered as insulation concretes due to compressive loss [10].Fibers have been used successfully through the latest two decades, where many researchers tried to enhance the properties of lightweight concrete using various types of fibers [6], [9], [15]. We can find a lot of industrial and natural types of fibers (Erhan et al., 2015; Khonsari et al., 2010). We can find a lot of industrial and natural types of fibers [9], [15]. We can get a more homogenous and isotropic concrete by adding fibers, also concrete becomes ductile [4]. Steel fiber and polypropylene fiber considered as the most popular kinds using in fibrous concrete [3]. Shape and ratio of fibers have large effects on the performance of fibrous concrete [6], [9], [15]. There are three classifications of fiber reinforced concrete, low (1% fiber ratio), moderate (1-2% fiber ratio) and high (> 2% fiber ratio) [9]. Using steel fiber with a (1-1.5%) ratio led to an enhancement in compressive strength, splitting-tensile strength and flexural strength by about (10-25%), (100%) and (150-200%), respectively [9]. Using wavy steel fiber into perlite concrete increased the compressive strength of concrete specimens, while PP fiber decreased it, also using SF and PP fiber with a 1% volumetric ratio developed indirect-tensile strength by about 100% and 40%, respectively [15]. Unit weight, compressive strength, splitting-tensile strength and flexural strength of LWAC mixture increased up with increasing SF ratio by about 8.5%, 21.1%, 61.2%, and 120.2%, respectively [8]. The compressive strength of LWAC can be developed by around (5-10%) for an SF volume fraction of (0-1%), also indirect-tensile strength increased by about more than 50% for an SF volume fraction of (1-1.5%) [9]. the best volume fraction of SF in LWAC is (1-1.5%) [2]. On the other hand, using PP fiber hasn't a great effect on the mechanical properties of LWAC like SF [3], [6], [15].

2. Experimental study

2.1. Materials

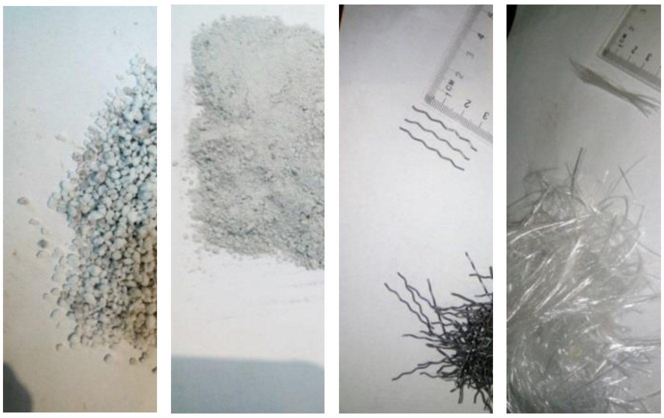
In this experimental work, Ordinary Portland Cement (OPC) type I with high grade 52.5 N and Silica Fume powder, photo1b, were used as the cementitious constituents. The specific gravity of the used cement and Silica Fume powder were 3.15 and 2.22, respectively. Supplementary specifications of the used silica fume powder are given in Table 1Cement and silica fume powder were used with constant values during this study, which were 520 kg/m3 and 15% (by weight of cement), respectively. A high-performance-water-reducer agent, Sikament-NN, was used as a super-plasticizer to obtain sufficient fluidity in all mixtures. Sikament-NN with a specific gravity of 1.2 was added by 4% of binder (OPC+ Silica Fume) content in all mixtures. The water used in this study was a clean tap water and the water/binder (W/b) ratio of .4 kept constant in all mixtures. Sand having a specific gravity of 2.6 and grain size less than .6mm, was used as the fine aggregate in this experimental work. Natural gravel having a specific gravity of 2.65 and 14 mm maximum nominal size was used as a part of the coarse aggregate in this experimental work. The weight of sand was about (1/3) of the overall weight of aggregate, where the weight of coarse aggregates (gravel + EPA) were about (2/3) of the overall weight of aggregate. Expanded perlite aggregate (EPA), photo1a, was used as a natural aggregate (NA) replacement in this study in order to decrease the unit weight of all concrete mixtures to obtain a LWAC. The percentages of replacement were 0%, 30%, and 40%. The perlite used with a specific gravity of .32, and Table 2 presented the other properties of the selected EPA. To study the effect of steel fiber, photo1c, and polypropylene fiber, photo1d, on the mechanical properties of LWAC, eight mixtures with three different volumetric ratios (0%, .5%, and 1%) were added to eight series of test specimens based on EPA30 and EPA40 control specimens. Steel fibers which were used in this presented work were a wavy shape with 30 mm long and 1mm diameter. PP fibers (50 mm) long were used to prevent early concrete cracking and to improve the durability of concrete. The specific gravity of the used steel fiber and polypropylene fiber was 7.8 and .9 respectively.

Table 1: Physical and Chemical Properties of Silica Fume [18]

Property	Measured values
Colour	Light grey
Specific gravity	2.2
Relative density (kg/m3)	300-400 (kg/m3)

Table 2: Physical Properties and Chemical Composition of EPA [19]

Property	Measured values
Chemical composition	
SiO2	72-76%
Al2O3	11-14%
Bound water	2-6%
Other oxides	5-13%
Physical properties	
Colour	Weight to greyish weight
Specific gravity	.32
Bulk density (kg/m3)	45-350 kg/m3
Grain size available	As desired, 5mm and finer
P.H.	6.5-7.5
Fusion point	1280-1350°c
Thermal conductivity at 24°c	.04-.06 w/m.k
Combustible and flammable ability	non
solubility	Soluble in heat concentrated alkali
Free moisture	.5% maximum



(A) **(B)** **(C)** **(D)**

Photo 1: Materials Used in Test Specimens.

2.2. Mix proportion

In this experimental study, 11 mixtures with constant and variable parameters were designed to study the hardened properties of LWAC with several unit weight classes. EPA ratios were 0%, 30%, and 40% and fibers ratios were 0%, .5%, and 1%. Materials used in this experimental work were cement, silica fume, water, SP, sand, gravel, perlite, SF, and PP fibers. The mix design was carried out depending on the absolute volume method and it is summarized in Table 3. A laboratory ban mixer with vertical rotation axis by forced mixing was used to mix all the concrete mixtures. EPA has a porous structure and high specific surface area and this increased its water demand, So before mixing, we kept it in water for 30 min to absorb its needed water and don't affect the effective water/binder ratio of the mixtures, then it was taken out of water and put on a fine mesh for the outflow of excessive surface water for about 30 sec. before mixing [9]. The mixing proportion was done as follows: firstly, all components expect of water and SP were mixed for a few minutes, then the water mixed with SP were added gradually and the concrete was mixed for 2 min. Next, fibers were added continuously into the mixer which rotated at a high speed for 4 min to ensure uniform distribution of fibers in mixtures.

Table 3: Mix Design (Kg/M3)

	Non-fibrous mixtures			Steel-fibrous mixtures				Polypropylene-fibrous mixtures			
Mix N0.	1	2	3	4	5	6	7	8	9	10	11
%EPA	0%	30%	40%	30%	30%	40%	40%	30%	30%	40%	40%
%fiber	0%	0%	0%	.5%	1%	.5%	1%	.5%	1%	.5%	1%
w/b	.4	.4	.4	.4	.4	.4	.4	.4	.4	.4	.4
Cement	520	520	520	520	520	520	520	520	520	520	520
Water	240	240	240	240	240	240	240	240	240	240	240
Silica	78	78	78	78	78	78	78	78	78	78	78
SP	24	24	24	24	24	24	24	24	24	24	24
Sand	473.7	193.6	161.7	191.8	190	160.3	158.8	191.8	190	160.3	158.8
Gravel	947.6	271	194	268.5	266	192.3	190.5	268.5	266	192.3	190.5
Perlite	0	116.2	129.4	115	114	128.2	95.3	115	114	128.2	95.3
Fiber	0	0	0	39	78	39	78	4.5	9	4.5	9

2.3. Test procedure

For each mixture, three samples of (100*100*100) mm cube, three samples of (100*100*500) mm prism and three samples of (100*200) mm cylinder were prepared to conclude the values of the unit weight, the cube compressive strength, the splitting or indirect tensile strength and the flexural strength of the perlite concrete. For every test, three samples from each perlite concrete mixture were confirmed.

At 28 day, cube samples were confirmed according to ASTM C-109 for compressive strength measurements by using 3000 KN capacity testing machine with a constant rate of loading 30 KN/Sec to record the failure load. At 28 days, cylindrical specimens of 100mm diameter and 200mm height were tested according to ASTM C-496 for indirect tensile test which indicates that the tensile strength can be estimated based on equation (1), where P is applied load, L is cylinder length, D is cylinder diameter and F is the required tensile strength.

$$F = 2P/\Pi\ LD \quad (1)$$

At 28 days, prismatic specimens were confirmed according to ASTM C-1018 under three-point bending for flexural strength which indicates that the flexural strength can be estimated based on equation (2), where p is failure load, L is center to center distance between the support = 400 mm, b is average specimen width=100 mm and d is average specimen depth = 100 mm.

$$Ftb = PL/bd2\ (MPa) \quad (2)$$

3. Results and discussion

Mechanical properties, unit weight, compressive strength, splitting-tensile strength and flexural strength are studied to show the effect of Expanded Perlite Aggregate (EPA), Steel Fiber (SF) and Polypropylene Fiber (PP) on the hardened Lightweight Aggregate Concrete (LWAC) properties.

3.1. Unit weight

Unit weight or the density of the lightweight aggregate concrete (LWAC) is considered an essential property, which was determined at 28-day curing. As known, any growth on the unit weight can enhance the strength and the other properties of the hardened concrete. Unit weight results of the perlite concrete are given in Table 4. Table 4 indicates that the unit weight of concretes decreases with increasing (EPA) content in all mixtures and this reduction of unit
weight is probably due to the minor value of the specific gravity of perlite aggregate and its porous structure when compared with the natural aggregate (NA). It was observed from the obtained data that the unit weight of concretes decreased with 22.8%, and 41.2% for EPA30, and EPA40, respectively, when compared to the reference sample (EPA0) that of containing no perlite aggregate, therefore, the replacement ratio of perlite with gravel has a large effect on the unit weight of specimens and the other properties of the hardened concrete. As is known, decreases on the unit weight can have a lower total weight of the structural elements, therefore, lesser amounts of reinforcing steel and reduced cross sections can be obtained, besides the lesser overall cost of the structure can be gained. Similar results were also obtained by other researchers [13], [14], [16].

Table 4: Results for Non-Fibrous Specimens

Mix No.	% EPA	***ρ*** (kg/m3)	Fcu (MPa)	Fsp (MPa)	Fr (MPa)
1	0%	2594	62.9	4.5288	5.7868
2	30%	2002	38.08	2.244	3.8
3	40%	1526	21.8	1.5858	2.19

The variations in unit weight with EPA and SF ratios are shown in Table 5. As seen in Table 5, the unit weight of perlite concretes improved with increasing steel fiber ratio and decreased with increasing EPA ratio. Increasing in unit weights for .5% SF ratio was 1.98 % and 2.05% for EPA30 and EPA40, and for 1% SF were 3.1% and 3.2% for EPA30 and EPA40 respectively compared to the control specimens that contain no fiber. This is may be due to the high specific gravity of steel fibers.

Table 5: Results for Steel-Fibrous Specimens

Mix No.	% EPA	% Steel Fiber	***ρ*** (Kg/M3)	Fcu (MPa)	Fsp (MPa)	Fr (MPa)
2	30 %	0 %	2002	38.08	2.244	3.8
4		.5 %	2041.75	41.2	3.7408	4.85
5		1 %	2064.15	39.7	4.392	7.01
3	40 %	0 %	1526	21.8	1.2858	2.19
6		.5 %	1557.3	23.75	2.1224	2.75
7		1 %	1574.8	22.826	2.5	3.95

The differences in the unit weight with EPA and PP fiber ratios are listed in Table 6. It can be noticed from Table 6 that the unit weight of perlite concretes reduced with increasing polypropylene fiber ratio and also decreased with increasing EPA ratio. Decreasing in unit weights for .5% PP and 1%pp fiber ratio were 2.2% and 2.3% for EPA30, and for .5% and 1% PP fiber ratio were 2.19% and 2.42% for EPA40, respectively compared to the control specimens that contain no fiber. According to the obtained records, it was noticed that the PP fiber has no obvious influence on the unit weight of LWAC and this is probably because of the degradation of polypropylene fibers creates voids inside of the concrete. The creation of these voids and increasing polypropylene fiber ratio, which lowers the density of concrete a bit more due to polypropylene fiber's relatively low density, decrease the density and increases the porosity of the sample [4].

Table 6: Results for Polypropylene-Fibrous Specimens

Mix No.	% EPA	% PP Fiber	***ρ*** (kg/m3)	Fcu (MPa)	Fsp (MPa)	Fr (MPa)
2		0 %	2002	38.08	2.244	3.8
8	30 %	.5 %	1958	35.72	2.77	3.42
9		1 %	1956	34.565	2.276	3.238
3		0 %	1526	21.8	1.2858	2.19
10	40 %	.5 %	1492.5	19.108	1.585	1.957
11		1 %	1489	17.813	1.35	1.854

3.2. Compressive strength

One of the best important mechanical properties of the hardened concrete is compressive strength property. Three cube samples in the series of each mixture were tested to achieve the typical results for the compressive strength test. Compressive strength values of perlite concrete at 28-day curing are presented in Table 4. It was noticed from the gained records that the compressive strength of perlite concretes reduced regularly with the unit weight of perlite concretes as drawn in Fig. 1. Other researchers reported also that the compressive strength is a function of unit weight (10,14). Reductions in compressive strength at 28-days curing period were 39.5%, and 65.4% for 30%, and 40% EPA replacement of NA, respectively, when compared to the control sample EPA0 which contain no EPA and this is probably because of the following: (a) the weak structure of EPA in the matrix, where the weakest component in lightweight aggregate concrete is the coarse lightweight aggregate rather than the hardened cement paste and the transition zone between cement paste and lightweight aggregate, so controlling the ultimate strength of lightweight aggregate concrete depending on controlling the strength of the lightweight coarse aggregate itself [2]; (b) In addition, as perlite dosage increased, the quantity of mixing waster also increased considerably, which had a negative effect on strength performance [17]; (c) Also, the compressive strength is a function of the unit weight. Mention that, water/binder ratio (.40) remains constant in all mixtures in this study, but the compressive strength value may be increased by decreasing water/binder ratio.

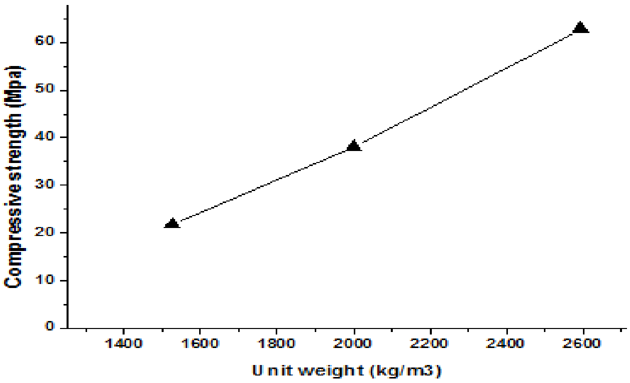


Fig. 1: The Relationship between Unit Weight and Compressive Strength for Non-Fibrous Specimens.

The developments in compressive strength with EPA and SF ratios are given in Table 5. Test results show that the compressive strength of concrete specimens increased with increasing steel fiber ratio and decreased with increasing EPA ratio. While the compressive strength of reference samples that contain no fiber was 38.08 and 21.8 MPa, on the other hand, the compressive strength of concretes of those made up of .5%SF were 41.2 and 23.75 MPa and of those made up of 1% SF, were 39.7 and 22.826 MPa for EPA30 and EPA40, respectively.
Compressive strength increased, but the addition of fibers has a minor effect on the improvement of the compressive strength values. This increment in compressive strength values may be because of the resultant arresting growth of cracks based on the bond of steel fiber and cement paste [2]. Using higher volume fraction of steel fibers more than .5% decreased the compressive strength due to the difficulty in dispersing the fiber and inadequate compaction of concrete [9]. Other researchers gave similar results [2,8,10]. The differences in compressive strength with EPA and PP fiber ratios are listed in Table 6. From test results, it obviously shows that the PP fiber hasn't a great effect on the compressive strength of all mixtures. Adding the PP fiber with ratios of .5% and 1% decrease the compressive strength by about 6.2% and 9.2% for EPA30 and by about 12.4% and 18.3% for EPA40, respectively, compared to the control sample which has no fiber, and this is probably because of the following: (a) fiber clumping (or balling), causing to inhomogeneous mixture; (b) Meanwhile, due to the large surface area of fibers, a large amount of cement mortar was required to coat the fibers, leading to poor compaction of concrete; (c) PP fiber causes a lower workability; (d) the amount and orientation of disperse fiber, which obstructed the voids; (e) PP was chemically inactive and hydrophobic, thus the potential for chemical bonding was limited [3], [17]. Other researchers provided similar results [3], [17].

3.2.1. Modes of compression failure

The failure mode changes from sudden explosive failure resulting in semi-complete damage of the specimen to a more ductile failure in which the specimen is still intact after failure. Photo (2) shows compression failure of concrete without fibers and concrete with fibers.

(A) **(B)** **(C)**

Photo 2: 2a) Compression Failure of Concrete without Fibers for Cube Specimens. 2b) Compression Failure of Concrete with Steel Fibers for Cube Specimens. 2c) Compression Failure of Concrete with Polypropylene Fibers for Cube Specimens.

3.3. Splitting-tensile strength

The splitting or indirect tensile strength presents a significant effect on the safety and the ductility of the hardened concrete. So, it is necessary to study it carefully. Three-cylinder specimens in the sequence of each concrete mixture were confirmed to achieve the typical results for the indirect-tensile strength test. Splitting-tensile strength test results of perlite concrete are set in Table 4. It was observed from the obtained data that the splitting-tensile strength of concretes decreases with increasing EPA ratio, which is similar to compressive strength results. Reductions for splitting-tensile strength at 28-days curing period were 50.45%, and 65% for 30%, and 40% EPA replacement of NA, respectively compared to the reference specimen EPA0 which has no EPA This reduction is may be due to the weak structure of the EPA in the matrix. Effect of EPA ratios on indirect tensile strength is drawn in Fig. 2.

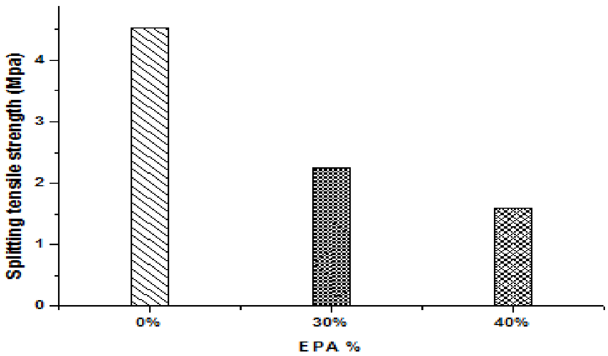


Fig. 2: Splitting-Tensile Strength Results for Non-Fibrous Specimens.

3.3.1. Effect of SF ratios on splitting-tensile strength

The variations in splitting-tensile strength with EPA and SF ratios are presented in Table 5 and summarized in Fig. 3. Test results indicated that there was an enhancement in indirect tensile strength with increasing steel fiber ratios. Addition of SF with ratio .5% and 1% increases the splitting-tensile strength by about 66.7% and 95.7% for EPA30 and by about 65% and 94.5% for EPA40, respectively and this is may be due to the mechanical properties of steel fibers which improves the bond strength of concrete, a relatively significant development in the tensile strength values were observed. Since the splitting-tensile strength is known to provide a sign of shear strength in diagonal tension, it is an important design parameter for beams and also the increase can be utilized in structures subjected to shear [8].
Test results carried by Jianming et al., (1997) [16] is used to evaluate the splitting tensile strength of steel fiber reinforced high strength lightweight concrete as shown in equation (3).

$$fsp = 0.94fspo(l - Vf) + 3.02Vf.lf/df \quad (3)$$

Where fspo = splitting tensile strength of high strength lightweight concrete; fsp = splitting tensile strength of steel fiber reinforced high strength lightweight concrete; vf =fiber volume fraction; and lf/df =fiber aspect ratio.
And from results given in Table 5, we can modify equation (3) to be qualified for determining splitting tensile strength for steel fiber lightweight aggregate concrete as following:

$$fsp = 1.35fspo(l - Vf) + 2.98Vf.lf/df \quad (4)$$

Where fspo = splitting tensile strength of lightweight aggregate concrete; fsp = splitting tensile strength of steel fiber lightweight aggregate concrete; vf =fiber volume fraction; and lf/df =fiber aspect ratio.

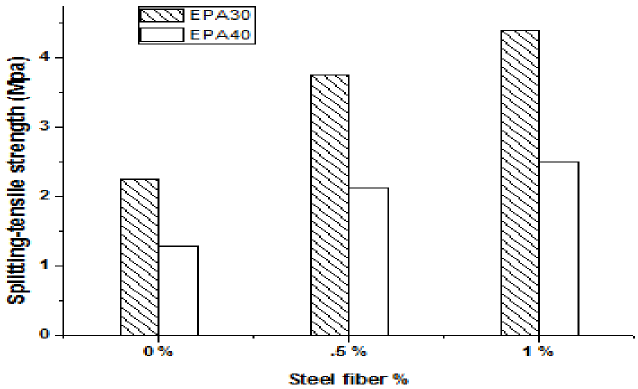


Fig. 3: Splitting-Tensile Strength Results for Steel-Fibrous Specimens.

3.3.2. Effect of PP fiber ratios on splitting-tensile strength

The variations in splitting-tensile strength with EPA and PP fiber ratios are given in Table 6 and summarized in Fig. 4. As can be noted from the gained data that the splitting-tensile strength increases first at .5%PP ratio and then decreases at 1% PP fiber ratio, The significant improvement in tensile strength was attributed to the bridging mechanism of fibers in impeding the development of cracks. In addition, it slightly improves post-cracking behaviour [3].

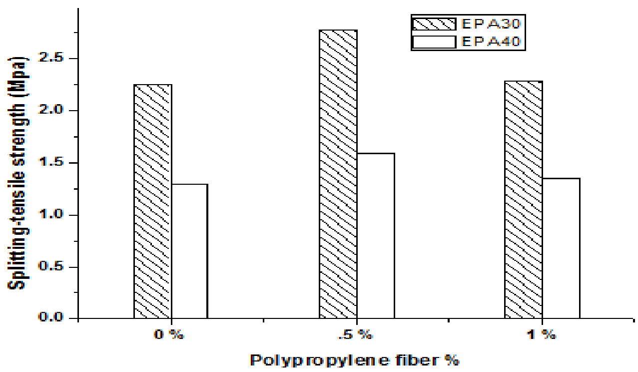


Fig. 4: Splitting-Tensile Strength Results for Polypropylene Fibrous Specimens.

3.4. Flexural strength

Three prismatic specimens in the series which are loaded at three points were tested to obtain the average results for flexural strength test of each concrete mixture. Flexural strength test results of perlite concrete are listed in Table 4 and summarized in Fig. 5. It was observed from the obtained data that the flexural strength of concretes decreases with increasing EPA ratio, which is similar to compressive strength results. Reductions in flexural strength at 28-days curing period were 34.3%, and 62.2% to 30%, and 40% EPA replacement of NA, respectively compared to the reference specimens EPA0 which has no EPA. This reduction is maybe because of the matrix being harder than the EPA.

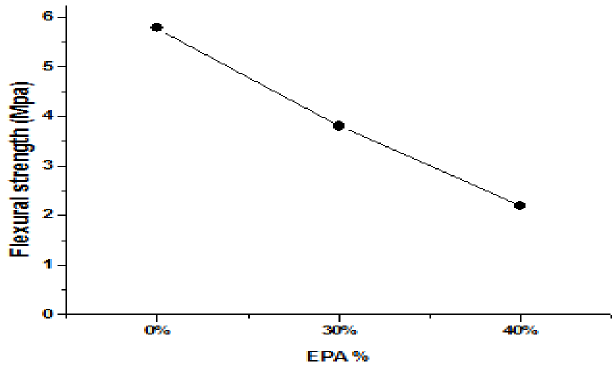


Fig. 5: Flexural Strength Results for Non-Fibrous Specimens.

3.4.1. Effect of SF ratios on flexural strength

The variations in flexural strength with EPA and SF ratios are given in Table 5 and summarized in Fig. 6. Test results indicated that there was an improvement in flexural strength with increasing the steel fiber ratios. Addition of SF with ratio .5% and 1%increases the flexural strength by about 27.6% and 84.4% for EPA30 and by about 25.5% and 80.4% for EPA40, respectively and this is may be due the fact that these fibers delay the unstable growth of cracks which usually occurs in flexure, After occurrence of initial cracking, the sample did not fail suddenly. This is probably due to the randomly oriented fibers crossing the cracked section, which resists the propagation of cracks and separation of the section. This causes an increase in the load-carrying capacity [6,8]. 1% SF can be utilized in structures subjected to bending moment such as beams and slabs.

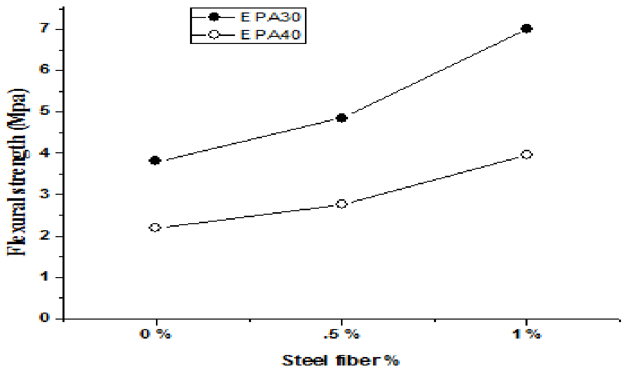


Fig. 6: Flexural Strength Results for Steel-Fibrous Specimens.

3.4.2. Effect of PP fiber ratios on flexural strength.

The variations in flexural strength with EPA and PP fiber ratios are given in Table 6 and summarized in Fig. 7. From the obtained results it can be noticed that the flexural strength of perlite concrete reduced with increasing PP fiber ratio. The lower effect of PP fibers on flexural strength improvement may be attributed to the lower tensile strength of these fibers and also the weaker bonding between PP fibers and the cement matrix [6].

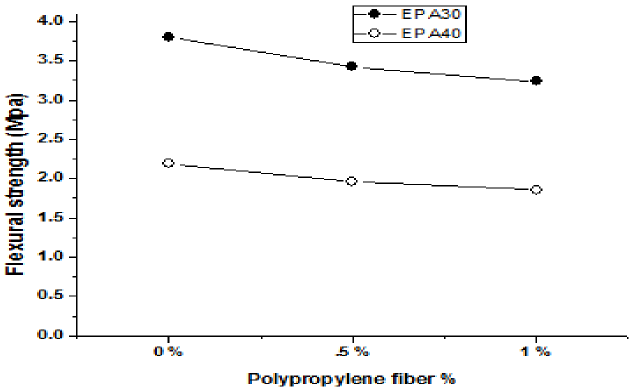


Fig. 7: Flexural Strength Results for Polypropylene-Fibrous Specimens.

4. Conclusions

The effects of EPA, SF, and PP fibers with different ratios on the mechanical properties of LWAC were investigated. And the conclusions can be summarized as follows:

- It is possible to produce LWAC using available local materials that if they carefully selected.
- Replacing EPA with gravel achieve the required reduction in unit weight of perlite concrete.
- Steel fiber slightly enhanced the compressive strength of perlite concrete, but it has a great effect on the other mechanical properties of LWAC.
- Steel fiber with volume fraction up to .5% gives good enhancement on the splitting-tensile strength of perlite concrete.
- Steel fiber with volume fraction up to1% can be used to enhance the flexural strength of perlite concrete.
- 1% steel fiber reduced the workability of perlite concrete.
- 1% steel fiber with 40%EPA didn't achieve the required results.
- On the other hand, PP fibers have no obvious effect on the mechanical properties of perlite concrete; furthermore PP fiber with volume fraction 1% may reduce them.

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