

## Cracking propagation and pattern behaviour of irregular-shaped polyethylene terephthalate fibre reinforced concrete beam

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**Abstract.** This paper reports the results on cracking propagation and pattern of reinforced concrete (RC) beam conducted using irregular-shaped polyethylene terephthalate (IPET) as a fibre. Three volume fraction of IPET fibre is used namely, 0.5%, 1% and 1.5%. All RC beam specimens are tested using four point loading under flexural capacity behaviour. Prior to structural test, the materials properties which include the compressive & tensile strength test and modulus of elasticity test were determined. These results are compared with control RC beam. It is found that the RC beam with IPET fibre does not significantly change the behaviour of failure mode, cracking propagation and pattern compared to control RC beam.

### Introduction

Concrete is a brittle material that has low material strength and low strain capacity [1]. Many deterioration and failures in the concrete such as crack, shrinkage and corrosion are due to the brittle nature of this material. The role of fibre inside concretes is to bridge across the cracks when the strain of the composite has exceeded the ultimate strain capacity of the brittle [2]. Besides, the fibres have the contribution in improving the deflection, ultimate loading and ductility of a structures. Previous studies by Kim et al., [3] and Fraternali et al., [4] have conducted PET fibres in RC beam. Nevertheless, both studies used the PET that is reproduced from the factory and in strip shape. As the irregular type of polyethylene terephthalate (PET) from straight recycled bottle wastes are yet to be studied, and one of the environmental potential means to the problem is to recycle this wastes in construction industry [5] [6] [7] [8], therefore, in this research, the irregular-shaped polyethylene terephthalate (IPET) is chosen as fibre in concrete for testing crack propagation and pattern.

### Experimental tests

A total of eight RC beams (B-0-1A, B-0-2B, B-0.5-1A, B-0.5-2B, B-1-1A, B-1-2B, B-1.5-1A and B-1.5-2B) with size of 2300x300x100 mm are tested under flexural capacity test setup after 28 days from casting. All specimens are reinforced with four T12 reinforcement bars and R6 shear stirrups with 100 mm spacing. The testing instrumentation setup is shown in Fig. 1. RC beams specimens with pinned and roller supports are tested using Universal Test Frame (UTF) with maximum load capacity of 3000 kN. The load is applied using manually controlled hydraulic jack with the loading rate of 1 kN/min. In order to obtain an accurate deflection measurement, a Linear Variable Differential Transducer (LVDT) is placed at three positions; mid span, and both sides under point loadings. Crack formation according to Hamdy & Radhouane [9] initiated at the flexural span between two concentrated loadings where this area indicated as pure bending where the flexural stress is highest and zero shear stress. A self compacting concrete (SCC) with grade 30 MPa is used for all RC beam specimens. The material mix proportion is indicated in Table 1 and all material used are conformed to the standard in SCC Guideline [10].

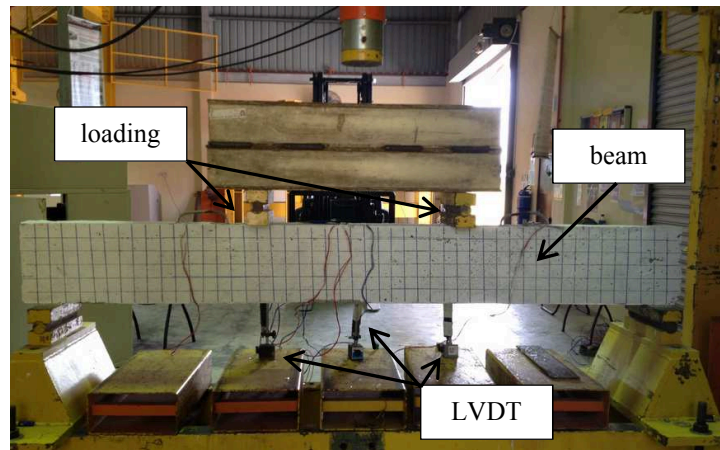


Fig. 1: Flexural capacity test setup for RC beam

Table 1: Material mix proportion for RC beam

Mix proportion			
	Detail		Unit weight (kg/m <sup>3</sup> )
Cement (C)	Ordinary Portland	Cement EN 197-1 [11]	300
Fly Ash (FA)	Class F	SCC Guideline [10]	90
Fine aggregate (S)	Sand with size of 4.75 mm	EN 12620:2002 [12]	980
Coarse aggregate (G)	Crushed gravel (12-20 mm)		805
Water (W)	-		175
W/C Ratio	-		0.58
			Volume (ml)
Superplasticizer	Mighty 21 VS (Koa Plasticizer Malaysia)	EN 934-2:2009 [13]	4680

## Result and analysis

### Mechanical properties

The results for compressive strength ( $f_{cu}$ ), splitting tensile strength ( $f_{ct}$ ) and elastic modulus ( $E_c$ ) are shown in Table 2. The  $f_{cu}$  for all batches of concrete in this research achieved the concrete Grade 30, where normal concrete is 36.03 MPa. The addition of IPET fibre at 1% and 1.5% of volume fraction decrease the  $f_{cu}$  at about 5 to 6.4% whereas 0.5% volume fraction PET fibre exhibits increasing in concrete strength at 0.5%. The  $f_{ct}$  for normal concrete is 3.4 MPa. Increments of 8.8 to 17.6% in  $f_{ct}$  are observed with the addition of PET fibre in concrete. The same trend for  $E_c$  is observed where the increment of 1.2 to 3.9% is figured out. The mechanical properties observed in this research are slightly improved compare to research done by Kim [3]. In that research, the  $f_{cu}$  and  $E_c$  exhibited decreased by 1 to 9% and 1 to 10% compared to normal concrete specimens. The increments in  $f_{ct}$  proportional to the IPET fibre volume fraction are expected to improve structural performance in further discussion.

Table 2: Results of mechanical properties

Batch	IPET (%)	Ave. $f_{cu}$ (MPa)	Ave. $f_{ct}$ (MPa)	Ave. $E_c$ (MPa)
1	-	36.03 ± 0.208	3.41 ± 0.010	25510 ± 177.553
2	0.5	36.23 ± 0.306	3.72 ± 0.015	25806 ± 165.973
3	1.0	34.23 ± 0.451	3.91 ± 0.208	26076 ± 51.215
4	1.5	33.73 ± 0.777	4.02 ± 0.067	26502 ± 185.914

### Cracking propagation and pattern

The cracking propagation and pattern results for control RC beam and RC beam with IPET fibres are shown in Fig. 2, Fig. 3 and Table 3.

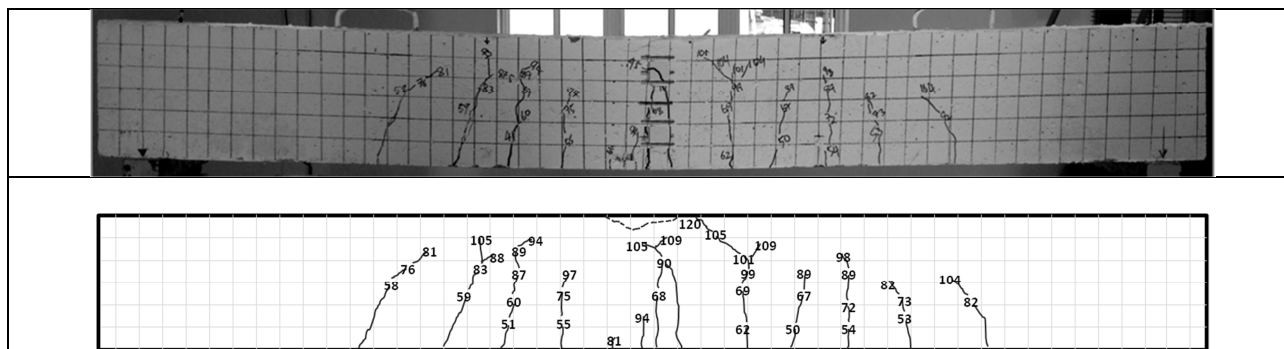


Fig. 2: Crack patterns at ultimate failure for B-0-1A

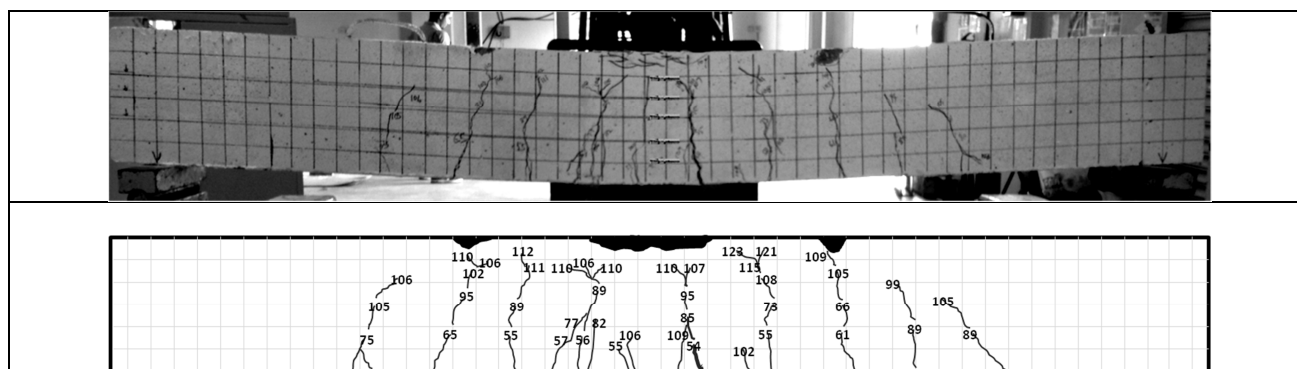


Fig. 3: Crack patterns at ultimate failure for B-0.5-2B

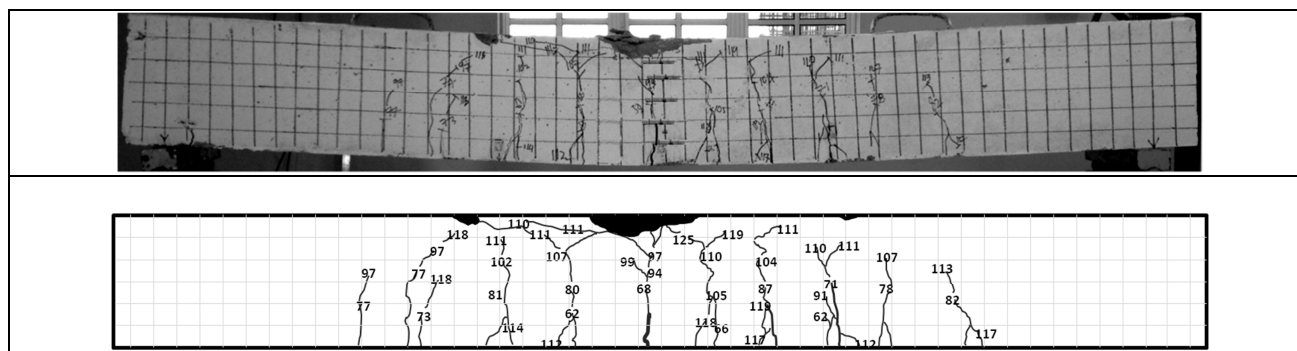


Fig. 4: Crack patterns at ultimate failure for B-1-1A

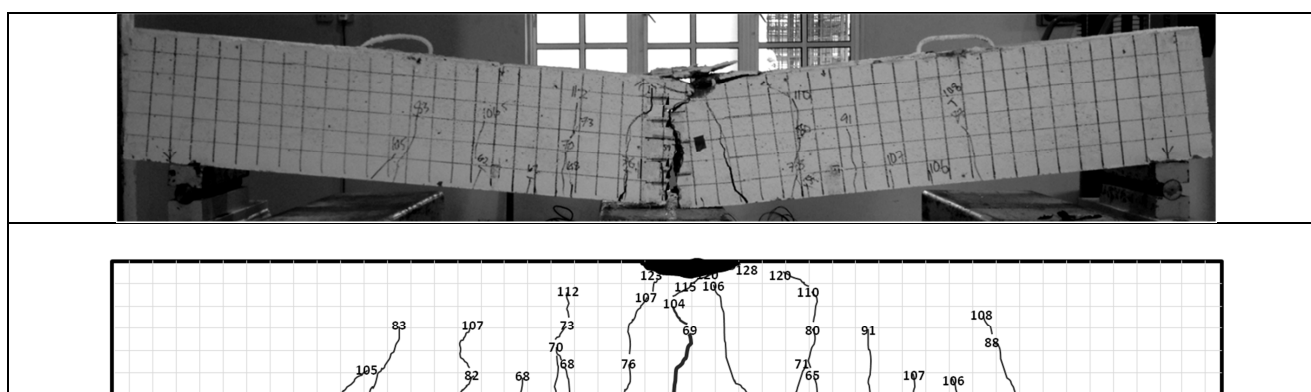


Fig. 5: Crack patterns at ultimate failure for B-1.5-1A

Table 3: Cracking propagation and pattern results

RC Beam	IPET fibres		Crack	
	Yes / No	%	Flexural	Compression
B-0-1A	No	0	√	-
B-0-2B			√	-
B-0.5-1A	Yes	0.5	√	√
B-0.5-2B			√	√
B-1-1A		1	√	√
B-1-2B			√	√
B-1.5-1A		1.5	√	√
B-1.5-2B			√	√

The cracks formation phase is observed to be formed at random positions as the trend are similar to the researcher by Barris et al., [2]. The cracks occurred in this area are vertically perpendicular to the direction of the maximum principle tensile stress induced by pure bending. As the load increased, additional inclined flexural cracks are developed in the mid span. At the stabilised crack stage, the flexural cracks developed become wider and the flexural shear crack started to develop at the shear span. This cracks propagation was observed for all RC beams specimens during testing until before the ultimate stage. At the ultimate stage, B-0-1A and B-0-2B specimens are failed by yielding of the tensile reinforcement and no concrete crushing occurred. At ultimate stage for RC beams specimens with IPET fibres namely B-0.5-1A, B-0.5-2B, B-1-1A, B-1-2B, B-1.5-1A and B-1.5-2B, the specimens are failed by both yielding of tensile reinforcement and concrete compression occurred at top of mid span. All RC beams specimens are observed failed in flexural and no shear failure was observed.

### Summary

In this research work, IPET fibre from recycled bottle wastes has been identified to improve the material and structural performance of concrete. The environmental and ecological benefit of effectively utilizing this waste material is another prime contribution to this research. The summarize of material and structural performance of concrete in this research are as follows;

- For mechanical properties of concrete, the addition of IPET fibre at 1% and 1.5% of volume fraction decrease the  $f_{cu}$  at about 5 to 6.4% whereas 0.5% volume fraction IPET fibre exhibits increasing in concrete strength at 0.5%. The  $f_{ct}$  and  $E_c$  of concrete added with IPET fibres increase at 8.8 to 17.6% ( $f_{ct}$ ) and 1.2 to 3.9% ( $E_c$ )
- For cracking propagation and pattern, all RC beam specimens point out flexural cracking behaviour a pure bending zone and no shear failure is observed.
- The compression cracks are observed for RC beams with IPET fibres. The function of IPET to increase the ultimate loads, deflection and ductility of RC beam.

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