

Research Article:

Mechanical properties of concrete reinforced with hybrid polypropylene- PET waste fibers

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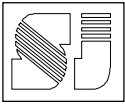
Abstract

In this article, flexural strength and compressive strength of concrete containing polypropylene fiber (PP), polyethylene terephthalate (PET) waste fiber and a combination between them were experimentally investigated. For this reason, laboratory experiments were performed on a total of 40 mixes. Results show that compressive strength property of concrete reinforced with PET waste fiber is not comparable to that of concrete reinforced with PP fiber, in which there is a compressive strength reduction, and the effect of PET fiber length on the strength is not important. Behavior of concrete contained PET waste fiber in flexure was found better. There is a good opportunity to use a hybrid fiber (25% PET and 75% PP) to enhance flexural strength of concrete.

1. Introduction

Plain concrete has a poor tensile strength characteristic and no post cracking toughness behavior, also microcracks develop even before loading, mainly because of drying shrinkage and volume change [1]. On these circumstances, there is a need to reinforce plain concrete by using materials with good stiffness and high tensile performance. Therefore, in the literature different kinds of fibers have been utilized to improve tensile properties of concrete composites [1]. Properties of fiber reinforced concrete are now well known by many experiments that performed during the past fifty years. For instance, some researchers reported that the addition of steel and polypropylene fibers is appreciably enhancing different properties of concrete [2, 3]. In addition, many investigations showed that if hybridization is made on using different fibers with regard to fiber's material or size, there is an improvement in the performance of the composite and modifying some of the important properties [4,5].

Hybridization of the steel fiber and palm fiber by volume fraction of 2% was made by Dawood and Ramli [4] for high strength concrete; there results showed that using 1.5% steel fiber and 0.5% palm fiber gives the higher increment in the flexural strength and toughness. Furthermore, an experimental works has been carried out by Chen and Liu [5] who showed that the combinations of different types of fibers resulted in an increase in the strength, among which carbon- steel fibers combination provides the best effects (a 27.6% increase in the compressive strength and a 38.3% of increase in the split tensile strength). Also, they observed that the carbon- steel fibers combination provided the lowest brittleness of concrete, and effectively reduced the shrinkage of concrete. Other tests by Shan et al. [6] showed that the fibers, when used in a hybrid form, can result in superior mechanical performance compared to their individual fiber- reinforced concretes. Moreover, they revealed that the rational flowability limits the



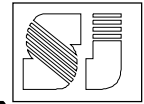
maximum dosage of steel fiber to 1.2% and polypropylene fiber to 0.15%. The hybrid fiber combinations performed better in all respects compared to the mono-steel fiber-reinforced concrete and mono-polypropylene fiber-reinforced concrete and concrete without fibers. The best volume fraction of SF and PPF were advised with 0.80% and 0.10%. For instance, an experiment by Hsie et al. [7] showed that the compressive strength, splitting tensile strength, and flexural properties of the polypropylene hybrid fiber (coarse monofilament and staple fibers) reinforced concrete are better than the properties of single fiber-reinforced concrete and Ouyang et al. [8] observed that the compressive strength, splitting tensile strength and flexural properties of steel-macro polypropylene hybrid fiber reinforced concrete are better than any others (polypropylene monofilament fiber, polypropylene fibrillated fiber, macro polypropylene fiber, and hooked steel fiber). Also, the fire resistance of steel-monofilament polypropylene hybrid fiber reinforced concrete was the best. Further, tests on concrete reinforced with hybrid steel-polypropylene fiber by Singh et al. [9] showed that concrete containing a fiber combination of 75% steel fibers + 25% polypropylene fibers can be adjudged as the most appropriate combination to be employed in hybrid FRC for compressive strength, flexural strength and flexural toughness. Furthermore, a fiber combination of polypropylene (PP)-carbon, carbon-steel, and steel-PP fibers for concrete has been investigated by Yao et al. [10]. Test results showed that the fibers, when used in a hybrid form, could result in superior composite performance compared to their individual fiber-reinforced concretes. Among the three types of hybrids, the carbon-steel combination gave concrete of the highest strength and flexural toughness. The reason was attributed to the similar modulus and the synergistic interaction between the two fibers. Far from the mentioned topic, plastic polymers are widely used nowadays because of many advantages as compared with metals. Among the widely used plastics one can mention polyethylene terephthalate (PET) which is mainly used as containers for liquid storage. Due to a huge number of plastic containers used by citizens worldwide, there is a large amount of post consumed bottles in a form of plastic waste. The plastic waste has been thrown causing environmental pollution problems, and to diminish the bad effects of the waste there is a need for recycling [11]. One form of the recycling process is the use of plastic waste in concrete production [12]. There is a chance to use shredded plastic waste as a fine aggregate replacement in concrete [13, 14], or in the form of plastic fibers to reinforce concrete composites [15] and to reinforce different mix proportions of cement mortars [16, 17]. However, the waste can be recycled to produce a relatively small

diameter, high quality plastic fiber to be used in concrete [18] essentially different from that obtained via simple crushing. Properties of concrete contained plastic aggregate and reinforced with plastic fibers have been extensively studied [19]. In this study, strength properties of concrete reinforced with PET waste fiber manually prepared from water drinking bottles have been studied. The issue of this study is relatively new, which is an attempt to produce a concrete with acceptable properties when contained PET waste fiber, via hybridization with the synthetic polypropylene fiber. The main objectives behind this experimental study can be summarized as follows:

- a. Comparison of the compressive and bending strengths of reinforced concrete with various amounts of polypropylene (PP) and polyethylene terephthalate (PET).
- b. To investigate the influence of PET waste fiber length on the properties of concrete.
- c. To investigate the effect of PP fiber replacement (25%, 50% and 75%) with different volumes of PET waste fiber.
- d. To investigate Relationship between flexural strength and compressive strength of PP and PET waste fiber reinforced concrete.

2. Methods and materials

Ordinary Portland cement was used (Type I ASTM C150/150M) commercially available produced by Tasluja cement factory-Sulaimani. The fine aggregate used in the production of concrete mixes was natural river sand. The specific gravity and absorption for fine aggregate were found to be 2.56 and 0.85%, respectively. The percentage passing of fine aggregate and ASTM C33 specification limits [20] are shown in Fig. 1, from which one can observe that the fine aggregate used conforms to the specification limits. The coarse aggregate used was natural aggregate obtained from a quarry in Darbandixan- Sulaimani with crushed stone, with nominal maximum size of 19 mm, specific gravity of 2.69, water absorption of 1.75%, and bulk density of 1582 Kg/m³. Fig. 2 shows the grading of coarse aggregate. One can find that the coarse aggregate used conforms to the ASTM C33 specification [20] grading limits. Potable drinking water was used for mixing and curing all specimens. Fiber Terephthalate polyethylene (PET) was made from 16-liter PET drinking water bottles. Each bottle has been cut to obtain the plastic fiber, minus the neck and bottom. A micrometer screw gauge measured the thickness of PET fabric, with an average thickness of 0.4 mm. With constant width of 1.2 mm and three lengths of 10, 20 and 40 mm, the plastic fiber was prepared the fibers were cut by using scissors. Fig.3 demonstrates ready-to-use collections of PET fibers. It was found that the specific plastic gravity was 1.24.

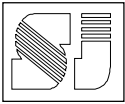


The type of Polypropylene fiber is a 12 mm long, high-performance multifilament fiber that shown in Fig. 4. The diameter, density and tensile strength of the fiber were found to be 34 micrometers, 0.91 g/cm³ and 3750 MPa respectively. Almost forty different concrete mixes shown in Table 1 were designed to be tested and were classified into different groups and the classification is based on the type and length of fiber. PET waste fiber of three various lengths of 10, 20 and 40 mm were used. Three dosages of fibers by volume were used in the study (0.5 %, 1% and 1.5 %). Two types of fibers were used and the types are (PET and PP) and hybridization of fibers was by (25%, 50% and 75%). After casting multiple test mixes, a concrete mix proportion of 1:1.60:2.34 (cement: fine aggregate: coarse aggregate) by weight with W/C = 0.47 was set for casting the specimens in order to achieve a proper concrete mix of design compressive strength equal to 35 MPa. Details of concrete mixes constituents are shown in Table 1. The materials for each concrete mix were weighted and then mixed into a rotating drum of (0.08 m³). Before the materials were placed, the inner surface of the mixer was washed and moistened. The mixing process began by eventually bringing in the mixer the fine and coarse aggregates and then cement and water. Later, the fiber was added to the mix gradually as shown in Fig. 7. The mixing operation continued until workable concrete was obtained workability limit was (75 mm) from mix design. For each trial mix 3 cylinders and 2 prisms were casted and after 24 hours. They have been removed from the molds and placed in the water tank at 25°C for curing. All samples were tested at the age of 28 days. Later, the specimens were then left to dry in the laboratory and then capped with a Sand-Sulphur compound and examined. For every concrete mix, after 28 days of casting the samples were capped and after 24 hours of capping according to the ASTM C39 Specification, three cylinders were tested to measure concrete compressive strength [21]. The specimens were tested using a celiktest compression machine of 4000 kN capacity under rate of loading equal to 0.5 MPa/sec as shown in Fig. 5. The results of the flexural strength test for concrete, and this test was performed using the ASTM C293 specification center- point load test [22], the specimens were prisms of 100x100x500 mm, an average of 2 measurements per combination, as shown in Fig. 6.

3. Results and Discussion

Test results of different mechanical properties of concrete reinforced with PP, PET waste and hybrid PP-PET fibers are stated in Figs. 8 through Fig.15. In the following sections the results are discussed in some detail. Fig. 8 shows variation of compressive strength of concrete specimens PP fibers and PET

waste fibers with different dosage of fibers. An enhancement had been made in compressive strength with increasing PP fiber volume up to 1.5%, reaching 6.6% as maximum value. The increase of compressive strength due to PP fiber addition was observed by Hsie et al. [7], while Kim et al. [23] and Chen and Liu [5] found a reduction in the strength when PP fiber was added by 1%. On the other hand, there is no strength enhancement on using 0.5% PP fiber based on tests by Yao et al. [10] and Kim et al. [23]. From the results of Fig. 8, one will observe that there is no possibility for PET waste fiber to improve compressive strength in addition to concrete in which there is a continuous strength loss with fiber increase. Maximum strength loss was found to be 9.8% with using 1% - 20 mm PET waste fiber. There is a small influence of PET fiber length on the compressive strength of concrete reinforced with 1.5%, because there is only 2.1% difference in compressive strength. The reason behind the strength loss of concrete contained PET waste fiber can be attributed to the poor quality of fiber produced by manually cut PET bottles, knowing that this plastic has a low tensile strength, and poor interfacial surface bond with hardened cement paste. Since the plastic fibers have been prepared manually, there is no chance to produce fiber with low diameter or high fiber aspect ratio; this may be another reason of low strength of the concrete composite. On the other hand, reduction in the compressive strength was attributed to the fact that pores and flaws are present with a minimum ratio in concrete due to the dense mass of its ingredients. When the fibers added to the concrete, it produces flaws and pores in the concrete which create a weak zone inside the concrete, and as a result cause propagation of the cracks. Furthermore, reduction in strength of concrete can be argued to the presence of extra voids inside the concrete due to the inclusion of the fibers. Therefore, the drawbacks of air voids were more effective to reduce compressive strength with regarding to fiber's duty for arresting crack openings. Compressive strength loss of concrete on using 0.75% and 1% PET fiber was also noted by Kim et al. [23] and Singh et al. [9], while found that there is no beneficial effect of PET fiber added up to 0.3% to concrete to enhance compressive strength. Fig. 9 Shows the effect of the of the fiber volumetric percentage on the concrete compressive strength for PP and hybrid fiber reinforced concrete (25%-75%)-(PP-PET). One can observe that there is no concrete strength loss on using the hybrid fiber and there is a strength enhancement of 4% when 10 mm PET fiber is added by 0.5%. In the basis, 25 percent of PET waste fibers have a reasonable chance of being used in concrete with PP fibers. However, there is a sufficiently serious lack in strength of up to 19.5% when 1% PET fiber is used beside PP fiber. Results

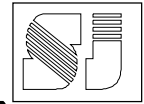


also show that there is a recovery in the compressive strength when the PET fiber increased to 1.5%. In general, the performance of the 40 mm PET fiber is better than that of other fibers. According to the results of Fig. 10, the effect of adding 10 mm PET fiber is better to make a hybrid fiber with 50% PET fiber, identical to the case of using 25% PET fiber (see Fig. 11), while there is no appreciable effect of fiber length when added by 1% and 1.5% to concrete. In general, the performance of concrete reinforced with 75% PET fiber is not differ from that of 50% PET fiber but there is some strength loss on using 10 mm PET waste fiber, as shown in Fig. 11. One can find that the effect of PET fiber length is available when 25% PET fiber is used and this effect will vanish when using a relatively large PET fiber in addition to PP fiber. Generally, there is no chance to mix PP fiber and large volume of PET waste fiber to produce a concrete with acceptable compressive strength, and the maximum PET fiber added seems to be not more than 25%. Fig. 12 shows the effect of fiber volumetric percentage on the flexural strength of PP and PET waste fiber reinforced concrete. One can find a flexural strength enhancement with increasing PP fiber in concrete mix reaching 73% at 1.5% fiber volume. Flexural strength enhancement of concrete as a result of using PP fiber was observed by Ouyang et al. [8] and Hsie et al. [7], while there is a flexural strength reduction by 7% for concrete contained 1% PP fiber tested by Singh et al. [9]. According to the results of Fig. 10, using 0.5%-40 mm length will lead to a flexural strength enhancement of 49.3%, larger than that of concrete with PP fiber by 9.2%, and in general the flexural strength of concrete with 40 mm PET fiber is larger than that of concrete with shorter PET fibers. Based on the results obtained, the flexural performance of concrete is reduced with the reduction of fiber length especially for fiber volumes of 0.5% and 1%. It should be noted that Pelisser et al. [18] found a 19.5% flexural strength enhancement on using 0.3% PET in concrete. Fig. 13 shows flexural strength of concrete with PP fiber and hybrid (25%-75%)-(PP-PET). We can observe that the behavior of concrete with hybrid fiber is quite similar to that of concrete mix with PP fiber, in which the maximum difference between flexural strength of concretes with PP fiber and hybrid fiber is only 8%. Identical to the case of concrete with PET fiber alone, the performance of 40 mm PET fiber is better than that of shorter PET fibers for concrete reinforced with hybrid fibers, the effect of PET fiber length is not large as compared with that of other concrete mixes. Fig. 14 shows flexural strength of concrete with PP fiber and ybrid (50%-50) -(PP-PET), and Fig. 13 shows flexural strength of concrete with PP fiber and hybrid PP-PET fiber (75%-25%)-(PET-PP). One can find that the flexural performance of concrete is reduced with the

increase of PP fiber replacement with PET waste fiber. Identical to the case of compressive strength, 25% PET fiber in the hybrid fiber is the best choice and the flexural performance will reduce with increasing PET fiber for concrete reinforced with hybrid fiber. It is important to study the relationship between flexural strength and compressive strength of concrete reinforced with hybrid fiber, because such relationship is available for different concretes and there are many design equations to calculate flexural strength based on compressive strength. Fig. 16 shows flexural strength-compressive strength relationship of PP and different fiber percentage and different PET fiber ratio. For concrete strengthened with PP there is a strong relation which indicates a frequent improvement in flexural strength with the increase in compression strength, mainly because of the regular effect of the PP fiber on different concrete properties modification. This effect can be attributed to the low diameter of PP fibers able to make a bridge of microcracks produced due to shrinkage of concrete. In contrast, there is no stable correlation for the case of concrete reinforced with PET waste fiber regardless of fiber length. Since the PET waste fiber has a relatively large cross-sectional area, there is a little chance to control microcracks. Because of the fact that there is a poor bond between a relatively large PET fiber and hardened cement paste, this will affect the homogeneity of concrete and, as consequence, energy absorption capacity during loading in addition to mode of failure in compression and in flexure will be different from those of concrete with PP fiber. Figs. 17 through 19 show flexural strength-compressive strength relationship of concrete reinforced with PP and hybrid fibers. One can find a not stable relationship for the case of hybrid fiber, because any addition of PET fiber to concrete beside the PP fiber will reduce the homogeneity of concrete and able to change mode of failure.

4. Conclusion

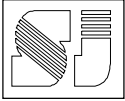
This study investigated the utilization of recycled plastic fibers (PET), industrial polypropylene fibers (PP) and hybridization between the PET and PP fibers to reinforce concrete composites. PET fibers made from polyethylene terephthalate plastic bottles with different size and volume fractions. The effect of the fibers on the concrete composites have been investigated by applying experimental programs of compressive strength and flexural strength tests at 28-day ages and analyzed in comparison to the control samples without any fiber dosages. Based on the extensive research work, the following conclusions can be drawn: Adding of polypropylene (PP) fibers to concrete composites enhances the compression and flexural strength and improves the performance of the concrete strength up to 1.5% volumetric dosage of the Polypropylene fiber



1. Adding of PET recycled fibers to the concrete composites leads to a reduction in the compressive strength of the concrete composite.
2. The hybridization between PET and PP fiber is not beneficial for improving the compressive strength of the concrete composite, while; there is a rise in the flexural strength of the concrete composite due to the addition of PET fibers.
3. Among all the hybridization dosages between PET and PP fibers, 25% of PET and 75% of PP is the best one combination for production of concrete composites with acceptable properties. The flexural strength and the compressive strength of the concrete are strongly connected to fiber reinforced with PP, and there is no contrast relationship for the case of PET fiber, and hybridization has no appreciable effect to improve the correlation.

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خصائص مقاومة الانضغاط والانحناء للخرسانة المسلحة
بألياف البولي بروبيلين الهجينة و نفايات البولي إيثيلين
تيرافتالات

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المستخلص

في هذه البحث ، تم دراسة قوة الانحناء وقوة الانضغاط للخرسانة المحتوية على ألياف البولي بروبيلين (PP) وألياف نفايات البولي إيثيلين تيريفثالبيت (PET) والجمع بينهما بشكل تجريبي. لهذا السبب ، تم إجراء تجارب عملية على ما مجموعه متكونة من ٤٠ مزيجًا. أظهرت النتائج أن خاصية مقاومة الانضغاط للخرسانة المسلحة بألياف نفايات PET لا يمكن مقارنتها بتلك الموجودة في الخرسانة المسلحة بألياف PP ، حيث يوجد انخفاض في قوة الانضغاط ، وتأثير طول ألياف PET على القوة ليس مهمًا. تم العثور على سلوك الخرسانة المحتوية على ألياف نفايات PET في الانتشاء بشكل أفضل. هناك فرصة جيدة لاستخدام ألياف هجينة (٢٥% PET و ٧٥% PP) لتعزيز قوة الانحناء للخرسانة.

الكلمات المفتاحية:

قوة الضغط؛ قوة الانحناء؛ ألياف نفايات PET ؛ ألياف البولي بروبيلين؛ ألياف هجينة.

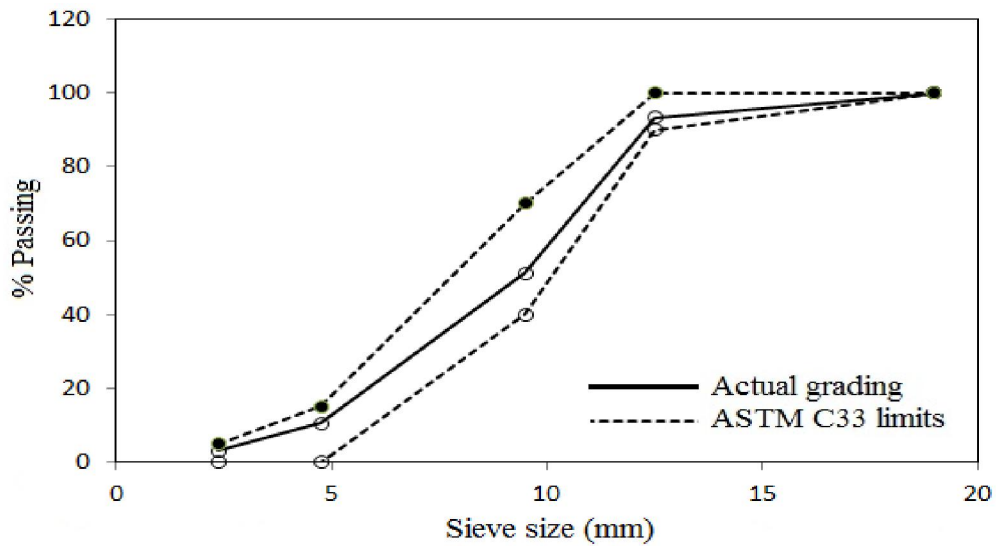
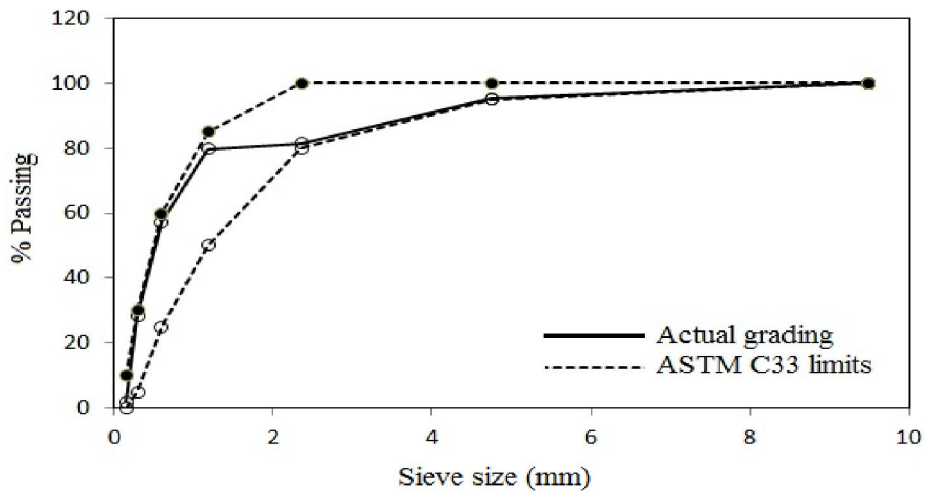
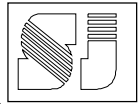


Figure 1: Grading of fine aggregate. Figure

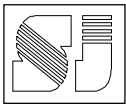
2: Grading of coarse aggregate.



Figure 3: Types of PET fibers used for concrete mixes.



Figure 4: View of polypropylene fiber.

Table 1: Mix proportion of concrete (kg/m³)

Mix code	Cement	FA	CA	Water	PET fiber	PP fiber
MC	436	697	1018	205	0	0
M-0.5-PP	436	697	1018	205	0	4.55
M-1.0-PP	436	697	1018	205	0	9.10
M-1.5-PP	436	697	1018	205	0	13.65
M-0.5-PET-10	436	697	1018	205	6.5	0
M-0.5-PET-20	436	697	1018	205	6.5	0
M-0.5-PET-40	436	697	1018	205	6.5	0
M-1.0-PET-10	436	697	1018	205	13	0
M-1.0-PET-20	436	697	1018	205	13	0
M-1.0-PET-40	436	697	1018	205	13	0
M-1.5-PET-10	436	697	1018	205	19.5	0
M-1.5-PET-20	436	697	1018	205	19.5	0
M-1.5-PET-40	436	697	1018	205	19.5	0
M-0.5-HY-PET-10-25	436	697	1018	205	1.63	3.41
M-1.0-HY-PET-10-25	436	697	1018	205	3.25	6.83
M-1.5-HY-PET-10-25	436	697	1018	205	4.88	10.23
M-0.5-HY-PET-20-25	436	697	1018	205	1.63	3.41
M-1.0-HY-PET-20-25	436	697	1018	205	3.25	6.83
M-1.5-HY-PET-20-25	436	697	1018	205	4.88	10.23
M-0.5-HY-PET-40-25	436	697	1018	205	1.63	3.41
M-1.0-HY-PET-40-25	436	697	1018	205	3.25	6.83
M-1.5-HY-PET-40-25	436	697	1018	205	4.88	10.23
M-0.5-HY-PET-10-50	436	697	1018	205	3.25	2.28
M-1.0-HY-PET-10-50	436	697	1018	205	6.5	4.56
M-1.5-HY-PET-10-50	436	697	1018	205	9.75	6.84
M-0.5-HY-PET-20-50	436	697	1018	205	3.25	2.28
M-1.0-HY-PET-20-50	436	697	1018	205	6.5	4.56
M-1.5-HY-PET-20-50	436	697	1018	205	9.75	6.84
M-0.5-HY-PET-40-50	436	697	1018	205	3.25	2.28
M-1.0-HY-PET-40-50	436	697	1018	205	6.5	4.56
M-1.5-HY-PET-40-50	436	697	1018	205	9.75	6.84
M-0.5-HY-PET-10-75	436	697	1018	205	4.88	1.14
M-1.0-HY-PET-10-75	436	697	1018	205	9.75	2.28
M-1.5-HY-PET-10-75	436	697	1018	205	14.63	3.41
M-0.5-HY-PET-20-75	436	697	1018	205	4.88	1.14
M-1.0-HY-PET-20-75	436	697	1018	205	9.75	2.28
M-1.5-HY-PET-20-75	436	697	1018	205	14.63	3.41
M-0.5-HY-PET-40-75	436	697	1018	205	4.88	1.14
M-1.0-HY-PET-40-75	436	697	1018	205	9.75	2.28
M-1.5-HY-PET-40-75	436	697	1018	205	14.63	3.41

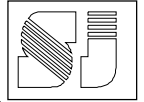


Figure 5: Sample of cylinder mix after testing.

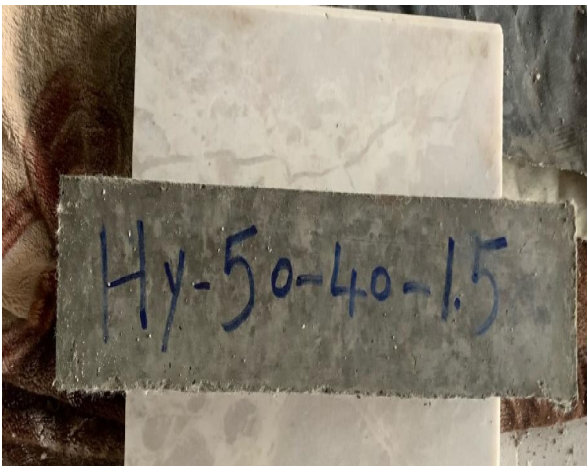


Figure 6: Sample of prism used for flexural testing.



Figure 7: Concrete mix with 10 mm PET fiber.

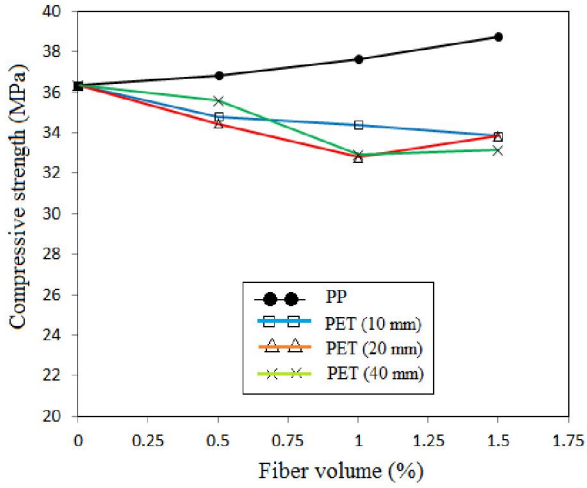
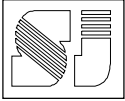


Figure 9: Variation of compressive strength with volume (PP, 100% PET)

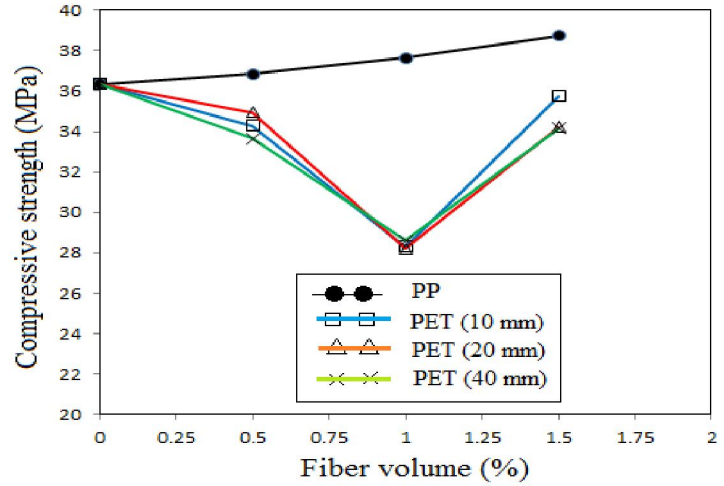


Figure 8: Variation of compressive strength with fiber

fiber volume (PP, Hybrid 75% PET)

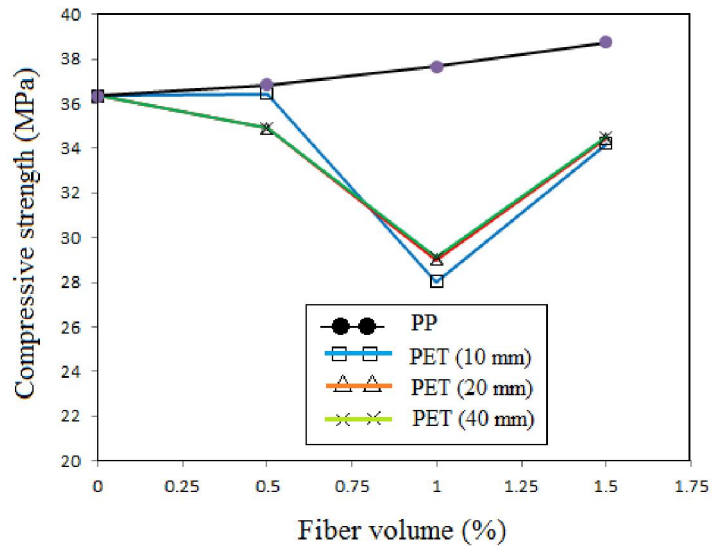


Figure 10: Variation of compressive strength with fiber volume (PP, Hybrid 50% PET)

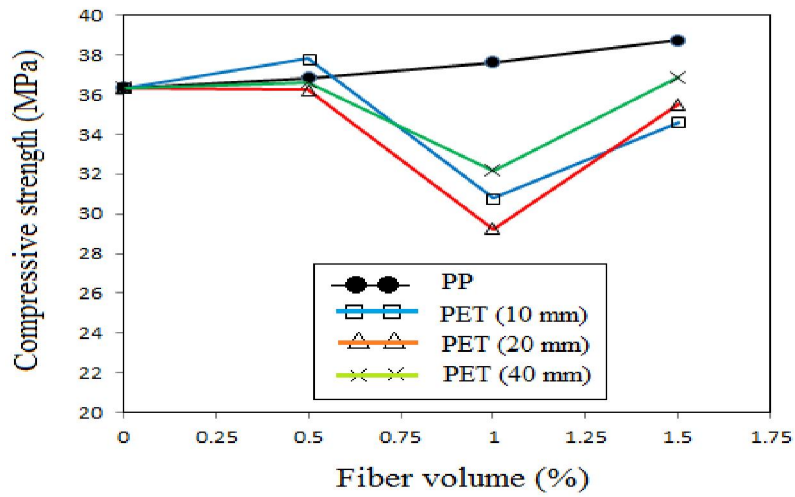
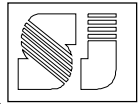


Figure 11: Variation of compressive strength with fiber volume (PP, Hybrid 25% PET)

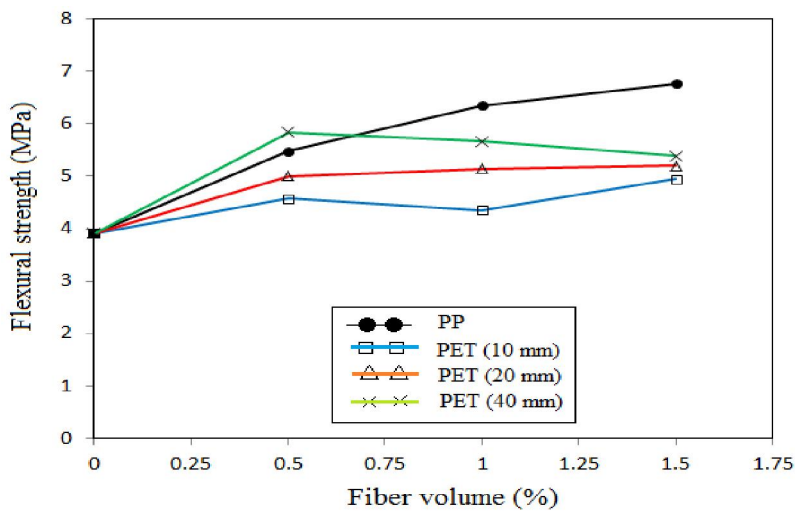


Figure 12: Variation of compressive strength with fiber volume (PP, 100% PET)

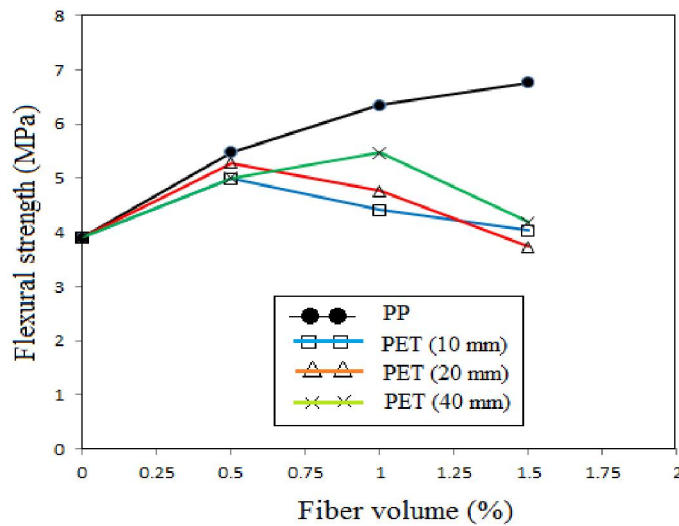


Figure 13: Variation of compressive strength with fiber volume (PP, Hybrid 75% PET)

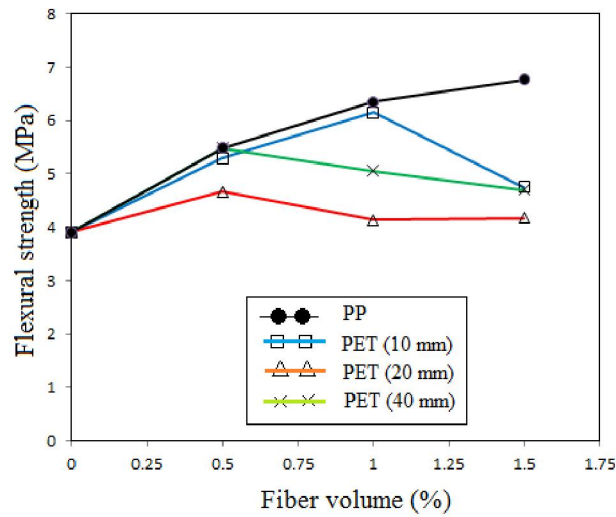
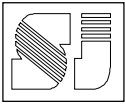


Figure 14: Variation of compressive strength with fiber volume (PP, Hybrid 50% PET)

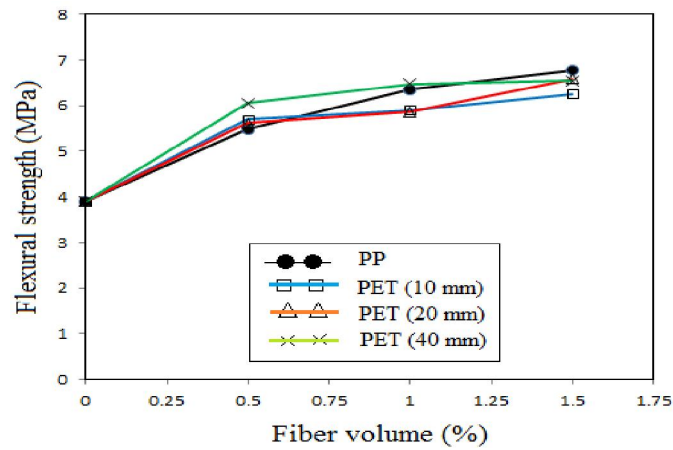


Figure 15: Variation of compressive strength with fiber volume (PP, Hybrid 25% PET)

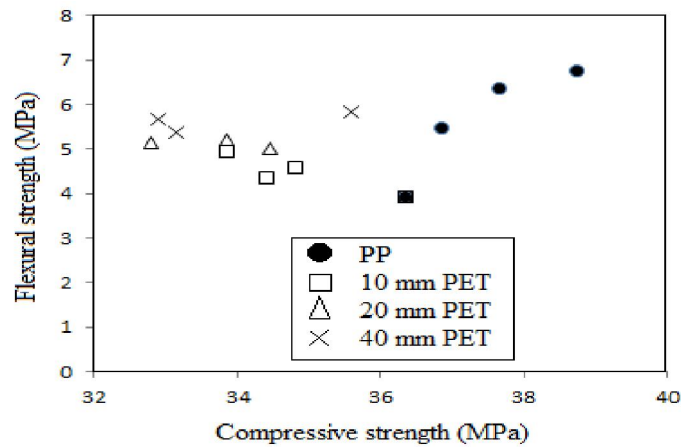


Figure 16: Flexural strength- compressive strength relationship (PP, 100% PET)

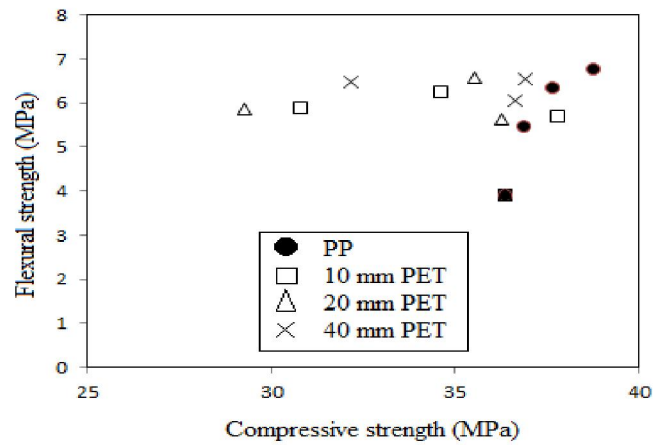
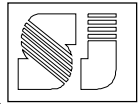


Figure 17: Flexural strength- compressive strength relationship (PP, Hybrid 25% PET)

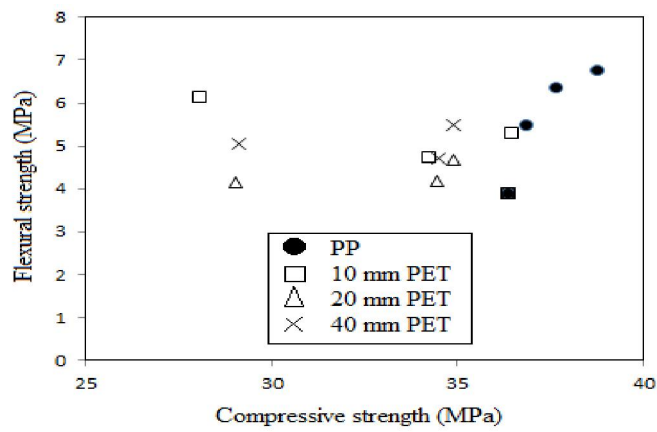


Figure 18: Flexural strength- compressive strength relationship (PP, Hybrid 50% PET)

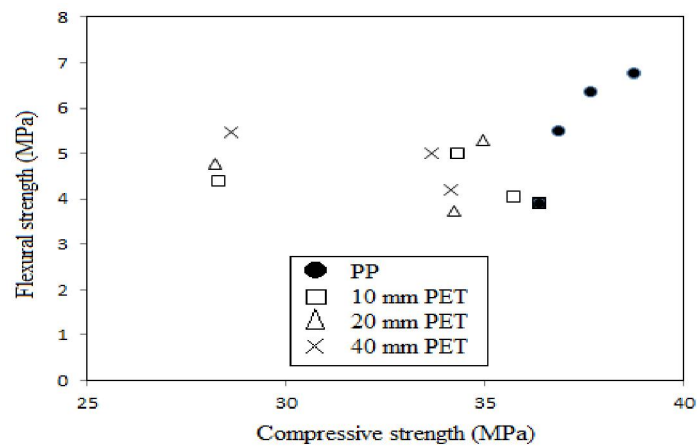


Figure 19: Flexural strength- compressive strength relationship (PP, Hybrid 75% PET)