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Mechanical properties of hybrid fiber reinforced lightweight aggregate concrete made with natural pumice

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ABSTRACT

The purpose of this study is to improve the ductility of pumice lightweight aggregate concrete by incorporating hybrid steel and polypropylene fibers. The changes in mechanical properties and also bulk density and workability of pumice lightweight aggregate concrete due to the addition of hybrid steel and polypropylene fibers have been studied. The properties were investigated include bulk density and workability of fresh concrete as well as compressive strength, flexural tensile strength, splitting tensile strength and toughness of hardened concrete. Nine concrete mixtures with different volume fractions of steel and polypropylene fibers were tested. A large increase in compressive and flexural ductility and energy absorption capacity due to the addition of steel fibers was observed. Polypropylene fibers, on the other hand, caused a minor change in mechanical properties of hardened concrete especially in the mixtures made with both steel and polypropylene fibers. These observations provide insight into the benefits of different fiber reinforcement systems to the mechanical performance of pumice lightweight aggregate concrete which is considered to be brittle. These results provide guidance for design of concrete materials with reduced density and enhanced ductility for different applications, including construction of high-rise, earthquake-resistant buildings.

1. Introduction

The advantages of light weight concrete over normal weight concrete are numerous and well known e.g. lower density, higher strength/weight ratio [1], lower coefficient of thermal conductivity [2,3], better fire resistance [4], improved durability properties [5,6] and etc. Reduced dead load obtained by use of lightweight concrete not only result in a decrease in cross section of columns, beams, walls and foundations, but also decrease the induced seismic loads and reduce the risk of earthquake damages to structures [7] since, the earthquake loads influencing the structures and buildings are proportional to the mass of those structures and buildings. Structural light weight aggregate concrete (LWAC) are usually produced by replacing a whole or a part of natural normal weight aggregate by artificial or natural light weight aggregate (LWA). Such aggregates, natural or artificial, are available in various parts of the world. Pumice is a type of natural lightweight aggregates of volcanic origin and it is found abundantly in volcanic area e.g. countries like Chile, Ethiopia, Greece, Spain, Turkey, the United States and Iran [8]. Due to the presence of active faults, Iran is subjected to considerable earthquake activities. Therefore, there is a vast interest in the utilization of structural lightweight aggregate concrete with adequate mechanical properties to improve seismic behavior of structures that located in high seismic risk areas of Iran.

The main objective of application of lightweight concrete in the buildings located in seismic zones is to improve seismic behavior of those structures. However, due to the weakness and brittleness of lightweight aggregate there are some defects in mechanical properties of hardened lightweight aggregate concrete. Brittle nature of lightweight aggregate leads to premature failure of the LWAC specimen after peak loads [9]. The weakness of LWA contributes on reduced tensile and flexural strength of LWAC. Brittleness of LWAC is on the contrary with the main objective of LWAC that requires ductile behavior in seismic loads. This disadvantage can be overcome by utilizing appropriate amount of fibers [10–12].

Several experimental investigations have pointed out the influence of the type and properties of reinforcing fibers, on the strength and ductility of the normal weight concrete under compressive, tensile and flexural loads [13–16]. The addition of fibers significantly improves many of the engineering properties of concrete, notably ductility, impact strength and toughness. A significant reduction in crack width and crack spacing is possible, especially at early ages [17]. Fibers also may be applied to control the detrimental effects of shrinkage. The fibers increase the early tensile strength and hinder, by mechanical bridging, the growth of initial cracks. For such applications short and thin fibers, even with low

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strength, may fulfill the requirements. Some experiments [18–21] also indicate that fiber reinforcing enhance tensile strength, flexural strength and fatigue strength of normal weight concrete. Nevertheless, most studies on fiber reinforced concrete have neglected lightweight concrete [14,22]. If lightweight concrete is used similar effects are expected but larger amounts of reinforcing fibers are required due to the brittle nature of the composite.

There are numerous studies on using pumice lightweight aggregate either in structural lightweight concrete production or lightweight concrete implemented for thermal insulation and masonry blocks [23–27]. However, there are few published studies on the use of steel or polypropylene fiber for reinforcing pumice lightweight aggregate concrete [28,29]. Also, there is not much published material on ductility properties of hybrid fiber reinforced structural lightweight aggregate concrete made with pumice. Yasar et al. [30] studied strength properties of lightweight concrete made with basaltic pumice and fly ash as two mineral admixtures. They used 500 kg/m^3 cementitious materials and obtained a lightweight concrete with about 30 MPa compressive strength and 1850 kg/m^3 air dried density at 28 days. The effects of pumice LWA gradation on mechanical properties of LWAC were studied by Sari and Pasamehmetoglu [31]. Other researchers [24] evaluated the influence of cement dosage and pumice aggregate ratios on some mechanical properties of LWAC and concluded that increasing pumice aggregate ratio will decrease thermal conductivity, density and compressive strength of concrete. Some characteristic of high strength fiber reinforced pumice lightweight aggregate concrete were also reported by Duzgun et al. [28] and Kayali et al. [32]. Behavior in compression of pumice lightweight concrete reinforced with fiber and transverse steel reinforcement is investigated by Compione and La Mendola [9]. Very brittle behavior of pumice lightweight concrete was observed in compression while the addition of steel fibers increased the residual strength and the energy absorption capacity of fiber reinforced LWAC. In spite of the advantages that have been reported in this area [33–35], much more research is still needed. This is especially necessary due to the diversity of the sources from which lightweight aggregates may be obtained. Besides, diversity of fiber types and various choices that are available within each type, necessitate more investigations.

This research contributes to the status of knowledge of hybrid steel and polypropylene fiber reinforced lightweight aggregate concrete. This paper describes and discusses mechanical tests carried out on fiber reinforced pumice lightweight aggregate concrete. These tests are a part of a comprehensive research program aimed at the feasibility study of utilizing domestic pumice lightweight aggregate for producing structural LWAC. The experimental investigation reported herein focuses on further study of ductility behavior of fiber reinforced lightweight aggregate concrete made with natural pumice aggregate.

2. Experimental program

To investigate the effect of both steel and polypropylene (PP) fibers on the properties of lightweight aggregate concrete, nine mixtures with varying volume of steel and PP fibers were prepared. The volume fraction of steel fibers varied between 0% and 1% of concrete, in steps of 0.5% while the volume fraction of PP fibers varied between 0% and 0.4% of concrete, in steps of 0.2%. The fiber contents of all nine mixtures are summarized in Table 1. All other parameters e.g. the cement content ($c = 475$ kg/m^3), the water/cement ratio (w/c = 0.3), the superplasticizer dosage (SP = 0.7%), the weight ratio of coarse lightweight aggregate to natural river sand (LWA/S = 0.56) were kept constant in all mixtures. The water absorption of aggregates within mixing time was determined and the batch proportions were adjusted accordingly.

2.1. Materials properties

The cement used in all mixes was ordinary Portland cement with a specific surface area of 2800 cm^2/g, which corresponds to ASTM Type I. In all mixes, 12 mm maximum size natural light weight pumice was employed as coarse aggregate and the fine aggregate was river sand with a maximum size of 4.75 mm. Properties of the steel and PP fibers which provided by the manufacturer are presented in Table 2. To obtain sufficient fluidity in fiber reinforced lightweight mixtures a polycarboxylic type superplasticizer was used in all mixtures.

Table 1
Fiber ratios in mixes.

Mix no.	1	2	3	4	5	6	7	8	9
Steel fiber ratio (%)	0.0	0.5	1.0	0.0	0.5	1.0	0.0	0.5	1.0
PP fiber ratio (%)	0.0	0.0	0.0	0.2	0.2	0.2	0.4	0.4	0.4

Table 2
Properties of fibers.

Fiber type	Density (kg/m^3)	Length (mm)	Diameter (mm)	Tensile strength (MPa)	Geometry
Steel	8000	35	0.55	1100	Hooked
Polypropylene	900	12	0.016	400	Fibrillated

2.2. Specimens and testing

All mixing and preparation of specimens were done at room temperature. Pumice lightweight aggregates were first moistened with enough water and left for ten minutes before blending with cement and sand to compensate the short time absorption of lightweight aggregates. The mixtures without fibers were mixed for 3 min then the slump tests were performed to evaluate workability of plain mixtures. Next, steel and/or PP fibers were added into the drum of a 75 l capacity pan-mixer and the drum rotated at high speed for 5 min afterwards to achieve a uniform distribution of the fibers in concrete. Traditional slump test usually fails to evaluate workability of fiber reinforced concrete. So, it is recommended to utilize the inverted slump cone test for evaluating workability of fiber reinforced concrete. The test is standardized in ASTM C995 [36]. In this test a vibrator is inserted into an inverted slump cone which is filled with concrete and the total elapsed time from the insertion of the vibrator until all the concrete has passed out of the slump cone is recorded. The less the discharging time, the more workable concrete. If the elapsed time is more than 120 s, the vibrator is taken out and the distance from the top of concrete level to top of cone is recorded as the result. After completing the workability tests, the following specimens were cast from each mix:

- Six 150 mm cubes to measure the compressive strength of hardened concrete at 3, 7 and 28 days and also the bulk density at 28 days.
- Two 150 × 300 mm cylinders for obtaining the compressive stress–strain relationship. The tests for stress–strain relationship were performed using displacement control facility.
- Further, two 150 × 300 mm cylinders for the splitting tensile strength tests.
- Three 100 × 100 × 500 mm beams for the flexural load–deflection relationship over a span of 300 mm under three points loading and also measuring the flexural strength. Both load and deflection were measured with a servo controlled hydraulic machine and a displacement transducer, respectively.

Even though it is more usual to use three specimens for each test, two specimens were used in tests to reduce the volume of concrete required for testing and to adjust it with the limit capacity of the pan mixer. In this way the volume of concrete required for measuring fresh and hardened properties of concrete will become 70 l which is less than the limit capacity of pan mixer (75 l). The specimens were kept covered in their molds for 24 h. After demoulding they were placed in 20 ± 2 °C water for 28 days. The specimens were removed from water and placed in a regular laboratory environment, 2 h before carrying out the tests. All tests were performed according to relevant ASTM standards [36].

3. Results and discussion

3.1. Workability and bulk density

The workability of fresh concrete before addition of fibers was almost the same in all mixtures. The slump values of all nine mixtures before addition of fibers were in the range of 15–20 cm. The fluidity of concrete was reduced significantly after addition of fibers. Therefore, the slump test could not be used to evaluate workability of fresh concrete. As outlined earlier, the workability of fiber reinforced concrete was measured by inverted slump cone test. The inverted slump cone test was also performed on the plain mix and the results of fiber reinforced mixes were compared with the plain mix to investigate the effect of fibers on workability of fresh concrete. The results of fresh concrete tests are presented in Table 3.

Polypropylene (PP) fiber showed lower effect on workability of fresh concrete, while steel fibers showed higher. For instance the discharging time of plain concrete is 22 s while the addition of 0.4% PP fibers increased the discharging time up to 67 s. In the case of steel fibers, addition of 0.5% and 1% fibers increased the discharging time to more than 120 s. Therefore, instead of discharging time, the distance from the top of concrete level to top of cone is recorded as the result. In spite of the reduced workability, the visual inspections reveal that adding fiber to the lightweight concrete improves the uniformity and stability of the fresh mix. The improved uniformity is due to the fact that fibers can form a network structure in concrete, which can effectively restrain the segregation of lightweight aggregates.

The bulk densities of hardened concretes which were measured at 28 days are listed in Table 3. It is noted from the bulk density results that the PP fibers have insignificant effect on the density of concrete specimens. But, the concrete density is mainly affected by incorporation of steel fibers. While the density of samples that contain no steel fibers were 1760, 1780 and 1740 kg/m^3 the density of concretes of those made up of 0.5% steel fiber were 1860, 1800 and 1880 kg/m^3 and of those made up of 1% steel fiber were 1870, 1880 and 1880 kg/m^3 for 0%, 0.2% and 0.4% PP fibers volume ratios, respectively. This is clearly due to the high specific gravity of steel fibers. Regression analysis using a linear relation between the volume percentage of steel fibers and the density of hardened concrete shows that addition of 1% steel fiber increases the density of concrete by about 118 kg/m^3. The effect of steel fibers on increasing the density of concrete specimens is very important in the case of lightweight concrete in which reduced density is of great importance. So, the designer should consider this phenomenon in proportioning of lightweight aggregate concrete.

3.2. Compressive behavior

Compressive characteristics are listed in Table 4 that includes compressive strength at 3, 7 and 28 days and also pre-peak compressive energy and total compressive energy (or toughness). Total compressive energy which is usually known as toughness is defined as the total compressive energy absorbed (total area under compressive stress–strain curve) while pre-peak compressive energy denotes the portion of energy absorbed until the maximum compressive strength (the area under stress–strain curve until maximum stress). Compressive stress–strain relationships of all mixes are shown in Fig. 1. Each compression test result in Fig. 1 and Table 4 is an average of two test specimens.

Table 3
Results of inverted slump test and bulk density.

Mix no.	Inverted slump test		Bulk density (kg/m^3)
	(s)	[a](cm)	
1	22	–	1760
2	120	12	1860
3	120	8	1870
4	45	–	1780
5	120	13	1800
6	120	10	1880
7	67	–	1740
8	120	4	1840
9	120	3	1880

[a] If the elapsed time is more than 120 s, the distance from the top of concrete level to top of cone is recorded as the result.

Table 4
Compressive characteristic.

Mix no.	Compressive strength (MPa)			Pre-peak energy (MPa)	Total energy (MPa)
	3 days	7 days	28 days		
1	12.5	16.0	18.7	3.49E−02	5.51E−02
2	19.5	20.8	30.2	4.92E−02	19.8E−02
3	20.4	21.7	28.9	5.29E−02	26.6E−02
4	15.0	17.8	20.8	3.86E−02	5.78E−02
5	15.7	21.9	27.0	5.72E−02	15.0E−02
6	15.6	18.9	25.6	5.91E−02	26.9E−02
7	12.7	15.4	17.1	3.46E−02	9.78E−02
8	17.5	21.2	26.0	6.47E−02	22.2E−02
9	16.9	20.4	26.5	5.23E−02	28.5E−02

From the compressive test results obtained in this research, it may be concluded that PP fibers have no obvious effect on compressive strength of concrete. From Table 4 it may also be concluded that the addition of steel fibers up to 0.5% of concrete volume improved the compressive strength of concrete by about 47%. Adding more steel fibers up to 1% of concrete volume was not so effective and no further strength increment were observed. In this case the compressive strength improvement was about 44%. For steel fiber volume fraction more than 0.5%, the effect of steel fiber on compressive strength seems insignificant and rather inconsistent.

Of course the main objective of adding fibers to the lightweight aggregate concrete, in this research, was to improve the ductility and post-peak behavior. Accordingly, the effects of fibers on compressive curves are discussed in more details. As is well established, PP fibers slightly enhance the energy absorption and toughness characteristic of concrete under compression. The effect of PP fibers on improving ductility of concrete in compression is more pronounced when no steel fibers incorporated in concrete mixes. In this case, the value of compressive toughness of plain concrete is 5.5×10^{-2} MPa while for the mix with 0.4% PP fiber, the value is 9.8×10^{-2} MPa that means the addition of 0.4% PP fibers doubled the toughness of LWAC. On the other side, steel fibers have a greater effect on energy absorption of concrete under compression. For comparison, the values of compressive toughness of steel fiber reinforced light weight aggregate concrete are about 19.8×10^{-2} MPa and 26.6×10^{-2} MPa for 0.5% and 1% steel fiber, respectively. The improvements are characterized by the increase in both compressive toughness and pre-peak compressive energy absorbed as a result of steel fiber addition. It is worth noting that the addition of steel fibers has more effect on the compressive toughness since the descending part of stress–strain curves are mainly affected by addition of steel fibers while these fibers have lower effect on the ascending part of the curve.

3.3. Flexural behavior

Flexural load deflection test results are shown in Figs. 2 and 3. Table 5 summarizes the flexural characteristic and also tensile strength of all concrete mixes. Each test result presented in Fig. 2, Fig. 3 or Table 5 is an average of three identical test specimens. As outlined earlier, total flexural energy (or flexural toughness) indicates the total area under flexural load–deflection curve while the pre-peak flexural energy refers to the portion of energy absorbed before ultimate flexural strength. Fig. 3 shows the effect of both steel and PP fibers on flexural strength of concrete. The test results show that an increase in steel fiber ratio increased the flexural strength in all cases. On the other side the addition of PP fibers

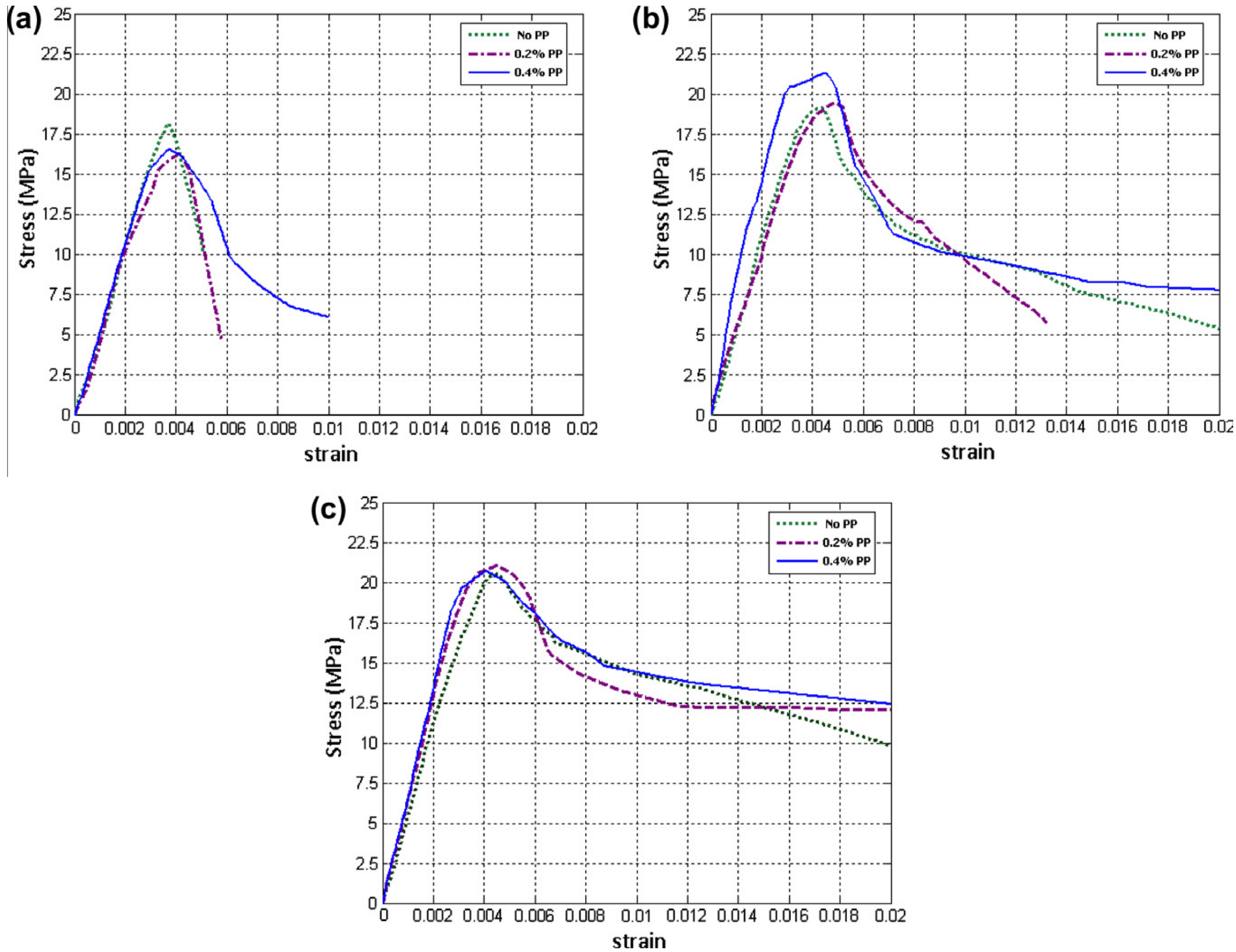

Fig. 1. Compressive behavior of concrete specimens: (a) steel fiber = 0%, (b) steel fiber = 0.5%, (c) steel fiber = 1%.

has a relatively lower effect on the improvement of the flexural strength values. For instance, increasing the SF ratio from 0% in the plain mix to 0.5% and 1% in fiber reinforced mixes increases the flexural strength by about 67% and 198%, respectively. On the other side, increasing the PP fiber from 0% to 0.2% and 0.4% increases the flexural strength by about 24% and 57% respectively.

Regression analysis using a second order polynomials between the volume percentage of steel fibers and the flexural strength of all concrete show that the addition of 0.5% and 1% of steel fibers in concrete mixes increases the flexural strength by about 50% and 150%, respectively. These results are in accordance with some works reported before [32,37]. It should be emphasized that the flexural strength of samples consistently increased up to the steel fiber volume of 1%. This trend is rather different from that seen before in compressive strength in which the compressive strength increased up to steel fiber volume of 0.5%. The significant effect of steel fibers on the flexural strength improvement is probably due the fact that these fibers delay the unstable growth of cracks which usually occurs in flexure, resulting in both strength increase and improved pre-peak and post-peak behavior. Similar trends were also reported by other researchers [28,29,38].

On the other side, PP fibers have a relatively lower effect on flexural strength. PP fibers increased the flexural strength from 2.1 MPa for plain mix to 2.6 MPa for mix with 0.2% PP fiber and to 3.3 MPa for mix with 0.4% PP fiber. The improving effect of PP fiber is meaningfully lower in the hybrid mixes incorporating both steel and PP fibers. For instance the flexural strength of mixture with 1% SF and 0% PP is 6.3 MPa. Addition of PP fibers to this mixture increased the flexural strength to 6.5 MPa (3% improvement) for mix with 1% SF and 0.2% PP and to 7.3 MPa (16% improvement) for mix with 1% SF and 0.4% PP. 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.

Fig. 2a shows that specimens without steel fibers had little ductility and once the maximum tensile strength was reached the specimens failed suddenly. However, specimens reinforced with steel fiber had a completely different failure characteristic. After occurrence of initial cracking, the sample did not fail suddenly since the fibers crossing the cracked section resist against the propagation of cracks. By studying Fig. 2 it is evident that steel fibers significantly increase both flexural strength and toughness of concrete. However, the effect of steel fiber on flexural characteristic is rather different from those on compressive characteristic. Steel fibers significantly increase both pre-peak flexural energy and toughness in flexure that means both pre-peak and post-peak flexural behavior are improved. On the other side, steel fibers mainly affect the post-peak behavior of concrete in compression but the pre-peak portion remains relatively unchanged. This is due to the fact that steel fibers significantly increase the flexural strength (up to about 150%) but they have much smaller effect on increasing the compressive strength (up to about 47%).

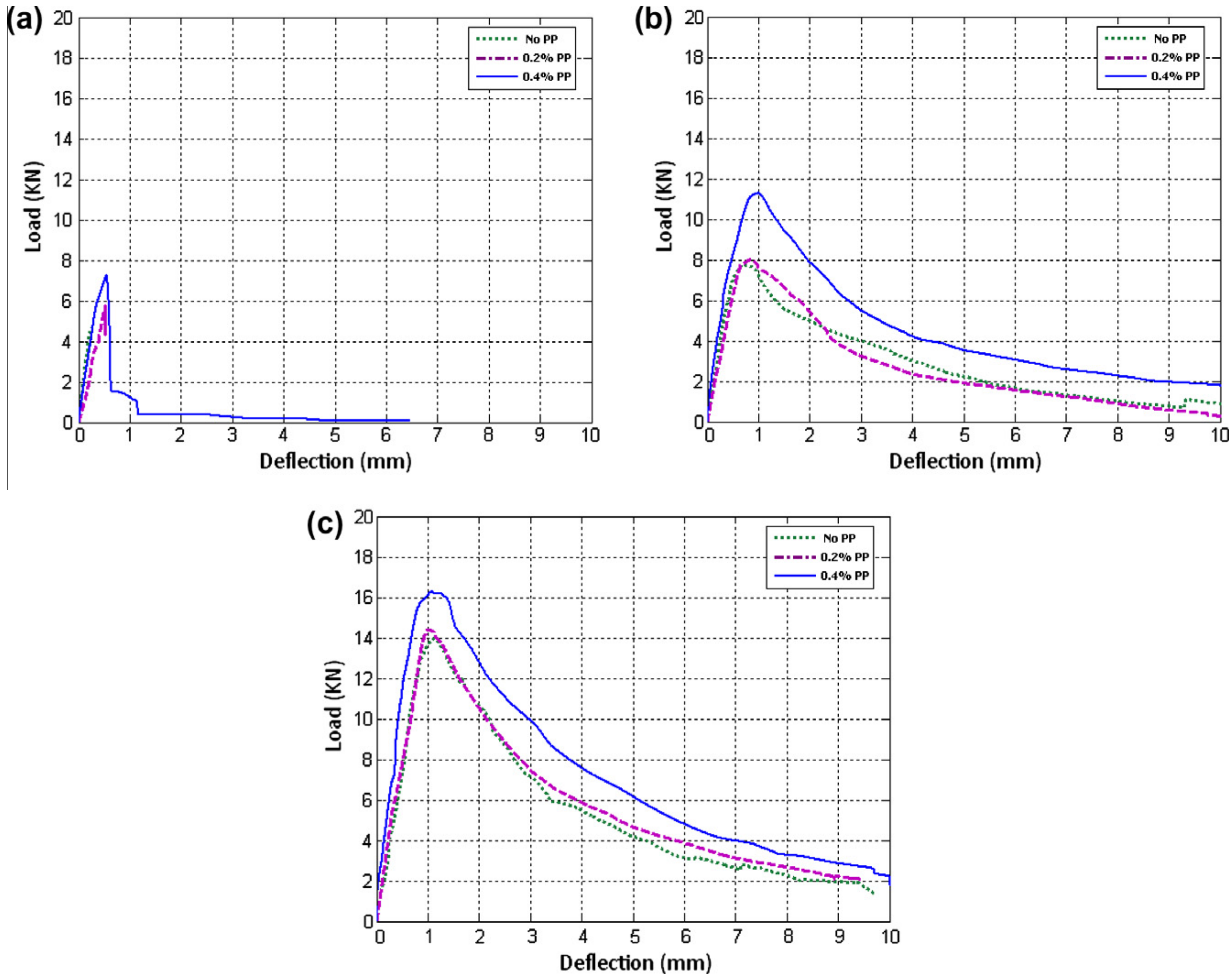

Fig. 2. Flexural behavior of concrete specimens: (a) steel fiber = 0%, (b) steel fiber = 0.5%, (c) steel fiber = 1%.

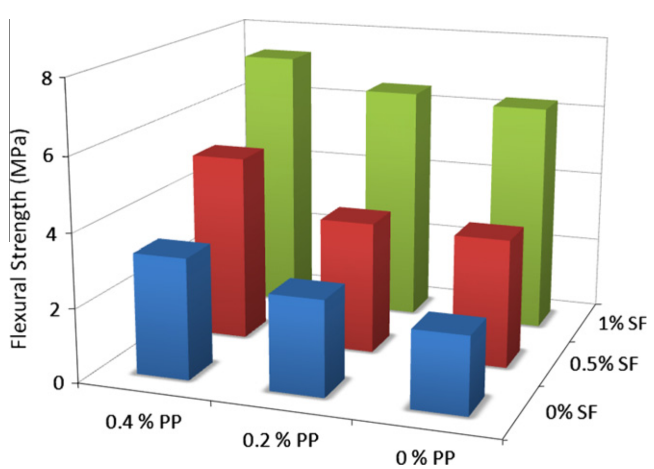

Fig. 3. Effect of steel and PP fiber on flexural strength.

Table 5
Flexural and tensile characteristic.

Mix no.	Tensile strength (MPa)	Flexural strength (MPa)	Pre-peak energy (N mm)	Total energy (N mm)
1	1.9	2.1	659	659
2	2.8	3.5	3661	28,851
3	4.1	6.3	9635	52,225
4	1.9	2.6	1412	1479
5	2.7	3.6	4146	26,780
6	2.9	6.5	7627	55,326
7	2.4	3.3	2367	4692
8	2.6	5.1	7740	45,906
9	2.5	7.3	11,920	71,112

Likewise the flexural strength, PP fibers have lower effect than steel fibers on ductility of lightweight concrete. For instance, the addition of PP fibers increased the total flexural energy of concrete from 659 N mm for plain concrete to 1479 N mm and 4692 N mm for the mix with 0.2% PP and 0.4% PP fibers, respectively. On the other side, addition of 0.5% and 1% steel fibers increased the total flexural energy of concrete up to 28,851 N mm and 52,225 N mm, respectively. Even though the addition of 0.2% PP increases the flexural strength, pre-peak energy and total energy of concrete however the improving effect is much lower than the improving effect of steel fibers. Concrete mixes incorporating 0.4% of PP fibers shows slightly better ductility behavior than those with 0.2% PP fiber. It seems that, for PP fiber volume fraction less than or equal to 0.2%, fiber effects on flexural behavior are insignificant and rather inconsistent. Therefore, it is suggested that at least 0.4% PP fiber should be used in concrete mixes to improve the flexural properties of lightweight concrete.

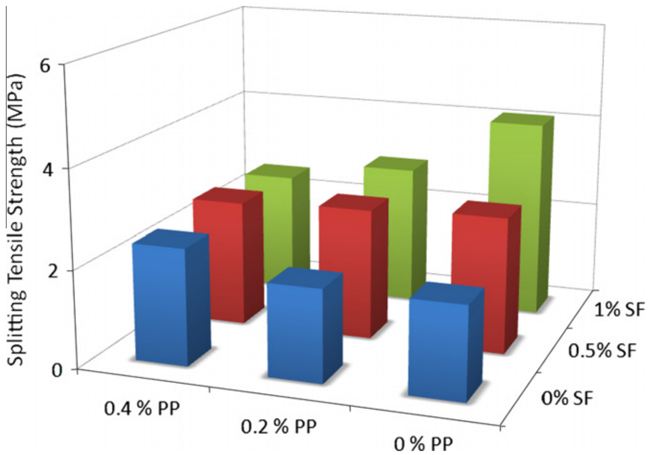

Fig. 4. Effect of steel and PP fiber on splitting tensile strength.

3.4. Splitting tensile strength

The variations in splitting tensile strength with steel and PP fiber ratio are presented in Fig. 4. The results show that steel fibers increase the tensile strength to some extent while the effect of PP fibers is fairly minor. The improvement of splitting tensile strength induced by incorporation of 0.5% and 1% steel fibers were 47% and 116% for mixes with 0% PP fiber, 42% and 53% for mixes with 0.2% PP fiber and 8% and 4% for mixes with 0.4% PP fiber, respectively. Comparing Fig. 3 with Fig. 4 it becomes clear that the improving effect of fibers on flexural strength is much more than the improving effect of fibers on tensile strength. The trend of strength gain due to the addition of steel fibers is almost the same as the trend seen before in compressive strength in which the strength increased up to steel fiber volume of 0.5% and no further strength gain is seen in the mixes with 1% steel fibers. The average ratio of splitting tensile strength to compressive strength in fiber reinforced mixes is about 11%. It is almost the same as the ratio in normal weight plain concrete.

4. Conclusions

This paper shows that structural LWAC with a density of 1740–1880 kg/m^3 and a compressive strength of 19–30 MPa can be made by using natural pumice as coarse aggregate. Fibers were used to mitigate the brittle nature of LWAC. An experimental research investigation was reported on the mechanical properties of hybrid steel and PP fiber reinforced pumice lightweight aggregate concrete. The main findings of this study are as follows:

- The blocking effect of steel and PP fibers in pumice lightweight concrete reduce the risk of segregation of the aggregates, and improve the uniformity of the mixture. However, the slump of the mixture was somewhat reduced as well. PP fibers, when compared with steel fibers, had smaller effects on fresh mix workability.
- Addition of steel fibers increases the bulk density of concrete specimens but there is not any meaningful correlation between the volume of PP fibers and bulk density of lightweight concrete. Linear regression analysis shows that the addition of 1% steel fibers increases the density of concrete by about 118 kg/m^3. The effect of steel fiber on increasing the density of concrete specimens which is also reported by other researchers [28,32] is very important in the case of lightweight concrete and should be considered in mixture proportioning of these types of concrete.
- Polypropylene fibers have no detectable effect on mechanical properties of hardened concrete at volume below 0.2% volume ratios. Besides, addition of 0.4% PP fibers in concrete mixes has a negligible influence on compressive characteristics. However, 0.4% PP fibers increased both flexural strength and flexural toughness to some extent. The improving effect of PP fibers is more recognizable in the mixes which do not contain any steel fibers. So, the minimum amount of polypropylene fibers to be used in lightweight concrete to prevent brittle behavior is about 0.4% by volume of concrete.
- Steel fibers significantly affect both flexural and compressive characteristic. But, the effects on flexural characteristic are rather different from those on compressive behavior. Steel fibers significantly increase the flexural strength (up to about 200%) but they have much smaller effect on increasing the compressive strength (up to about 50%). Besides, steel fibers significantly influence both descending and ascending part of flexural curve while these fibers mainly affect the descending part of compressive curve and the ascending part remains relatively unchanged. This is probably due to the fact that fibers delay the unstable growth of micro cracks which usually occurs in flexure, resulting in both strength increase and improved pre-peak and post-peak behavior.
- Incorporation of both PP and steel fibers improved the splitting tensile strength of LWAC however the magnitude of strength improvement due to the incorporation of fibers is smaller than that in flexural strength. The highest tensile strength was recorded in the mix with 1% steel fiber in which the tensile strength was increased from 1.9 MPa in plain mix to 4.1 MPa in fiber reinforced mix. On the other side the flexural strength were increased from 2.1 MPa in plain mix to 7.3 MPa in the hybrid fiber reinforced mix. In this way the maximum improvement in tensile strength is 116% while the maximum improvement in flexural strength is 284%.
- The importance of ductile behavior of concrete structures subjected to seismic loading has been widely acknowledged by engineers and researchers and design codes account for this capacity. These observations emphasize the advantage that steel fibers contribute to ductility of pumice lightweight aggregate concrete which is considered to be brittle. Thus, more efficient and also economical solutions may be possible by incorporating both pumice lightweight aggregate and reinforcing fibers in concrete mixes. These will results in a reduced dead load and also ductile behavior in all mode of loading. However, the scope of this study is certainly far too limited to provide some experimental data on the effect of hybrid fiber on mechanical properties of LWAC. Further research is needed to optimize the mixture proportions and also to examine the effect of hybrid steel and PP fibers on the other properties of pumice lightweight aggregate concrete e.g. shrinkage, creep, durability parameters, fire resistance and etc.

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