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A Comparative Study on Compressive and Tensile Strength of Recycled Ring Waste PET Bottle (RPET) Fibre

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Abstract— Polyethylene Terephthalates (PET) is most of plastic container normally being discarded and resulted in environmental pollution. One of a better means is to recycle PET in concrete. This paper describes an experimental investigation of the relationship between tensile strength and compressive strength of concrete containing Ring type of waste PET bottle (RPET) fibre. The RPET were obtained by simple mechanical cutting from waste bottles into 5 and 10 ± 1 mm in width of the waste bottle to produce the RPET-5 and RPET-10 fibre. Comparative studies were conducted with two different water-binder ratios which are 0.45 and 0.55. Concrete containing with 0.0%, 0.25%, 0.50%, 0.75%, 1.00%, 1.25%, and 1.50% volume of RPET fibre content were produced in cylindrical specimens in 150 mm . All specimens were tested at the age of 28 days. It has been found that ultimate tensile strength of RPET concretes were greater compared to normal concrete. Incorporation RPET fibre in concrete has produced $f_{t-5} = 0.0567 f_c^{\,1.14}$ and $f_{t-10} = 0.1343 f_c^{\,0.91}$ empirical expression between compressive and tensile strength for RPET-5 and RPET-10 fibre concrete respectively. It can be concluded that incorporation of RPET in concrete is possible to produce concrete with good performance.

***Keywords*— Compressive strength, tensile strength, & empirical expression**

I. Introduction

Polyethylene terephthalate (PET) is one of potential waste which could be used in various applications. Efforts have been made to explore their usage in concrete such as that waste in concrete fibre performance [1]. The development of new construction materials using recycled PET fibre is important to both the construction and the PET recycling industries. A vast work has already been done on the use of plastic waste as an aggregate or a fibre in concrete. Frigione [2] and Marzouk et.al [3] had tried replacing or recycling the waste PET as the artificial aggregate in concrete. Others previous study show reprocessed of waste PET in concrete to produce fibre concrete [4]. Nevertheless, previous researches revealed that PET waste fibre in concrete has a significant role in terms of bonding and strength [4-5]. PET waste has very a weak bond with cement paste [6-7].

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It can be pointed out that increasing PET waste in concrete would increases the size of porosity and interfacial transition zone in concrete matrix and result reduction in strength [8-9]. Lamellar fibre have been widely used in research shows that at high stress in concrete fibre, the lamellar fibre was tended to slip off [5]. Therefore, to overcome the limitations that traditional straight or irregular fibre have, ring type fibre is used in this study. This paper will shows an attempt is made to develop a relation between concrete strength in the early age of fibre concrete and produced the relationship between tensile strength as a simple empirical prediction expression. Once, the relationship expression of RPET fibre concrete strength be established, it is possible to predict it is tensile strength of RPET fibre concrete.

II. Materials

The cement used in all mixtures was a commercially available Portland cement (PC), which corresponds to MS 522: 2007 [10]. Fly ash (FA) class F was used in this study. The aggregates and crushed sand from the same local source were used. The maximum aggregates size was 19 mm. The maximum size of fine aggregates conforming to BS EN 12620 is 4.75 mm [11]. The type of superplasticizer was used is Darex Super 20 Superplasticizer conforming ASTM C-494 Type A & F [12].The waste bottle was used in this study as the fibre concrete. Waste bottles were cleaned to remove impurities. The waste bottle has been cut in a ring shape. The diameter of ring waste PET was fixed at 60 ± 5 mm. Size width of ring fibre was fixed at 5 and 10 ± 1 mm. Figure 1 and 2 show the ring bottles of PET.

Figure 1 (a). Waste PET bottles

Figure 1(b). Waste Ring PET bottle

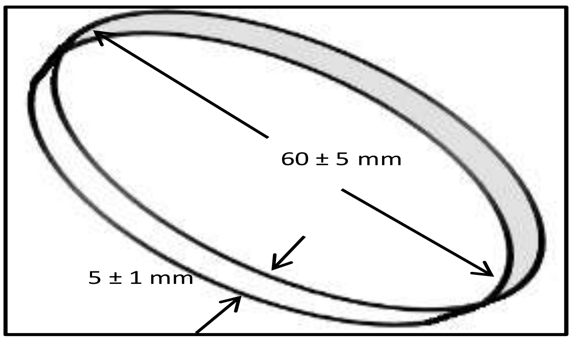

Figure 2(a). The dimension of RPET-5 fibre

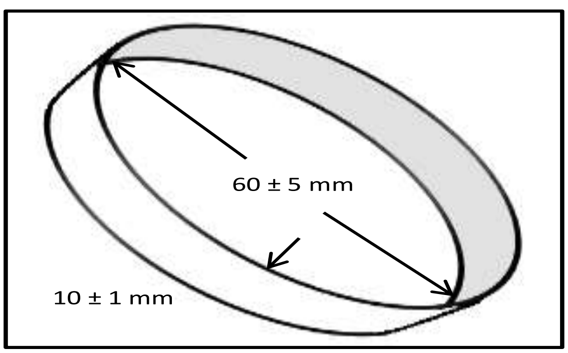

Figure 2(b). The dimension of RPET-10 fibre

III. Experimental Procedures

A. Preparation Mixtures SCC RPET

RPET fibre reinforced concrete self-consolidating concrete mixtures were designed according to Irwan [8]. The absolute volume method was used to calculate the absolute volume of each SCC component to occupy one cubic meter of concrete as shown in TABLE I. The concrete mixtures were prepared using a tilting drum mixer revolving mixer of 200L maximum capacity. The customized SCC mixtures were essentially prepared by adapting the mixing procedure SCC fibre concrete.

The mix was prepared by adding the designed amount of prepackaged materials to the mixer. Fine sand, cement, and fly ash were thrown one by one into the dry mixer and the materials mixed for 60 seconds. Super plasticizer and water was mixed as one package liquid material. Thereafter half of liquid was poured into the mixer and mixing continued for 60 seconds. Subsequently half of the remaining amount of liquid was added in 4 times at 60 second intervals. After mixing in 60 seconds, the coarse aggregates were added and mixing continued for 120 seconds. This was followed by adding fibre gradually to the mixer and after all fibres were added, mixing continued for 120 seconds to ensure uniform fibre distribution

TABLE I. MIX PROPORTION

Mix Designation	
w/b ratio	0.45 & 0.55
Percentages of RPET, (%)	0, 0.25. 0.50, 0.75, 1.00, 1.25, & 1.50
Cement, (Kg/m^3)	300.0
Fly Ash, (Kg/m^3)	90.3
Coarse Aggregates, (Kg/m^3)	805
Fine Aggregates, (Kg/m^3)	980
Water, (Kg/m^3)	176 &215
Super-plasticizer (ml/kg^3)	4680

B. Test of Hardened Concrete

The behaviour of the concrete fibre was performed by measuring properties of RPET fibre concrete in a hardened state. It involved the determination of compressive and tensile strength. Concrete cylinder specimens with dimensions 150 mm in diameter and 300 mm in length were prepared with different volume of fibre content and water binder ratio for compressive strength test. The specimens were tested at age of 28 days after curing. The compressive strength tests were conducted in accordance with BS 1881 – 116: 1983 [12]. These cylindrical specimens were tested using Universal Testing Machine (UTM) with a maximum loading capacity of 1000 kN based on BS 1881-115: 1986 [13]. Tensile tests consisted of applying a diametric compressive force along the length of cylindrical specimen size 150mm x 300 mm in length. The specimens were tested at the age of 28 days after curing as prescribed in BS EN 12390-6:2000 [14]. All testing measurements were obtained from three samples from each batch. The total sample for all sample concrete is 84 samples. The average of these three samples is presented and discussed in the section IV.

IV. Results and Discussion

All the concrete mixes show that concrete fibre at 0.45 and 0.55 water binder obtain small increases in strength compare to the normal concrete until it achieves at 1.0% volume of RPET fibre content. It can be recognized that tensile strength of fibre concrete were increased by 15.2% and 22.4% for RPET-5 and RPET-10 respectively compared to the normal concrete. Meanwhile, it can be pointed out that compressive of RPET fibre shows increased by 7.2% and 15.6% for RPET-5 and RPE-10 fibre concrete. This pattern result also obtains and agreeable by Choi et al [3], Dora Foti [5], Fernando et al [15], and Ramadevi et al [16]. Figure 3 shows the relationship between splitting tensile and compressive strength obtain from this study. Based on the Figure 3, the empirical expression for RPET-5 and RPET-10 concrete obtain from this study is;

$$f_{t-5} = 0.0567 f_c^{\,1.14} \qquad (1)$$

$$f_{t-10} = 0.1343 f_c^{\,0.91} \qquad (2)$$

Where f_t is the splitting tensile strength and f_c is compressive strength measures both in MPa. It can be recognised that on Figure 3, TABLE II, and TABLE III show that the best regression line for this study is approximate to the empirical relation of steel fibre concrete suggested by by Xu et al [17] with average differences of 1.00 for RPET-5 fibre concrete. Meanwhile, it can be recognised that Eurocode[18] shows the best regression line for this study is approximate to the empirical relation of RPET-10 fibre concrete by average differences of 1.06. The empirical relation are made by Xu [17[, Eurocode [18], Neville [19], and Rapheal [20] respectively are expressed below;

$$f_t = 0.21 f_c^{\,0.83} \qquad (3)$$

$$f_t = 0.30 f_c^{\,0.67} \qquad (4)$$

$$f_t = 0.23 f_c^{\,0.67} \qquad (5)$$

$$f_t = 0.20 f_c^{\,0.7} \qquad (6)$$

The results of experimental and predicted tensile strength from Eq. 1 to 6 are listed in Table 1 and 2. It can be recognised that the tensile strength of RPET-5 and RPET-10 fibre concrete obtained from this study is approximately between in line empirical relation expressed by SFRC(3) and Eurocode(4) equation respectively.

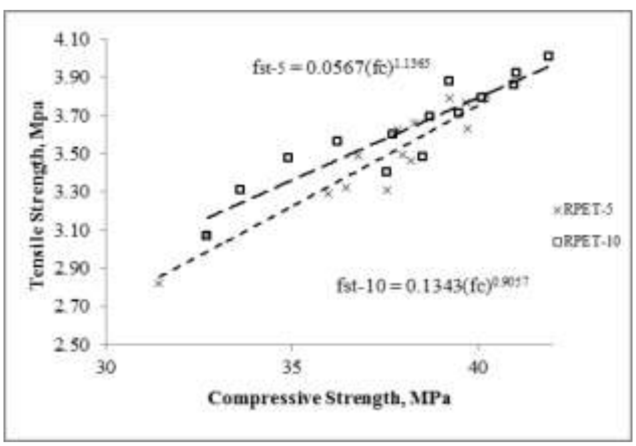

Figure 3. Relationship between tensile strength and compressive strength of RPET-5 and RPET-10 concrete fibre concrete (experimental and theoretical)

TABLE IIA: COMPARISON OF COMPRESSIBE AND TENSILE STRENGTH FOR RPET-5 FIBRE CONCRETE (EXPERIMENTAL AND THEORETICAL)

RPET, %	W/B	Comp. Str. f_c (MPa)	Ten. Str. f_{st} (MPa)	Exp / Predicted f_{st} (MPa) Eq. (1)	Eq (3)	Eq (4)	Eq (5)	Eq (6)
0.00	0.45	37.53	3.31	3.49	4.26	3.40	2.61	2.53
0.25		38.2	3.47	3.56	4.32	3.44	2.64	2.56
0.50		39.7	3.63	3.72	4.46	3.53	2.71	2.63
0.75		40.23	3.80	3.78	4.51	3.57	2.73	2.66
1.00		39.23	3.79	3.67	4.41	3.51	2.69	2.61
1.25		36.77	3.49	3.41	4.18	3.36	2.57	2.49
1.50		35.98	3.29	3.33	4.11	3.31	2.54	2.46
0.00	0.55	32.72	3.08	2.99	3.80	3.10	2.38	2.30
0.25		36.45	3.32	3.38	4.15	3.34	2.56	2.48
0.50		37.96	3.50	3.54	4.30	3.43	2.63	2.55
0.75		38.29	3.66	3.57	4.33	3.45	2.64	2.57
1.00		39.67	3.77	3.72	4.46	3.53	2.71	2.63
1.25		37.82	3.63	3.52	4.28	3.42	2.62	2.54
1.50		31.44	2.82	2.85	3.67	3.02	2.32	2.23

TABLE IIB: COMPARISON OF COMPRESSIBE AND TENSILE STRENGTH FOR RPET-5 FIBRE CONCRETE (EXPERIMENTAL AND THEORETICAL)

RPET, %	W/B	Comp. Str. f_c (MPa)	Ten. Str. f_{st} (MPa)	Exp / Predicted f_{st} (MPa) fst/fc (1)	fst/fc (3)	fst/fc (4)	fst/fc (5)	fst/fc (6)
0.00	0.45	37.53	3.31	0.95	0.78	0.97	1.27	1.31
0.25		38.2	3.47	0.97	0.80	1.01	1.31	1.35
0.50		39.7	3.63	0.98	0.81	1.03	1.34	1.38
0.75		40.23	3.80	1.01	0.84	1.07	1.39	1.43
1.00		39.23	3.79	1.03	0.86	1.08	1.41	1.45
1.25		36.77	3.49	1.02	0.83	1.04	1.35	1.40
1.50		35.98	3.29	0.99	0.80	0.99	1.30	1.34
0.00	0.55	32.72	3.08	1.03	0.81	0.99	1.29	1.34
0.25		36.45	3.32	0.98	0.80	0.99	1.30	1.34
0.50		37.96	3.50	0.99	0.81	1.02	1.33	1.37
0.75		38.29	3.66	1.03	0.85	1.06	1.38	1.43
1.00		39.67	3.77	1.01	0.85	1.07	1.39	1.43
1.25		37.82	3.63	1.03	0.85	1.06	1.38	1.43
1.50		31.44	2.82	0.99	0.77	0.93	1.22	1.26
			Average	1.00	1.00	0.82	1.02	1.33

TABLE IIIA: COMPARISON OF COMPRESSIBE AND TENSILE STRENGTH FOR RPET-10 FIBRE CONCRETE (EXPERIMENTAL AND THEORETICAL)

RPET, %	W/B	Comp. Str. f_c (MPa)	Ten. Str. f_{st} (MPa)	Exp / Predicted f_{st} (MPa) Eq. (2)	Eq (3)	Eq (4)	Eq (5)	Eq (6)
0.00	0.45	3.58	4.26	3.40	2.61	2.53	3.58	4.26
0.25		3.66	4.35	3.46	2.65	2.58	3.66	4.35
0.50		3.75	4.44	3.52	2.70	2.62	3.75	4.44
0.75		3.88	4.58	3.61	2.77	2.69	3.88	4.58
1.00		3.96	4.66	3.66	2.81	2.73	3.96	4.66
1.25		3.73	4.41	3.51	2.69	2.61	3.73	4.41
1.50		3.47	4.13	3.32	2.55	2.47	3.47	4.13
0.00	0.55	3.16	3.80	3.10	2.38	2.30	3.16	3.80
0.25		3.24	3.89	3.16	2.42	2.34	3.24	3.89
0.50		3.35	4.01	3.24	2.49	2.40	3.35	4.01
0.75		3.60	4.27	3.41	2.62	2.54	3.60	4.27
1.00		3.80	4.49	3.56	2.73	2.65	3.80	4.49
1.25		3.88	4.58	3.61	2.77	2.69	3.88	4.58
1.50		3.68	4.37	3.47	2.66	2.58	3.68	4.37

TABLE IIIB: COMPARISON OF COMPRESSIBE AND TENSILE STRENGTH FOR RPET-10 FIBRE CONCRETE (EXPERIMENTAL AND THEORETICAL)

RPET, %	W/B	Com. Str. f_c (MPa	Ten. Str. f_{st} (MPa	Exp / Predicted f_{st} (MPa) fst/f (2)	fst/f (3)	fst/f (4)	fst/f (5)	fst/f (6)
0.00	0.45	37.53	3.31	0.95	0.78	0.97	1.27	1.31
0.25		38.2	3.47	0.97	0.80	1.01	1.31	1.35
0.50		39.7	3.63	0.98	0.81	1.03	1.34	1.38
0.75		40.23	3.80	1.01	0.84	1.07	1.39	1.43
1.00		39.23	3.79	1.03	0.86	1.08	1.41	1.45
1.25		36.77	3.49	1.02	0.83	1.04	1.35	1.40
1.50		35.98	3.29	0.99	0.80	0.99	1.30	1.34
0.00	0.55	32.72	3.08	1.03	0.81	0.99	1.29	1.34
0.25		36.45	3.32	0.98	0.80	0.99	1.30	1.34
0.50		37.96	3.50	0.99	0.81	1.02	1.33	1.37
0.75		38.29	3.66	1.03	0.85	1.06	1.38	1.43
1.00		39.67	3.77	1.01	0.85	1.07	1.39	1.43
1.25		37.82	3.63	1.03	0.85	1.06	1.38	1.43
1.50		31.44	2.82	0.99	0.77	0.93	1.22	1.26
			Average	1.00	0.84	1.06	1.38	1.42

V. Conclusion

The relationship between compressive and tensile strength using waste bottle as RPET fibre in concrete were developed. This paper presented empirical expression to predict the tensile strength in the early age of RPET fibre concrete. Herein, empirical expressions of tensile strength for early age of fibre concrete are $f_{t-5} = 0.0567 f_c^{1.14}$ and $f_{t-10} = 0.1343 f_c^{0.91}$ for RPET-5 and RPET-10 fibre concrete respectively. Hence, practical empirical expression approach has been described for prediction at the end age of 28 days tensile strength of fibre concrete based on the values of compressive strength test. It can be used as a reliable tool for assessing the design strength of concrete through predicting early strength of RPET fibre concrete.

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