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Title: Effects of hybrid polypropylene-steel fiber addition on some hardened properties of lightweight concrete with pumice breccia aggregates

The paper by Widodo, Satyarno, and Tudjono addresses an experimental performance comparison of lightweight concrete with hybrid fiber addition. Some interesting results are presented with five different concrete mixtures which fibers were added at different volume fractions.

But there are some topics that need more discussion:

1. Page 2: Authors need to include some chemical composition of the cement used in the mixture preparation (a definition of pozzolan Portland cement is defined but no phase concentration is presented).
2. Page 3: Need to include the previous reference where the optimum PPF addition of 0.10% was obtained.
3. Page 3: The authors need to include information on the results' variance, standard deviation or the variation coefficient (μ/σ) to know possible scatter.
4. Page 3: The authors defined as Control the mixture where steel fibers were not added. What about a mixture with also no polypropylene fiber was also added? This mixture should be the real control one.
5. Page 4: All figures with the results need to include minimum and maximum values as exemplified in Figure 1.
6. Page 4: Apparently the test results were obtained at 56 days of specimen casting (age). Why not 28 days of age as it is regularly tested any mechanical properties of concrete?
7. Page 4: Need to include, in Table 2, the average value (μ) followed by the standard deviation (σ) in the format $\mu \pm \sigma$.
8. Pages 7 and 8: Figures 6 and 7 should include the stress-strain results for a real control specimen: 0% PPF and 0% SF.

Additional editorial comments are included, by hand in blue color, in attached file which includes the scanned pages.

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Effects of hybrid polypropylene-steel fiber addition on some hardened properties of lightweight concrete with pumice breccia aggregate

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ABSTRACT

Lightweight concrete application in construction field is growing rapidly in these recent years due to its advantages over ordinary concrete. In this research, pumice breccia which can be found abundantly in Indonesia proposed to be utilized as the coarse aggregate. In spite of its benefits, lightweight concrete exhibits its brittle characteristics and lower tensile strength compared with normal concrete. On the other hand, fiber addition into concrete mixes becomes more widely used to improve its tensile characteristic. The geometrical size and modulus of elasticity of fibers are the main factors which will affect the performances of fiber reinforced concrete. The use of different types of fiber in a suitable combination may potentially improve the mechanical properties of concrete and result in synergic performance. This paper experimentally examines the effects of hybrid polypropylene-steel fiber addition on some hardened properties of pumice breccia aggregate lightweight concrete. Five groups of test specimens with fixed volume fraction of polypropylene fiber combined with different amounts of steel fiber were added into the mixes to investigate the density, compressive strength, modulus of elasticity, splitting tensile strength and the modulus of rupture of the concrete. Test results indicate that hybrid fiber addition leads significant improvement to the compressive strength, modulus of elasticity, splitting tensile strength and the modulus of rupture of the pumice breccia lightweight aggregate concrete and meet the specification for structural purposes.

Keywords: Hardened properties, hybrid fiber, lightweight concrete, pumice breccia.

1. Introduction

1.1 Background

Lightweight concrete (LWC) application in construction field is growing rapidly in these recent years both for structural and non-structural purposes due to its advantages over ordinary concrete. The demand for lightweight concrete in many applications of modern construction is increasing, owing to the advantage that lower density results in a significant benefit in terms of load bearing elements of smaller cross sections and a corresponding reduction in the size of the foundation. The maximum density of concrete which can be classified as lightweight concrete in some European construction codes is limited to 2000 kg/m^3 [1], while the limitation in Indonesian National Standard is 1900 kg/m^3 [2], compared with that of 2400 kg/m^3 for normal weight concrete (NWC). Some techniques that widely used for lightweight concrete development include utilization of natural lightweight aggregates such as pumice, diatomite, and volcanic cinders, or artificial by-products such as perlite, expanded shale, clay, slate, and sintered pulverized fuel ash (PFA). Lightweight aggregate can be defined as mixture of uncrushed and/or crushed grains for natural and/or manufactured minerals which in most of the national codes required a limitation of the particle density not exceeding 2000 kg/m^3 or a dry-loose bulk density not exceeding 1200 kg/m^3 [1-5]. In this research, pumice breccia which can be found abundantly in Indonesia proposed to be utilized as the coarse aggregate in the mixes.

In spite of its benefits, lightweight concrete exhibits its brittle characteristics and lower tensile strength compared with normal concrete. In the other hand, fiber addition into concrete mixes becomes more widely used to improve concrete tensile behavior. The geometrical size and modulus of elasticity of fibers are the main factors which will affect the performances of fiber reinforced concrete. In order to optimize the benefits of fiber addition in concrete construction, the application of different fiber types into fresh concrete mixes was introduced and commonly known as hybrid fiber reinforced concrete (HyFRC). It becomes more popular in these recent years and expected to provide better physical and mechanical properties in concrete for structural purposes. The use of different types of fiber in a suitable combination may potentially improve the mechanical properties of concrete and result in synergic performance [6-9]. Addition of steel fiber generally provides contribution on the energy absorbing mechanism (bridging action), while non-metallic fibers offer its ability to delay the formation of micro-cracks and avoid catastrophic breaking, and also has much lower density [9].

1.2 Objectives

The main objectives of this research include: (1) developing hybrid fiber reinforced lightweight concrete mixes which should be suitable for structural applications using locally available materials, (2) examining the properties of the developed fiber reinforced lightweight concrete mixes, including demoulded density, compressive strength, modulus of elasticity, splitting tensile strength and the modulus of rupture, and (3) studying the flexural load–displacement behavior of the lightweight concrete with hybrid fiber addition.

2. Experimental Work

2.1 Materials and Mix Proportion

In this research, polypropylene fiber (PPF) and steel fiber (SF) were chosen and mixed as hybrid fiber. Polypropylene used due to its inexpensive, inert in high pH cementitious environment and easy to disperse. In this research, monofilament polypropylene with 18 μm diameter, 12 mm length, and 0.91 g/cm^3 density were used. Steel fiber chosen as the macro fiber based on its proven ability on the energy absorbing mechanism (bridging action), and its ease to be found. The steel fiber that applied in this research is hooked-end steel fiber having 60 mm length, and 0.75 mm of diameter.

The mixtures were prepared with Pozzolan Portland Cement (PPC). The coarse aggregate prepared using continuously graded crushed lightweight pumice breccia from Bawuran Mountain, Bantul District in the Special Province of Yogyakarta which is one of the largest pumice breccia deposits in Indonesia. This pumice breccia has dry-loose bulk density of 760 kg/m^3 with particle density of 1620 kg/m^3 which is satisfied to the technical specification of lightweight aggregate. Therefore, it is proposed to be utilized as coarse aggregate in the mixes. The coarse aggregate with maximum size of 20 mm were pre-wetted and submerged in water in 24 hours and then air-dried to be in saturated surface dry condition before mixing process. Well-graded natural sand which has specific gravity of 2.65 was employed as the fine aggregate. Silica fume, naphthalene formaldehyde sulfonate based superplastisticizer, and set retarder were also utilized as concrete admixtures in this research. Fiber addition were applied using 0.10% volume fraction of polypropylene fiber (based on the optimum PPF addition that achieved in the previous preliminary research), and various steel fiber addition of 0.0%, 0.5%, 1.0%, 1.5% and 2.0% by volume into the mixes. Detail of mixes proportion can be found in the following Table 1.

Table 1: Mix Proportion

Material	Mix Type				
	A	B	C	D	E
Water (lt/m^3)	225.00	225.00	225.00	225.00	225.00
Portland cement (kg/m^3)	455.00	455.00	455.00	455.00	455.00
Silica fume (kg/m^3)	45.00	45.00	45.00	45.00	45.00
Coarse aggregate (kg/m^3)	606.81	606.81	606.81	606.81	606.81
Sand (kg/m^3)	538.52	538.52	538.52	538.52	538.52
Superplasticizer (lt/m^3)	4.70	4.70	4.70	4.70	4.70
Set retarder (lt/m^3)	0.70	0.70	0.70	0.70	0.70
Polypropylene (kg/m^3)	0.90	0.90	0.90	0.90	0.90
Steel fiber (kg/m^3)	0.00	33.50	67.00	100.50	134.00

2.2 Details of Experimental Tests

Fresh characteristics of concrete mixes were evaluated using slump test method based on ASTM C-143 [10]. In order to observe the density on demoulding as declared in BS EN 8500:1 2006 [11], specimens' weight and dimensions were measured 24 hours after concrete casting. For the investigation of hardened concrete properties, the compressive strength, modulus of elasticity, splitting tensile strength, and the modulus of rupture were investigated. Concrete specimens were cured with water immersion for 56 days at the ambient temperature. Compressive strength and modulus of elasticity evaluation for all the variants of concrete mixes with different fiber contents were done on three cylinders of 150 mm in diameter and 300 mm length, based on ASTM C-469 [10]. The compressive strength and modulus of elasticity of the concrete was determined as the average of those three specimens for each variant. In order to observe tensile strength, the Brazilian splitting tensile test was carried out on three cylinders with 150 mm diameter and a height of 300 mm based on ASTM C-496 [10], and the tensile strength of concrete was taken as the average of the those three cylinders for each variant. Modulus of rupture test conducted based on simple beam with center-point loading following the procedure in ASTM C-293 [10]. The test was carried out on three beams with 100 mm x 100 mm of cross sectional dimension and 500 mm length, and the modulus of rupture of the concrete was taken as the average of the those three beams for each variant.

3. Results and Discussion

In this research, the effect of steel fiber addition on the workability of polypropylene fiber reinforced lightweight pumice breccia aggregate concrete evaluated using slump-test method based on ASTM C-143 [10]. Comparison of the measured slump of the fresh fiber reinforced lightweight concrete mixes can be found in Figure 1. Based on the following graph, it can be observed that the addition of steel fiber into the mixes tends to lower the workability of the lightweight concrete mixes.

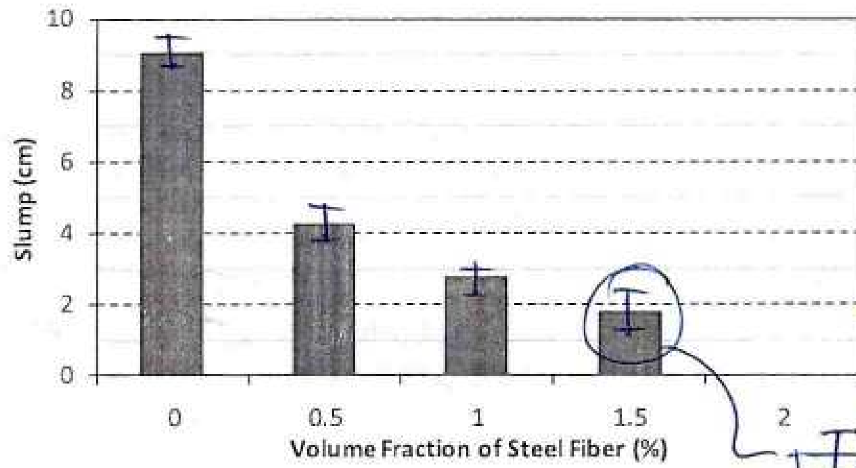


Figure 1: Effect of Steel Fiber Addition on the Workability of Hybrid Fiber Reinforced Lightweight Pumice Breccia Aggregate Concrete Containing 0.1% PPF Mixed with Various Volume Fraction of SF

In order to evaluate the effects of hybrid polypropylene and steel fiber addition on hardened properties of lightweight pumice breccia aggregate concrete, the compressive strength, modulus of elasticity, splitting tensile strength and the modulus of rupture of the concrete specimens tested after 56 days of water immersion curing. The following Table 2 shows the results of the tests.

Table 2: Effects of Hybrid Polypropylene-Steel Fiber Addition on Hardened Properties of Lightweight Pumice Breccia Aggregate Concrete

Volume Fraction of Steel Fiber (%)	Demoulded Density (kg/m^3)	Compressive Strength (MPa)	Modulus of Elasticity (MPa)	Splitting Tensile Strength (MPa)	Modulus of Rupture (MPa)
0.0	1764.783 ±	16.445 ±	7317.496 ±	1.239 ±	2.782 ±
0.5	1857.325 ±	19.149 ±	9125.917 ±	2.565 ±	4.449 ±
1.0	1874.057 ±	20.135 ±	8191.957 ±	3.058 ±	7.155 ±
1.5	1902.088 ±	19.707 ±	7492.722 ±	3.993 ±	7.997 ±
2.0	1932.855 ±	18.560 ±	6836.531 ±	3.763 ±	7.979 ±

Effects of fiber content on demoulded density of hardened lightweight pumice breccia aggregate concrete can be observed in Figure 2. The demoulded density tends to increase in accordance with the addition of steel fiber into the mixes. It can be clearly predicted in the mix design calculation since steel fiber has much higher density compared to the lightweight pumice breccia concrete.

Even though the demoulded density of hybrid fiber reinforced lightweight pumice breccia aggregate concrete increasing due to the presence of steel fiber, it can be observed that the density of the lightweight concretes with hybrid polypropylene and steel fiber addition up to the combination of 0.1% PPF and 1.5% SF are still acceptable to be classified as lightweight concrete based on the maximum limit of lightweight concrete density which is required in the Indonesian national standard and most of the International standards.

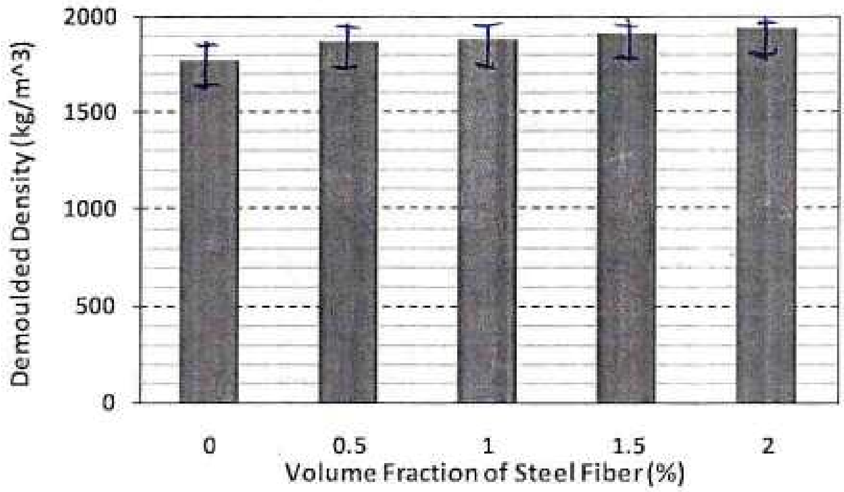


Figure 2: Effect of Steel Fiber Addition on the Demoulded Density of Hybrid Fiber Reinforced Lightweight Pumice Breccia Aggregate Concrete Containing 0.1% PPF Mixed with Various Volume Fraction of SF

Compressive strength evaluation of hardened fiber reinforced lightweight pumice breccia aggregate concrete can be found in the following Figure 3. Test results indicates that the compressive strength tends to increase up to 22.44% when the fibers added with the combination of 0.1% PPF and 1.0% SF, and then tends to decrease after the optimum volume fraction but still shows higher compressive strength compared to the reference mix.

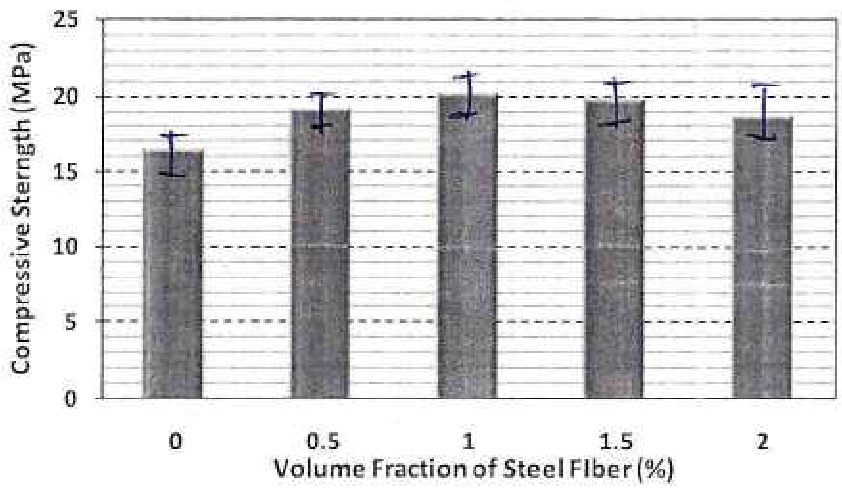


Figure 3: Effect of Steel Fiber Addition on the Compressive Strength of Hybrid Fiber Reinforced Lightweight Pumice Breccia Aggregate Concrete Containing 0.1% PPF Mixed with Various Volume Fraction of SF

Modulus of elasticity of the hardened fiber reinforced lightweight concrete also investigated at the same time with compression test as shown in Figure 4. The modulus of elasticity tends to increase up to 24.71% when the fibers added with the combination of 0.1% PPF and 0.5% SF but then tends to decrease. Even though the modulus of elasticity tends to decrease after the optimum value of fiber hybridization, the hybrid fiber reinforced lightweight pumice breccia aggregate concrete still achieves higher modulus of elasticity compared to the reference concrete unless for mixed 0.1% PPF and 2.0% SF as shown in Figure 5.

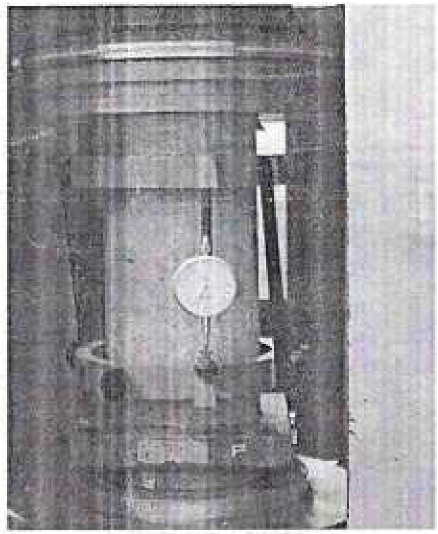


Figure 4: Compressive Strength and Modulus of Elasticity Test set up

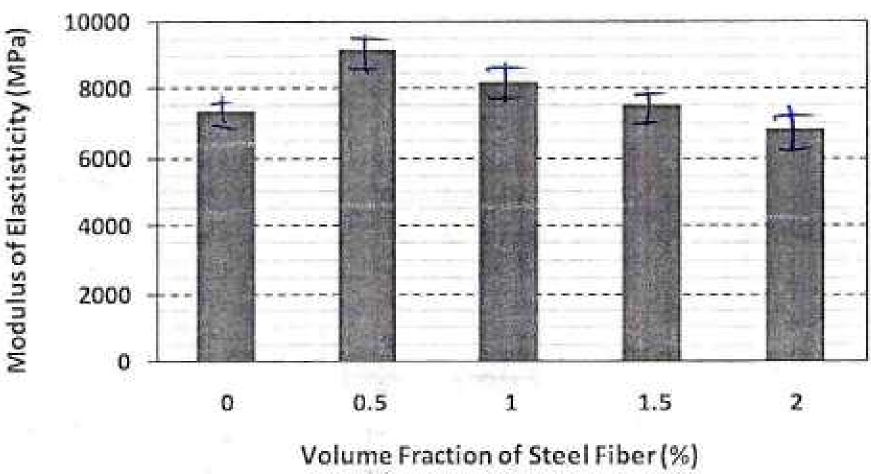
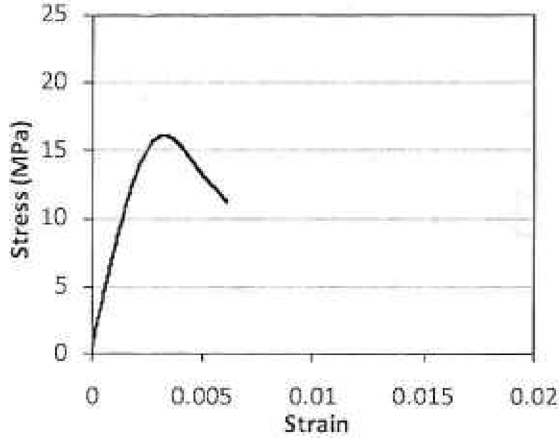
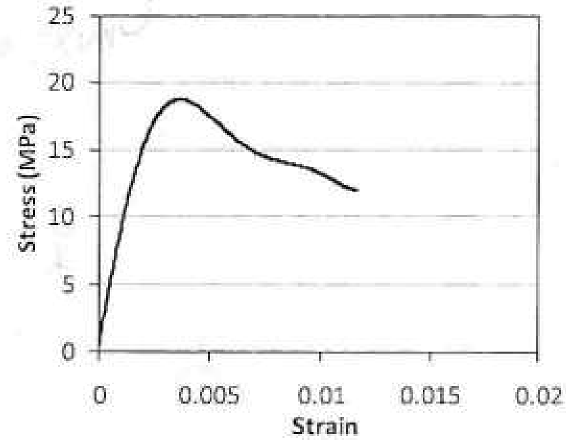


Figure 5: Effect of Steel Fiber Addition on the Modulus of Elasticity of Hybrid Fiber Reinforced Lightweight Pumice Breccia Aggregate Concrete Containing 0.1% PPF Mixed with Various Volume Fraction of SF

In order to get more comprehensive results, the curves that show stress-strain relationship in concrete compression tests are also shown in Figure 6. Based on the stress-strain curves, it can be observed that hybrid fiber reinforced lightweight pumice breccia aggregate concrete showing better post-peak behavior in resisting applied compression force compared to the reference concrete. Hybrid fiber reinforced lightweight pumice breccia aggregate concrete variants exhibit higher residual strength and better strain capacity. This can be observed due to the effect of steel fiber that contributes on the energy absorbing mechanism by bridging action to distribute macro-cracks that caused by applied external force, while polypropylene fiber shows its contribution to delay the formation of micro-cracks, improve the pull-out strength of steel fiber and avoid catastrophic breaking. Furthermore, it can be concluded that the addition of hybrid polypropylene-steel fiber into lightweight pumice breccia aggregate concrete mixes shows its contribution to improve post-peak behavior and avoid sudden failure in concrete compression test as shown in the following graphs.



(a)



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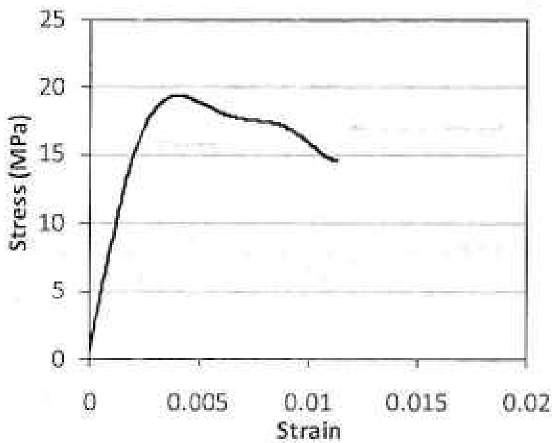

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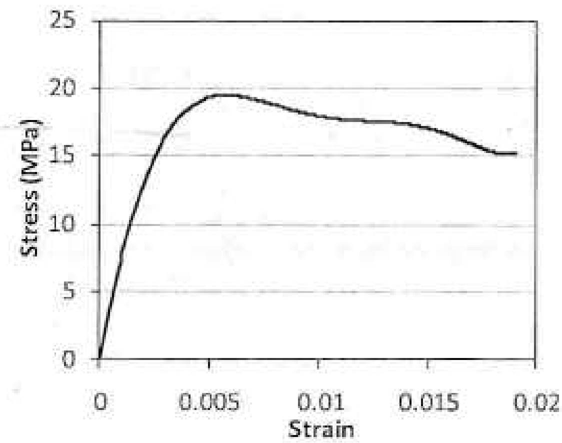

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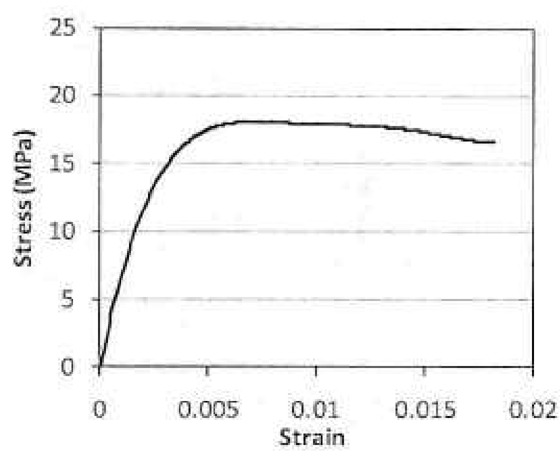

(e)

← (8) and no fiber performance? 0% PPF and 0% SF?

Figure 6: Stress-Strain Behavior in Compression Test of Hybrid Fiber Reinforced Lightweight Pumice Breccia Aggregate Concrete Cylinders Containing 0.1% PPF Mixed with (a) 0.0% SF, (b) 0.5% SF, (c) 1.0% SF, (d) 1.5% SF and (e) 2.0% SF

Test results which are related to the effects of hybrid fiber addition on the splitting tensile strength of hardened lightweight pumice breccia aggregate concrete can be observed in the Figure 7. Hybrid fiber addition significantly improves the splitting tensile strength up to 222.28% when the concrete mix added with the combination of 0.1% PPF and 1.5% SF. After the optimum volume fraction of hybrid fiber addition, the splitting tensile strength tends to decrease but still achieves much better tensile strength compared to the reference mix.

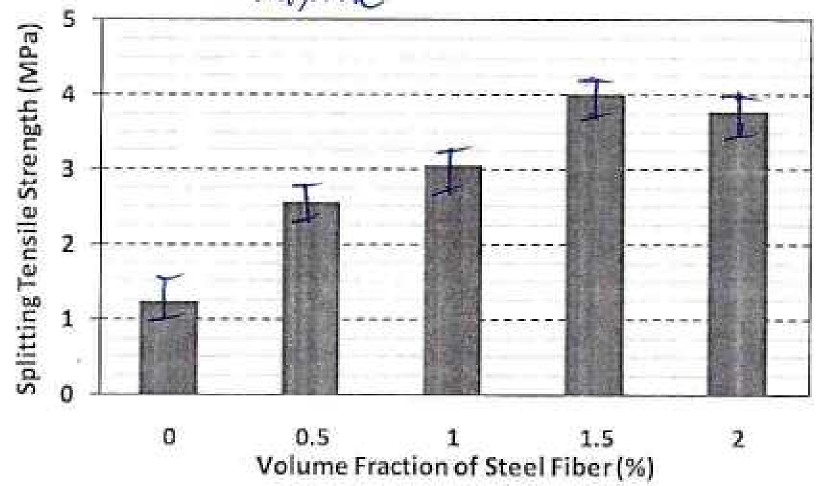

Figure 7: Effect of Steel Fiber Addition on the Splitting Tensile Strength of Hybrid Fiber Reinforced Lightweight Pumice Breccia Aggregate Concrete Containing 0.1% PPF Mixed with Various Volume Fraction of SF

Experimental results which are evaluated the effects of hybrid fiber addition on the flexural strength of hardened lightweight pumice breccia aggregate concrete can be observed in the Figure 8. Hybrid fiber addition consequently leads significant improvement on the modulus of rupture up to 187.46% when the concrete mix added with the combination of 0.1% PPF and 1.5% SF. After the optimum volume fraction of fibers addition the modulus of rupture tends to decrease but still obtains much better result compared to the reference concrete mix.

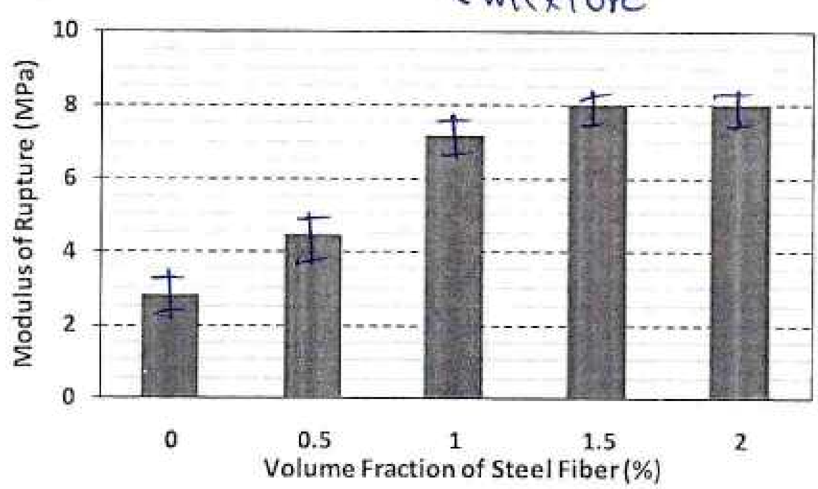

Figure 8: Effect of Steel Fiber Addition on the Modulus of Rupture of Hybrid Fiber Reinforced Lightweight Pumice Breccia Aggregate Concrete Containing 0.1% PPF Mixed with Various Volume Fraction of SF

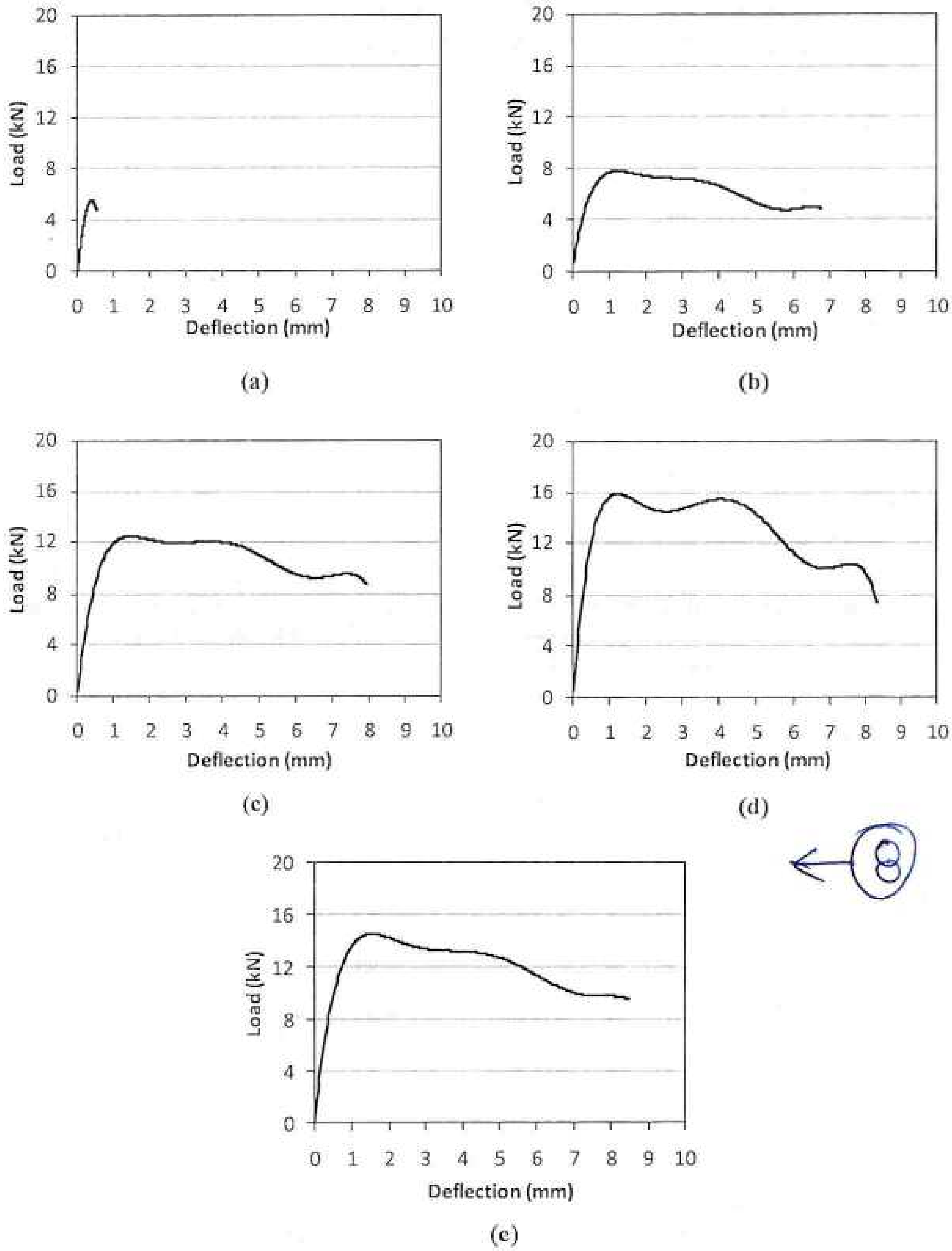

Figure 9: Load-Deflection Behavior in Three Points Bending Test of Hybrid Fiber-Reinforced Lightweight Pumice Breccia Aggregate Concrete Beams Containing 0.1% PPF Mixed with (a) 0.0% SF, (b) 0.5% SF, (c) 1.0% SF, (d) 1.5% SF and (e) 2.0% SF

Figure 9 shows load-deflection curves of all concrete variants to get more comprehensive results in the flexural behavior of hybrid fiber reinforced lightweight pumice breccia aggregate concrete. Based on the load-deflection curves, it can be observed that hybrid fiber reinforced lightweight pumice breccia aggregate concrete showing better post-peak behavior in resisting applied bending moment compared to the reference concrete. Hybrid fiber reinforced lightweight pumice breccia aggregate concrete variants exhibit more ductile behavior and higher residual strength. This characteristic can be obtained due to the effect of steel fiber that contributes on the energy absorbing mechanism by bridging action to distribute macro-cracks that caused by applied external force, while polypropylene fiber shows its contribution to delay the formation of micro-cracks, improve the pull-out strength of steel fiber and avoid catastrophic breaking. Furthermore, it can be concluded that the presence of hybrid polypropylene-steel fiber addition in lightweight pumice breccia aggregate concrete shows its contribution to improve post-peak behavior and avoid sudden tension failure in concrete section when it utilized to resist bending moment.

4. Conclusions

Based on the tests results of the fresh and hardened properties of fiber reinforced lightweight pumice breccia aggregate concrete, the following conclusions can be drawn:

(1) In the fresh state of lightweight pumice breccia aggregate concrete, the addition of fibers consequently causes lower workability.

(2) The demoulded density of fiber reinforced lightweight concrete tends to increase in accordance with the amount of steel fiber addition but generally can be classified as lightweight concrete based on most international standards of concrete structures.

(3) The compressive strength of lightweight concrete can be improved proportionally up to 22.44% when the hybrid polypropylene-steel fiber added with the combination of 0.1% PPF and 1.0% SF then tends to decrease but still shows better performance compared to the reference concrete mix.

(4) The modulus of elasticity also improved in accordance with the addition of hybrid fiber up to 24.71% when the concrete added with the combination of 0.1% PPF and 0.5% SF then tends to decrease but generally higher than the reference concrete mix.

(5) Higher splitting tensile strength of hardened fiber reinforced lightweight concrete specimens can be obtained up to 222.28% when the hybrid fiber added with a combination of 0.1% PPF and 1.5% SF then decreases after the optimum value but still achieves much higher strength compared to the reference concrete mix.

(6) The modulus of rupture of fiber reinforced lightweight concrete specimens can be improved proportionally up to 187.46% when the hybrid polypropylene-steel fiber added with the combination of 0.1% PPF and 1.5% SF then decreases but still exhibits much better flexural performance compared to the reference concrete mix.

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Disclosure

The paper has not been previously published, is not currently submitted for review to any other journal, and will not be submitted elsewhere before a decision is made by this journal.

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