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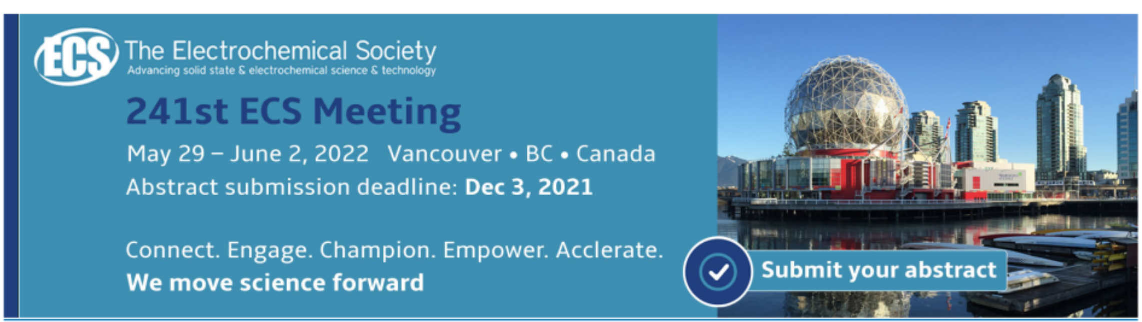

Flexural behavior of reinforced concrete beams using PET plastic as partial replacement of coarse aggregate

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Abstract. The growth of daily consumption of different types of plastic containers such as Polyethylene Terephthalate (PET) is observed over the world. Using plastic wastes in conjunction with other building materials such as concrete has a promised future. This study investigates the flexural behavior of reinforced concrete beams using Polyethylene Terephthalate (PET) plastic as partial replacement of course aggregate. Four beams were tested under static load, which consisted of two control beams (CB) and two PET plastic beams (PB). The dimension of beams was 150 mm x 250 mm and length of 3300 mm. A 10% of course aggregate was replaced by using PET plastic. In addition, 0.5% 3D steel fiber by weight of cement was added to the mixture to increase the tensile strength of the normal concrete and PET concrete. The load-displacement and strain graphs of all beams were drawn, and the flexural capacity, stiffness, and failure mode were compared and discussed. The results indicated that the flexural strength of PB was decreased by 18.77% compared to CB due to the lower compressive strength of PET concrete. Moreover, all the beams were failed under flexure due to concrete crushing at the compression zone of the beams.

1. Introduction

Plastic waste is one of the most serious environmental issues in many countries. The issues are in the processing and provision of land for final waste disposal. Plastics, due to their non-biodegradable nature, take more than 100 years to decompose completely. Plastic consumption continues to rise year after year, increasing waste. Thus, it is essential to identify alternative solutions to reuse plastic waste for various uses. Researchers from various disciplines have conducted studies and actions to solve this issue. One of the solutions is by recycling plastic waste. However, this method is ineffective significantly because only about 4% can be recycled, and the rest is piled up in landfills. Hence, more efficient plastic waste management is needed. Plastic waste can be used as artificial aggregates in asphalt mixtures [1] and concrete mixtures as the solutions.

Concrete has been identified as a viable alternative in dealing with plastic waste [2,3]. Because aggregate accounts for 65-80% of the volume of concrete, employing plastic waste as a substitute for aggregate can drastically reduce waste. This is in line with core environmental measures such as waste prevention, waste recycling, landfill preservation, waste processing into energy sources, and raw material conservation [4]. Concrete, on the other hand, has limited properties, including low tensile strength, ductility, and impact energy absorption [5]. Some concrete components and structures, such as wall panels, bridge decks, airport pavements, and road pavements, are subjected to impact loads. As a result, these structural components must have great impact resistance and load-bearing capacity. Mohammadhosseini et al. [6] reported that the addition of plastic fibers to the concrete could overcome the brittle nature of concrete. In addition, it is also has a significant effect on increasing the load and the ability to resist the impact loads.

In recent years, several types of plastics have been studied, including polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polypropylene (PP). These studies focused on the effect of plastic waste addition on the workability of fresh concrete and the mechanical behavior of hard concrete [7,8,9].

Ismail et al. [9] found that when the percentage of plastic waste (consisting of 80% polyethylene and 20% polystyrene) increases, the workability increases, and the density decreases. In addition, Al-According to Manasser et al. [11], concrete containing plastic aggregates from car bumpers has a more ductile behavior than comparable concrete made with conventional aggregates. This ductile behavior is important in reducing crack formation in concrete structures. Furthermore, as the number of plastic increases, the compressive strength and split tensile strength of concrete decrease. Another study found that adding steel fibers to normal concrete significantly improved its mechanical properties (compressive strength, flexural strength, and split tensile strength) [12].

Irmawaty et al. [12] conducted a study on plastic waste as a substitute for aggregate. The study aims to determine the mechanical behavior of fiber concrete using PET plastic waste as a partial replacement for aggregate. The variation of PET plastic content is 0%, 10%, 15%, and 20% of the volume of coarse aggregate. Mechanical testing on concrete showed that the greater the addition of PET plastic content, the more significant the decrease in the value of compressive strength, flexural strength, split tensile strength, and modulus of elasticity of concrete. The results also show that the 10% PET percentage is the optimum percentage. The study also recommended adding steel fiber to increase the mechanical properties (compressive strength, flexural strength, split tensile strength).

Based on those mentioned above, this study used PET (Polyethylene Terephthalate) plastic bottle waste as coarse artificial aggregate. To increase the strength of the plastic waste concrete, 0.5 percent steel fiber is added to the cement weight. The flexural behavior of the beams was examined using the flexural capacity, crack pattern, and load-displacement response.

2. Methods

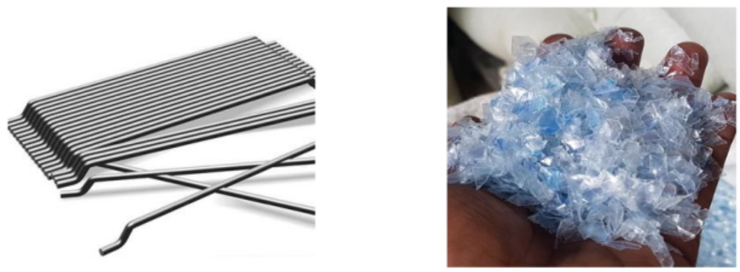
2.1 Concrete mix proportions and mixing

Table 1 shows the mixed design used in this study. The mix design was taken based on experimental results carried out by Irmawaty [12]. As can be seen, the PET plastic content is 10% of the volume of coarse aggregate, where this percentage is the optimum percentage. The PET plastic in this study was obtained by shredding the PET plastic bottles using a special machine. The PET plastic used was passed ¾" and retained on sieve No. 4, the maximum size is 19 mm and the minimum size is 4.75 mm. Dramix 3D 80/60 presentation is 0.5% by weight of cement. Superplasticizer presentation was 0.5% by weight of cement. Water cement factor (w/c) was 40%.

Table 1 Mix design (m^3)

Material	**Weight (kg/m3)**	
	0% PET	**10% PET**
Water	182,69.	182.69
Cement	462.50	462.50
Sand	613.49	613.49
Gravel 2 - 3	1021.63	919.47
Dramix 3D 80/60	2.31	2.31
PET waste	0.00	46.38
Superplasticizer	2.31	2.31

The concrete mixing process is carried out using a mixer machine. The mixing method in this study was developed by following ASTM C1116 / C1116M - 10a(2015) [13]. Before mixing, the aggregates were weighed and prepared under Saturated Surface Dry (SSD) conditions. For each batch of mixing, coarse aggregate, PET, cement, and fine aggregate were mixed for 30 seconds before adding water with superplasticizer and mixing for another 30 seconds. The concrete mixer is then turned off, and the mixing is done by hand. The mixing with a mixer machine was then resumed. Steel fibers were continuously added to the fresh concrete while mixing, and mixing continued for another two minutes until a homogeneous mix was obtained. Three 100 x 200 mm cylinders were cast for each concrete mix batch to measure concrete compressive strength.



a. Steel fiber b. PET waste

Figure 1 Steel fiber and PET waste

2.2 Test specimens

Four reinforced concrete beams were cast in two groups. Except for the presence of shredded PET as a coarse aggregate replacement, each group has the same properties. Figure 2 shows dimension, flexure, and shear reinforcement details. The cross-section of all beams was 100 mm wide and 150 mm deep, with an overall length of 1200 mm and a clear span of 1100 mm. The beams were designed to be failed in flexure. A 13 mm rebars were used for tensile rebars and 8 mm rebars were used for shear reinforcement (stirrup). The average yield strength of 406.9 MPa and 397.2 MPa and the average ultimate strength of 579.9 MPa and 552.1 MPa for 13 mm and 8 mm, respectively. The steel bars are tested. Further detail of the specimens can be seen in table 2. CB was a control beam without PET particles, while PB was a PET beam with 10% PET particles.

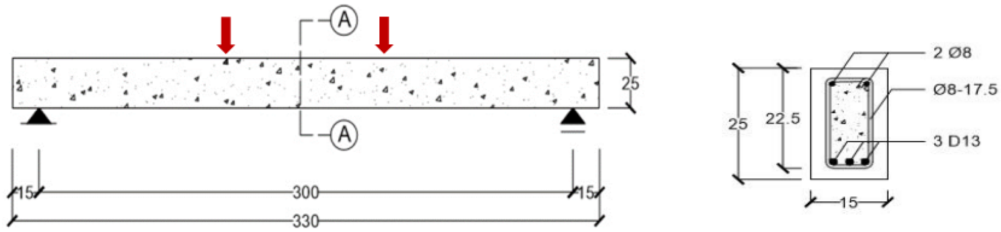


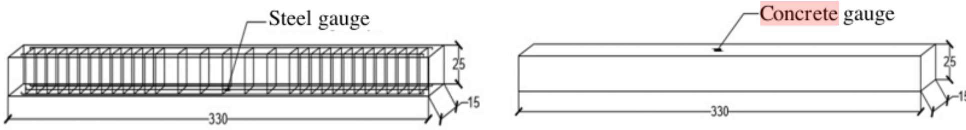
Figure 2 Details of specimens

Table 2 Variation of specimens

	PET volume	Compressive strength (MPa)	Number of specimens
CB	-	30.02	2
PB	10%	18.38	2

2.3 Instrumentations and setup

All specimens were tested after 28 days of curing. To facilitate the observation of crack formation during testing, all beams were white painted. Figure 3 shows the location of transducers and strain gauges. Three transducers were located under the loading points and mid-span of specimens. One strain gauge was placed at mid-span of steel bars to measure the strain at the longitudinal rebars. Another strain gauge was also attached at the top surface of concrete to measure the strain at compression zone of the beam. The recorded strain in steel bar and concrete was useful to identify the strain behaviour and failure mode of the beam.



a. Strain gauge at steel bars b. Strain gauge at concrete

Figure 3 Location of strain gauge

Each beam was subjected to two point loads by using a hydraulic jack with a 1500 kN capacity (figure 4). The magnitude of the applied load was measured using a load cell. The tests were conducted under displacement control with an average rate of 0.3 mm/sec. Furthermore, during the beam test, cylinder specimens were tested for compressive strength. The tests followed ASTM C39 specification.

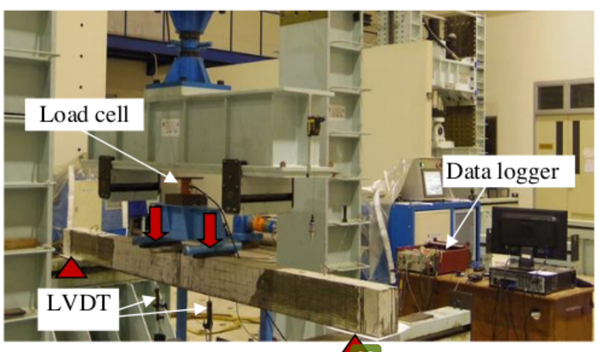


Figure 4 Loading test

3. Results and discussion

3.1 Concrete mix proportions and mixing

Results of concrete compressive strength are shown in table 2. The average compressive strength of normal concrete and PET concrete was 30.02 MPa and 18.38 MPa, respectively. Results indicated that the average strength reduction was 38.7% when there is 10% PET in the concrete. This was because the addition of plastic reduces workability. The low workability of concrete causes porosity in the concrete, so that the compressive strength of the concrete decreases. In addition, the smooth plastic surface could a decrease in the bond between the aggregates in the concrete.

3.2 Load-displacement behavior

Figure 5 shows a graph of load and deflection relationship of CB and PB. The deflection shown in the graph is the displacement in the middle of the span. Table 3 summarizes the experimental results.

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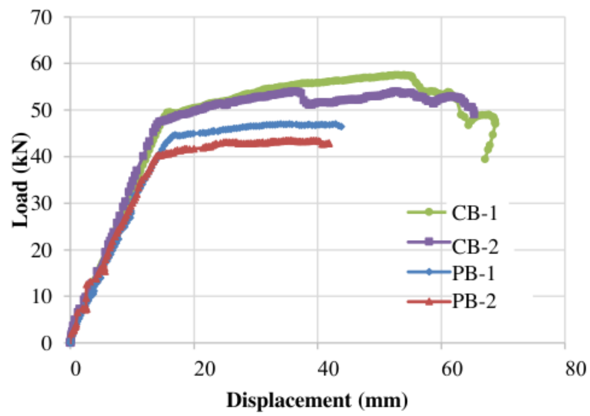


Figure 5 Load-displacement behaviour

Table 3 Experimental results

Specimen	Load (kN)			Displacement (mm)			Failure mode
	P_{crack}	P_{yield}	$P_{ult.}$	δ_{crack}	δ_{yield}	$\delta_{ult.}$	
CB-1	11.1	49.44	57.51	2.56	15.63	53.03	Flexural failure
CB-2	9.7	47.51	53.91	2.52	14.37	52.99	
Average	10.4	48.48	55.71	2.54	15.00	53.01	
PB-1	10.1	44.65	46.98	2.83	16.95	42.85	
PB-2	9.8	40.32	43.52	2.86	14.39	36.03	
Average	9.95	42.49	45.25	2.85	15.67	39.44	

In general, CB-1 and CB-2 show similar behaviour from beginning until the peak load. It can be seen that the load-deflection stiffness was almost the same. Cracking load and yielding load of CB-1 and CB-2 was almost same but the yielding load of CB-1 was higher than that of CB-2. Meanwhile, PB-1 and PB2 also show almost the same deflection load behavior from the initial load to the peak load. However, the yield and ultimate loads of PB1 are larger than those of PB-2. This happens because of the uneven distribution of plastic in the two test objects, resulting in slightly different loads.

By comparing PB to CB, the beams showed similar behavior at the beginning of loading where the load-deflection stiffness PB approaches CB. The initial crack load of the two variations of the test specimens is almost the same, where the initial cracks of CB and PB where 10.4 kN and 9.9 kN, respectively. At 25 kN, the stiffness of the PB begins to decrease compared to CB. At this stage, the number of cracks that occur in PB is more than that of PB. This was the effect of PET that can inhibit the rate of crack development so that new cracks appear along the tested span. When the load is increased, the reinforcement begins to reach yield strain which is characterized by a significant decrease in beam stiffness. The yielding load of CB and PB was 48.5 MPa and 42.5 MPa, respectively. The results emphasised that the use of 10% PET reduced the yielding load was about 14.1%. However, the deflection that occurs is not affected by 10% PET, where the CB deflection PB approaches the CB deflection. Furthermore, the beam reaches the peak load, which is indicated by the crushing of the concrete on the compression zone of the beam. The average ultimate loads on the CB and PB beams are 55.7 kN and 45.25 kN with deflections of 53.01 and 39.4 MPa, respectively. These results indicate that the use of 10% PET has a significant effect on the ultimate load and deflection of the beam.

In Figure 5 it can also be seen that CB shows more ductile than PB. This is because 10% PET with a smooth surface will reduce the bond between the matrix and the aggregate. So this also affects the bond between the matrix and the steel fiber added to all test objects. A good bond contributes to ductile behavior by improving post-peak response and enhancing tensile behavior, resulting in more strain (deformation) before failure.

3.3 Load capacity

Figure 6 shows a comparison of the ultimate load on CB and PB. As shown, the ultimate load of PB was decreased by 18.8% than that of CB. This was because the addition of 10% PET reduced the compressive strength of concrete. The compressive strength of PET concrete was reduced by 38.7% compared to normal concrete.

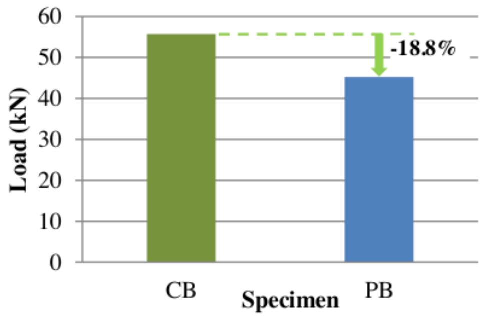


Figure 6 Ultimate capacity

3.4 Load-strain of rebars and concrete

Figure 7 shows the load-strain relationship of the longitudinal rebars. CB-1 yielded at a strain of 2036 με and a load of 49.44 kN, while CB-2 yielded at a strain of 2008 με and a load of 47.51 kN. Thus, the average yield load of CB is 48.48 kN. After the yield load, the strain on CB-1 was error so that it can cannot be measured the strain at the next load. For PET beam specimen, strain of PB-1 cannot be showed in figure 7 because of an error in the strain gauge, which affected the accuracy of the measurement. For PB-2, the strain could function well where the longitudinal rebars yielded at a load of 40.32 kN. This yielding point was identified based on the yield strain value obtained from the tensile strength test (ε_y = 2000 με). Moreover, the yielding point can be also identified from the disproportionate increase in strain with an increase in load. By comparing the yielding load of CB and PB, it can be concluded that that the use of 10% PET could reduce the yielding load of the beam by 14.09% compared to CB. This was due to the reduction in the cross-sectional area of the beam which was replaced with PET concrete could reduce the stiffness and strength of the beam.

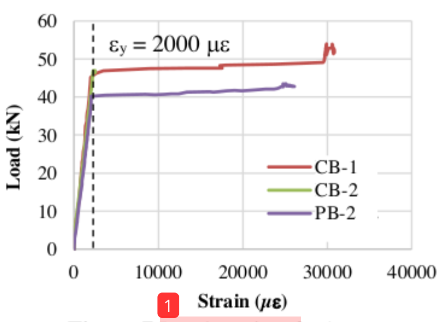


Figure 7 Load-strain of rebars

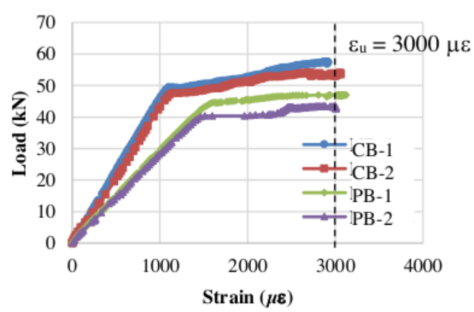


Figure 8 Load-strain of concrete

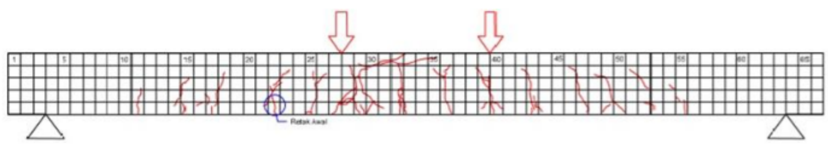
Figure 8 shows the load-strain relationship of concrete. As shown, all strain gauges can function properly from beginning until the peak load. The use of PET plastic in beams affected the strain of concrete at each load where the strain in the CB beam is smaller than that of the PB at the same load. For example, at 30 kN, the strain in CB-1 was 620 με while PB-1 is 1010 με. This was because the compressive strength of CB concrete was higher than that of PB, thus affecting the strain distribution in the compression zone depth.

Based on the results of the stress-strain relationship between steel and concrete, it can be seen that the main reinforcement yields before the concrete crushed. This indicates that the failure mode in all beams is characterized by yield reinforcement before the concrete collapses (under-reinforced).

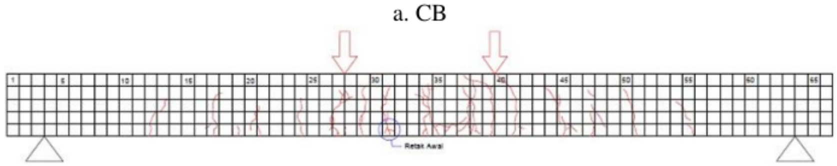
3.5 *Load-strain of rebars and concrete*

Figure 9 shows the crack pattern of CB-1 and PB-1 beams. In general, the crack pattern that occurs in all beams, both Normal (BN) and PET (PB) beams, is the same, namely the flexural crack pattern. This is indicated by cracks in the vertical direction to the main axis of the beam.

Initial cracks in the two test specimens occurred in the constant moment region between the loading points. When the load is increased, the crack propagates vertically and new cracks appear towards the support. At the ultimate load, the number of cracks in PB is more than that of CB. This is because of the influence of PET which can inhibit the rate of crack development.



a. CB



b. PB

Figure 9 Crack pattern

4. Conclusions

a. The addition of 10% PET to concrete was found to be ineffective in controlling compressive strength loss caused by the PET plastic material. When PET concrete was compared to normal concrete, its strength was reduced by 38.7%.

b. The ultimate load capacity of a 10% PET content beam was reduced by 23.1% compared to the control beam. The deflection at peak load was also reduced. When PET was added to the concrete, the load-deflection response changed slightly.

c. The failure mode is not changed when 10% PET content is used where all beams failed under flexure.

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