Construction and Building Materials 183 (2018) 451–464

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Performance of plastic wastes in fiber-reinforced concrete beams

F.S. Khalid [a,*], J.M. Irwan [a], M.H. Wan Ibrahim [a], N. Othman [b], S. Shahidan [a]

[a] Jamilus Research Center (JRC), Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja 86400, Johor, Malaysia
[b] Micropollutant Research Centre (MPRC), Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja 86400, Johor, Malaysia

HIGHLIGHTS

- Synthetic fibers did not affect the control behavior of beamat the yield and ultimate loads.
- At the cracking stage of beam containing fibers showed that the strength of the first crack improved compared to the normal concrete.
- The synthetic fibers in the reinforced concrete produced significant results, particularly in the linear elastic region.
- The mechanism fiber bridging of the RPET fiber was more evident compared to the irregularly shaped fibers.
- The RPET fibers incorporated into the concrete failed by rupture, which is caused by the tensile stress.

ARTICLE INFO

Article history:
Received 5 February 2018
Received in revised form 10 June 2018
Accepted 14 June 2018

Keywords:
Waste plastic
Synthetic fiber
Fiber concrete
Beam reinforced concrete

ABSTRACT

Synthetic plastics are typically discarded, thus causing environmental pollution. Plastic wastes are recycled as fiber in concrete to solve this problem. In this study, synthetic fibers in a concrete matrix were investigated through compressive strength, splitting tensile, fracture energy, and flexural beam tests. The results show that an increase in fiber content improves the tensile strength of the concrete matrix. A high fiber content results in a substantial amount of fibers crossing a fractured section, thereby activating failure resistance mechanisms. Ring-shaped fibers, which are mainly designed to activate fiber yielding instead of fiber pullout, are better than irregularly shaped polyethylene terephthalate and waste wire fibers. Incorporating plastic fibers into concrete does not significantly change the failure mode of reinforced concrete beams compared to that of normal concrete beams. However, the first crack load presented improved results. The reinforced concrete containing ring-shaped plastic fibers with a width of 10 mm (RPET-10) exhibited remarkable results during the first crack load with an increment of 32.3%. It can be concluded that ring-shaped PET waste produces fiber concrete with a performance comparable to that of commercial synthetic fibers.

1. Introduction

The amount of synthetic plastic consumed annually has been steadily increasing. The intensifying synthetic plastic consumption can be ascribed to the practical features of synthetic plastic, namely, factory fabrication, lightness of plastic products and low production cost [1,2]. Plastic has been extensively used in bottles and food casings, industrial products, communication materials and housing, among other uses. Although several methods have been employed for the disposal of synthetic wastes, most treatments are inadequate because of excessive synthetic waste generation. Therefore, one of the alternatives is to recycle synthetic wastes and use them as fiber reinforcement for concrete. Synthetic fibers are popular for reinforcing lightweight precast concrete elements such as double walls, pipes and sleepers [3,4,5]. These applications can effectively control cracks [6] and prevent dry shrinkage cracks of concrete [7]. Besides, synthetic fibers have been used to improve the toughness of concrete with enhanced crack resistance [8]. Foti [9] studied the use of polyethylene terephthalate (PET) bottles as fiber to improve concrete ductility and found that the average tensile strength of the ring-shaped fibers is sufficiently high and comparable to the most commonly used carbon or steel fiber to reinforce concrete. The PP/PE blended fiber reinforced composites (HyFRCs) at fiber volume as 2.9% obtained mechanical enhancement of 38 ± 2% on compressive and 40 ± 1% flexural strengths compared to normal concrete [10]. Morphological observations show strong mechanical interactions between fibers and the cement matrix as similar to the chemical/mechanical interactions observed for polyacrylonitrile reinforced composites

* Corresponding author.
E-mail address: faisalsh@uthm.edu.my (F.S. Khalid).

https://doi.org/10.1016/j.conbuildmat.2018.06.122
0950-0618/

(PANFRCs). A comparison between steel fiber and synthetic fiber has been made. It shows that all types of fibers in concrete seem to yield better results for the same fiber content. In addition, the improvement appears to decrease when the total fiber content increases above a volume fraction of 1% [11]. The high fiber content can cause difficulty in mixing, which leads to poor compaction, non-uniform distribution of fibers, and an increase in void volume [11,12]. Foti [13] studied mechanical behavior of 3 types of possible structural reinforcing with rheoplastic mortar on reinforced concrete pillars. Foti [13] claimed that whole reinforcement (30 cm) of the concrete core obtains significant result compared to specimen with rheoplastic mortar covered at height of 28 cm.

Many researchers claimed that the pullout fiber strength increases as the embedded length of the fibers increases in the concrete matrix [14,15]. The embedded length range of 45–55 mm increased the fiber strength by 39.3%–48.1% according to Richardson et al. [16]. This difference is related to the surface fiber area connected to surface concrete as this area determines the friction of the fiber and interfacial bond energy [17,18]. In their study, Ochi et al. [19] found that polyvinyl alcohol (PVA) fibers exhibited the highest tensile strength, whereas PET fibers had the lowest tensile strength (172 MPa) [19]. The smooth surface of fibers such as polypropylene (PP) fibers has a weak bond with concrete thereby preventing sufficient friction between concrete and fibers [20]. Compared to commercial plastic fibers, PET fibers exhibit adequate tensile strength. The surface contact area between the fibers and concrete influences both pullout energy and interfacial energy [6,17]. A high pullout energy is produced by a high area of surface fiber that is connected to the concrete. Fibers measuring 15, 20, and 24 mm in length with 0.4% of PP fiber content were used in a study by Vairagade et al. [21]. The authors found that the average strength values ranged from 1.2% to 4.5% for fibers measuring between 15 mm and 24 mm in length. A long fiber has a large surface area that is connected to the concrete matrix. It can be concluded that interfacial bond strength and friction energy during load compression are higher than those of a short fiber. Therefore, fiber surface area which depends on fiber length significantly influences strength.

The increase in PET fiber content also increases tensile strength. Irwan et al. [22] observed there was increased strength for concrete with 0.5% of fiber content compared to normal concrete. Irwan et al. [22] claimed that fiber content is not the main component that improves the compressive strength of Fiber Reinforced Concrete (FRC). Instead, it is the shape and size of the fibers which influence compressive strength [23]. Ramadevi et al. [24] found that concrete containing 2% of waste PET as fine aggregate material exhibited an increase in compressive strength compared to normal concrete. The concrete containing 0.5% and 1% of fiber content demonstrated an increase in strength of 4.0% and 15% respectively compared to normal concrete. In fact, most of the researchers said that the PP and high-density polyethylene (HDPE) fibers have high resistance towards an alkaline environment, which is no agreement about the durability of PET fibers in a concrete matrix [25,26]. In addition, the SEM picture of the polymer mortar matrix shows that it has very low porosity in comparison to the cement mortar of even various grade [27]. Nili et al. [28] observed an increase of 3% in the compressive strength of concrete with 0.2% fiber content. When fibers were added into concrete, the failure pattern changed from a single large crack to a group of narrow cracks [12]. The crack can be substituted by micro-cracks due to the presence of fibers bridging in concrete [28].

A long fiber indicates a high surface contact area which is able to function as fiber bridges during compression as observed by Nia et al. [29]. Therefore, a long fiber presents high friction energy against pullout stress because of the fiber-bridging mechanism. In addition, Mohammadi et al. [30] compared toughness indices which show that mixes with long fibers have higher indice values than those with short fibers. However, it has also been observed that a concrete mix with better workability was obtained when the percentage of shorter fibers used in the mix increased. Foti [9] used waste plastic bottles as recycled fiber material. Concrete with 0.75% of ring fibers showed an increased strength of 5% compared to concrete containing 0.5% of ring fibers [9]. Foti [31] claimed that the presence of PET strips has successfully given the concrete slabs a very ductile behavior which allowed them to avoid complete failure. This confirms the improvement in impact strength and suggests various possible uses for PET reinforced concrete. Recycled PET fibers in concrete measuring 10 mm, 15 mm, and 20 mm in length with 0.18% and 0.3% of fiber content were studied by Pelisser et al. [32]. The authors found that the size of the fiber area significantly contributes to flexural toughness indices. Adding recycled PET fibers enhanced the toughness and energy absorption of FRC under flexural load. An increase in fiber length increases the size of the fiber area that is connected to the cement matrix and contributes positively to the flexural toughness indices, particularly in I_{10} and I_{20} [33,34]. Irwan et al. [22] used fiber contents of 0.5%, 1%, and 1.5% in concrete mixes to demonstrate the change in flexural toughness with fiber content; compared to 0.5% and 1% of fiber content, 1.5% of fiber content increased the flexural toughness index of I_{20} of FRC by 22.4% and 5.7%, respectively [35].

Three fiber content percentages (0.33%, 0.42%, and 0.51%) were used in Hasan et al.'s [36] study. Gradual improvements of approximately 6.48% and 6.89% were also achieved for concrete with 0.42% and 0.51% of fiber content, respectively. In plastic fiber reinforced concrete beams, Kim et al. [37] examined the deflection behavior of a reinforced concrete (beam when PET fibers were added. In this research, the specimens with manufactured synthetic fibers clearly demonstrated an improvement in deflection behavior. For reinforced concrete beams with 0.5%–1% of PET fiber content, deflection and ultimate load capacity increased by 7–8 times for deflection and 25.5%–31.9% for ultimate load capacity. Foti [38] studied beam with reinforcement bar made with PET and CFRP are arranged as continuous bars and strips, respectively. The specimen reinforced with CFRP showed a more ductile behavior compared to PET bar. However, PET bar can be used in all those cases where the operational loads are low. Currently no published data was found on the use of ring-shaped, irregular or wire wastes for fiber reinforced concrete beams. Therefore, this study aims to investigate the behavior of reinforced concrete beams containing synthetic waste, also known as fiber concrete. Compressive and fracture tests were also conducted to determine the mechanical behavior of synthetic plastic waste in concrete.

2. Materials and methods

Waste PET bottles (Fig. 1) were used in this study. The fibers used in the experiment were ring-shaped PET (RPET-5 and RPET-10) fibers with widths or cross-sectional diameters of 60 ± 5 mm, as shown in Fig. 2. The experiment also used irregularly shaped PET fibers, synthetic waste wire fibers, and manufactured synthetic macro-fibers (Mega Mesh 55), as shown in Figs. 3, 4, and 5, respectively. The sizes of the sieved waste PET granules were approximately 5–20 mm. The waste wire was cut into 55 mm lengths. The manufactured synthetic fiber used was 55 mm in length, with a tensile strength of 425 N/mm^2 and an aspect ratio (L_f/d_f) of 45.

The water–binder ratio was 0.55. A total of 57 specimens were prepared for the tensile strength test. All the concrete specimens were tested using three cylinders for each batch of concrete mixture. The second experiment consisted of compressive tests and tensile tests. The next experiment was a fracture energy test of