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CONTENTS

Experimental study on strain hardening and deflection hardening conditions of recycled textile reinforced cementitious composites

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Abstract. This study investigated the conditions of strain hardening and deflection hardening for recycled Polyethylene textile reinforced cementitious composites (RPE-TRCCs). Experimental program with tension and four-point bending tests were conducted. Two types of recycled textile were used as reinforcements within mortar matrix. The results show that the strain hardening and deflection hardening of RPE-TRCCs could be measured as using four and one layer of textile, respectively. Tensile and flexural resistance of RPE-TRCCs increased by 200-280% and 35-135%, as the layer number increased from one to four.

Keywords: Recycled polyethylene textile reinforced cementitious composites, deflection hardening, strain hardening, tensile and four-point bending test.

1 Introduction

The construction and building were responsible for 40% of all global greenhouse gas emission and generated approximately 35% of global waste [1–3]. Consequently, gradual replacement traditional materials and recycling waste materials to be as reinforcements were necessary to sustainable future [3,4].

Plastic waste was recycled to be short reinforcement [5–8]. Polyethylene terephathalate (PET) contributed to enhanced better mechanical and chemical resistance of reinforced mortar matrix [9–13]. Recycled nylon fibers improved the first cracking flexural strength and fracture energy of reinforced mortar matrix [7,13–15]. However, the reinforcement efficiency of recycled plastic waste focused on only first cracking. A question is that if the recycled plastic waste reinforced mortar matrix could generate a hardening behavior exhibiting high performance with a high energy absorption capacity.

This study investigated the hardening condition of recycled waste reinforced mortar matrix (RPE-TRCCs) by conducting an experimental program with tensile and four-points bending tests. The detailed objectives are: (1) to study hardening and softening behavior of RPE-TRCCs, (2) to find the experimental conditions of hardening behavior for RPE-TRCCs.

2 Hardening versus softening behavior

Fig. 1 illustrates the typical strain hardening and softening behavior of the composites. The strain softening behavior is characterized by two stages including a linear elastic stage from starting point to the first peak point, and softening stages with a sudden drop of stress after first crack

[16,17]. Meanwhile, the strain hardening behavior is illustrated by three distinct stages including linear elastic, strain hardening, and softening stages, in which the post cracking strength was higher than the first cracking one [16,17]. According to [16,17], the formation of multiple cracks occurred during strain hardening stage, which enhanced energy absorption capacity of the composites.

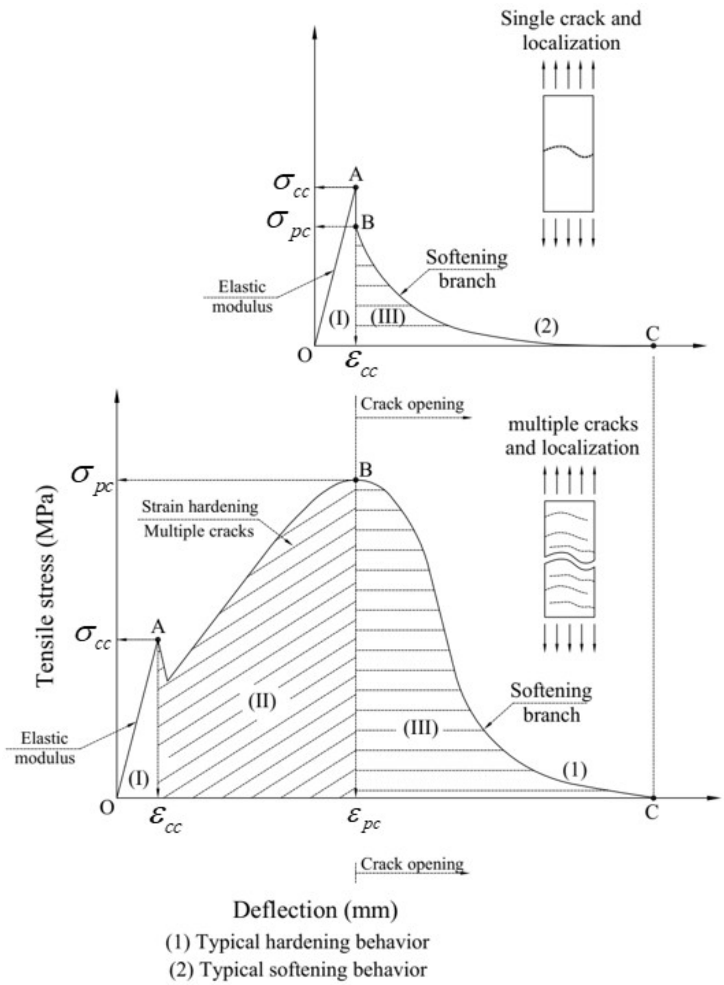


Fig. 1 - Typical hardening and softening behavior [16,17]

3 Experimental study on hardening conditions of RPE-TRCCs

3.1 Experimental program

Fig. 2 illustrates an experimental program conducted to investigate the strain/ deflection hardening conditions of RPE-TRCCs. Two types of recycled textiles included polyethylene 1 (PE1) and polyethylene 2 (PE2) were used as reinforcements within mortar matrix. The specimens with different layer number including 1 layer (1L), 2 layers, (2L), and 4 layers (4L) were prepared. The tensile tests (T) were conducted to investigate the tensile strain hardening behavior whereas four-points bending tests (B) were conducted to investigate the deflection hardening one. Totally, 12 series of specimens were prepared to investigate the above objectives:

3.2 Material and specimen preparation

After recollecting from the oceans, waste textiles were cleaned by water, then fully dried at the laboratory temperature prior to cutting into textile layers. PE1, a knotless fabric was formed from braided bundles, whereas PE2, a knotted fabric was manufactured by knotting the twisted bundles into fixed knotted points. The compositions of mortar matrix included cement type 1 (C) with a fineness of 3630 cm^2/g, silica sand (S) with an average diameter of 0.5mm, pure water (W), and superplasticizer (S) containing 25% solid. The weight ratio of matrix composition (C/S/W/S) was 1/1.5/0.45/0.0009. The details of mortar preparation could be found in [18–22].

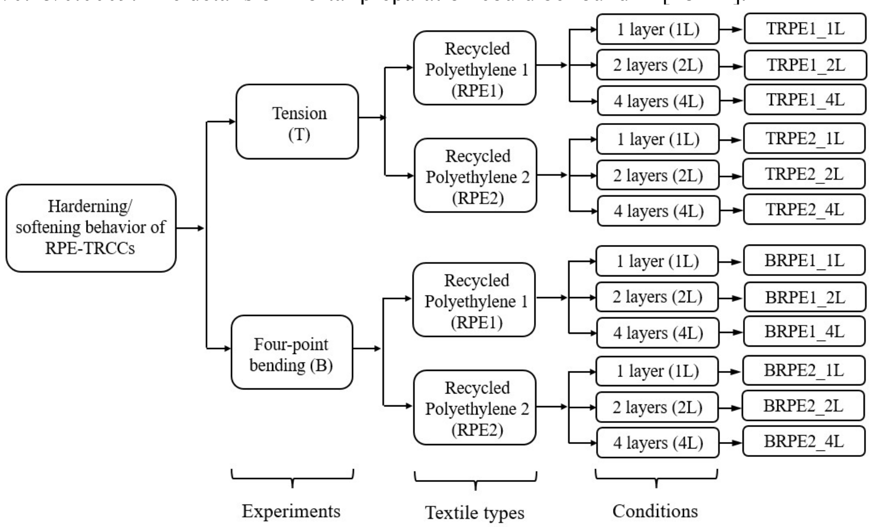


Fig. 2. Experimental program

The tensile and flexural specimens were cast layer by layer using dog-bone shaped molds with a cross-sectional area at gauge length of 50×25 mm, and prism molds with a dimension of 400×100×50 mm, respectively. The recycled textiles were put symmetrically at the middle thickness of tensile specimen, and at the tensile zone of flexural beams. The first layer of mortar matrix was poured into the mold and smoothed. The recycled textile was then put in the smoothed matrix. Other layer of concrete and textiles were subsequently put into the molds. Details of specimen preparation could be found in [18–22].

3.3 Test setups and procedures

Fig. 3 illustrated the tensile and four-points bending tests. As shown in Fig. 3a, tensile load transferred to specimen through three hinge system, and two linear variable transducers attached both sides of specimens measured the elongation of specimen [18,20,22]. As shown in Fig. 3b, the flexural load applied to specimen through two upper supports, and a LVDT attached at bottom of beam measured the deflection of specimen during bending [21]. Both tensile and flexural loads were speeded as 1 mm/min [19–22]. The tensile load of RPE-TRCCs at first and post cracking point were evaluated where flexural load at the limit of proportion (LOP) or first cracking and at 5 mm of RPE-TRCCs were measured because the modulus of rupture point (MOR) could not be obtained until 5 mm due to the limitation of LVDT [19,21].

3.4 Test results and discussion

3.4.1 Tensile behavior and flexural response of RPE-TRCCs

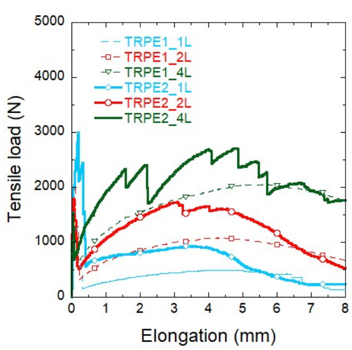
Fig. 4 illustrates the tensile stress versus elongation and flexural load versus deflection curves of RPE-TRCCs. In the tensile results RPE-TRCCs, post cracking behavior was measured in which the stress significantly dropped after the first matrix cracking, then reversely recovered to the post cracking point [19,21]. However, the level of recovery of stress depended on the textile types and layer number. In the results of all series of specimens using RPE1, post cracking point was lower than first cracking point, which exhibited the tensile strain softening in which post cracking stress was lower that first cracking stress [21]. Meanwhile, the results of specimen using RPE2 exhibited both strain hardening and softening. RPE-TRCCs using 1 and 2 layers produced softening behavior whereas RPE-TRCCs using 4 layers produced strain hardening behavior in which post cracking stress was higher than first cracking stress. During strain hardening stage, the stress dropped and reversely increased, corresponding to each crack [18,20,22].

As shown in Fig. 4b, after matrix cracking (LOP), flexural load dropped then reversely increase to MOR [19,21]. RPE-TRCCs under flexure produced both deflection hardening and softening behavior, regarding of textile types and layer number. Deflection softening behavior was observed in test results of BRPE1_1L and BRPE1_2L whereas other series produced deflection hardening behavior.

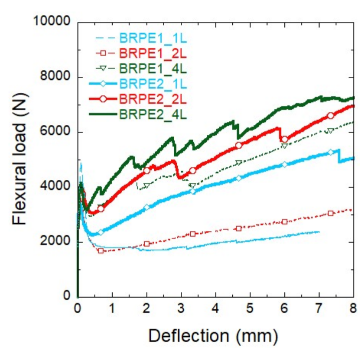
(a) Tensile test setup

(b) Four-point bending test setup

Fig. 3. Tensile and four-point bending test setups



(a) Tensile load versus elongation curves of RPE-TRCCs



(b) Flexural load versus deflection curves of RPE-TRCCs

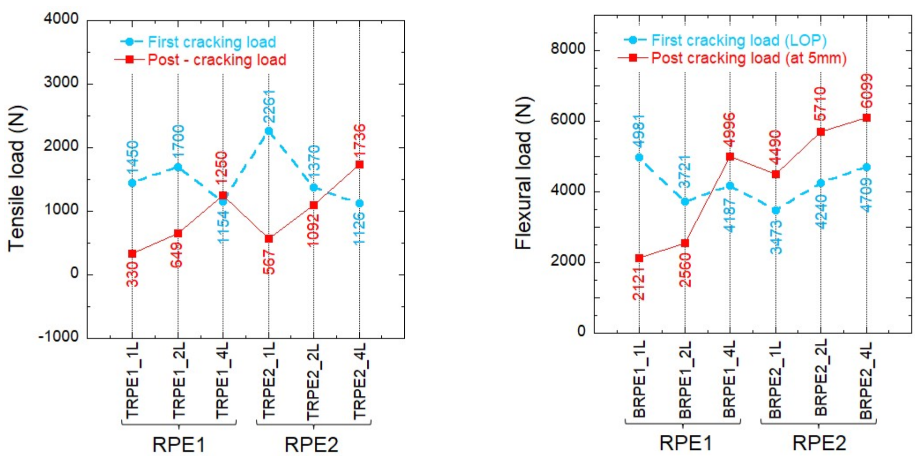
Fig. 4. Tensile load versus elongation and flexural load versus deflection curves of RPE-TRCCs

3.4.2 Strain hardening condition of RPE-TRCCs

Fig. 5 illustrates the comparison between the first cracking load and post cracking load of RPE-TRCCs under tension and flexure. By evaluating two these parameters, the hardening and softening behavior could be clarified.

As shown in Fig. 5a, the post cracking load of TRPE2_4L and TRPE1_4L (1736 and 1250 N, respectively) were higher than their first cracking load (1126 and 1154 N, respectively) which proved that TRPE2_4L and TRPE1_4L produced tensile strain hardening behavior. Meanwhile, other remaining series produced strain softening behavior with post cracking load lower than their first cracking load. As shown in Fig. 5b, the post cracking load of all series using RPE2 (4490, 5710, and 6099 N for BRPE2_1, BRPE2_2, and BRPE2_4, respectively) were higher than the first cracking ones (3473, 4240, and 4709 N for BRPE2_1L, BRPE2_2L, and BRPE2_4L, respectively), whereas only BRPE1_4L using 4 layers of RPE1 produced higher post cracking load (4996 N) than first cracking load (4187 N). These results proved that the strain hardening behavior of RPE-TRCCs could be obtained as using 4 layers of RPE2 within tensile specimens whereas their deflection hardening one could be obtained as using only 1 layer of RPE2 within flexural specimens.

Fig. 5 also illustrated the effects of layer number and textile types on the tensile and flexural resistance of RPE-TRCCs. As shown in Fig 5, the tensile resistance and flexural load of RPE2-TRCCs increased by 206% (from 567 to 1736 N) and 35% (from 4490 to 6099 N), and those of RPE1-TRCCs increased by 280% (from 330 to 1250N) and 135% (from 2121 to 4966 N), respectively, as the number of layers increased from 1 to 4. In comparison, RPE2 was more effective than RPE1 in reinforcing mortar matrix. The tensile load (567, 1092, and 1736 N) and flexural load (4490, 5710, and 6099 N) of the composites using RPE1 were higher than those (567, 1092, and 1136 N) and (4490, 5710, and 6099 N), respectively, of the composites using RPE1 as using the same layer number.



(a) Tensile load (b) Flexural load

Fig. 5. Comparison between first cracking load and post cracking load of RPE-TRCCs under tension and flexure

4 Conclusions

This study experimentally investigated the condition of hardening behavior for RPE-TRCCs under tension and flexure. Hardening and softening behavior of RPE-TRCCs were studied. The following conclusions could be concluded:

- RPE-TRCCs under tension and flexure produced both hardening and softening behavior in which the hardening behavior included initial elastic, hardening, and softening behavior whereas the softening response included initial elastic and softening stages.
- Tensile strain hardening and flexural deflection hardening could be obtained as using 4 layers and 1 layer of RPE2, respectively.
- Tensile and flexural resistance of RPE-TRCCs increased by 200-280% and by 35-135%, respectively, as the layer number increased from one to four. RPE2 was more effective than RPE1.

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