Zkušenosti vědecko-výzkumných pracovníků a doktorandů

Kučerová, Anna ; Tesárek, Pavel ; Koubský, Tomáš
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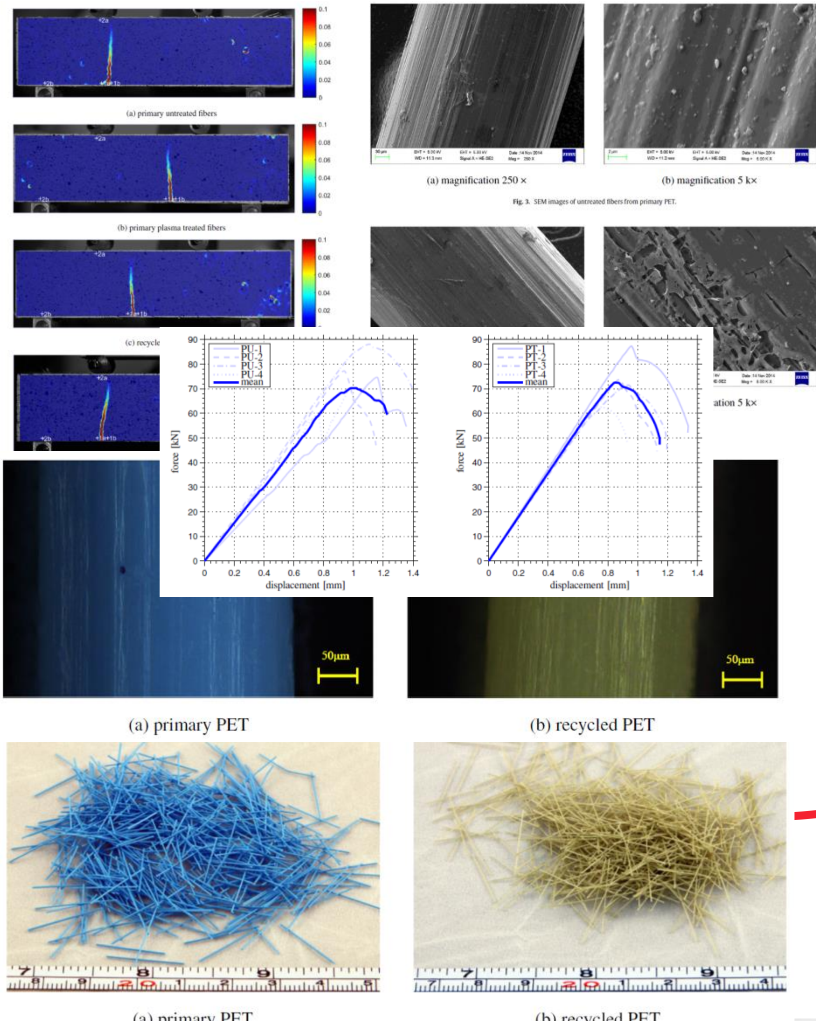

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Impact of surface plasma treatment on the performance of PET fiber reinforcement in cementitious composites

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A B S T R A C T

The purpose of this study is to demonstrate the influence of plasma treatment on the surface properties of PET fibers used as micro reinforcement in cementitious composites. The stress transfer across cracks that untreated fibers are able to accomplish can be enhanced via plasma treatment. The increase in surface roughness and the activation of polar groups result in the reduction of surface energy as observed during wetting angle measurements. The improvement in adhesion between primary (non-recycled) fibers and the surrounding matrix brought about a more pronounced strain hardening of the specimens tested in four-point bending. Plasma treatment of thinner fibers from recycled PET led to a lower capacity for transferring tensile stresses due to the reduced cross-sectional area of the fibers. The considerable bridging force provided by the plasma treated primary PET fibers resulted in the prevention of excessive and abrupt cracking, and limited crack openings.

1. Introduction

Fiber-reinforced concretes with discrete, short, and randomly distributed fibers have become popular in the construction industry over the past few decades. In some cases, fibers are intended to be the primary or even only reinforcement, while in other cases they only replace a portion of conventional reinforcement provided by steel rebars [1–3]. In order to reinforce a cementitious matrix, fibers must be easy to disperse in order to ensure uniform distribution, have suitable mechanical properties, and must be durable even with a long-term exposure to an alkaline cementitious matrix [4,5]. All of the above mentioned properties have been reported for poly(ethylene terephthalate) (PET) fibers [6,7].

Machovič et al. [8] have revealed that newly-formed multi-molecular layers enable chemical bonding between a PET surface and C-S-H gels in hydrated cements. Moreover, it has been established that PET fibers do not have any influence on the hydration of Portland cement [6]. The use of PET fibers enhances concrete properties and utilizes waste produced by the disposal of PET beverage containers effectively. Current worldwide production of PET products exceeds 6700 million kg/year and a dramatic increase of production has been reported in China and India [5]. Recently, recycled PET has been utilized as replacement for conventional steel bars or carbon fiber reinforced polymer (CFRP) strips [9–11], because of its corrosion-resistant nature and low cost.

PET fibers as dispersed reinforcement in engineered cementitious composites (ECCs) can produce enormous deformations when compared to ordinary Portland cement concrete [12–14]. The key to ensuring the ductility in ECCs is fiber-bridging of cracks. To achieve this strain-hardening behavior, matrix tensile strength must be lower than the maximum bridging stress that can be transferred by fibers [15]. The hydrophobic surface of PET fibers results in poor adhesion to any cementitious matrix and can therefore be very limiting [16,17]. To overcome this, various strategies have been employed to modify the surface structure of the fibers in order to make them more hydrophilic. Strategies include wet chemical treatment, flame treatment, mechanical micro-indentation, and various plasma treatments. Wet chemical treatment such as etching in an alkaline environment may cause a significant loss of mechanical fiber strength and the etching intensity is difficult to control. The disposal of waste products from such chemical modifications can introduce environmental burdens [18]. Flame or heat treatment causes fibers to become brittle under tensile stresses and can even trigger fatal polymer degradation. Mechanical micro-indentation is usually too rough and can significantly reduce the fiber cross-sections and is extremely difficult to implement on short fibers with small diameters [17]. Cold plasma treatment of fibers appears to be the most suitable non-damaging and energy-efficient alternative, with easily controllable outcomes [19].

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postprocessing tool, Ncorr_post [43], was used for DIC calculation and analysis. Cracking patterns were visualized with a map of maximum principal strain in which concentrations can be attributed to the formation of cracks. Virtual extensometers that gather the magnitude of displacement in two arbitrary points were employed to monitor the crack opening and deflection of the tested specimens.

Images used for DIC analysis were taken with a DSLR camera Canon 70D at 10-second intervals in uncompressed format (.raw), yielding approximately 35 px/mm definition. Perfect illumination provided by artificial lighting allowed for a short exposure time (1/125 s), with the light sensitivity (ISO) parameter set to 100. A focal length (zoom) of 55 mm with a distance between the camera and the observed surface of 80 cm ensured a minimal lens distortion effect. Setting the subset spacing and radius to 8 px and 32 px, respectively, yielded displacement and strain fields consisting of 840 by 210 discrete values per specimen.

Despite the strain hardening present during bending of the majority of PU, PT and RU specimens, no multiple cracking or branching of cracks was observed and tensile strain localized into a single cohesive crack. The cracking patterns captured with DIC on selected chosen representative specimens are presented in Fig. 16. Cracks are visualized with a map of maximum principal tensile strain and the numbered marks indicate the positions of virtual extensometers. The first virtual extensometer (1) was located 3 mm from the bottom of the specimens, and the relative extensometer distance was 6 mm. Such a position and spacing allowed documentation of the crack opening without bias from elastic deformations or boundary effects. A second extensometer (2) was located in the vicinity of the supports in order to monitor the true deflection of the specimen.

The relationship between loading force action on the specimens during four-point bending and crack opening is presented in Fig. 17. The larger force needed for opening of the crack in the case of the primary plasma treated fibers provides clear evidence of more efficient activation of the fibers when compared to primary untreated fibers. The poor cohesion of the crack bridged by recycled plasma treated fibers proves that these are not sufficiently strong enough to reinforce a cementitious matrix. The same conclusions hold when interpreting the DIC measurement results based on the dependence of the crack opening on specimen deflection (Fig. 18). The enhanced capacity of stress transfer across the cracks bridged by primary plasma-treated fibers ensured increased bending stiffness. As a consequence, specimen deflection was two times lower than the deflection of specimens reinforced by primary untreated or recycled plasma treated fibers.

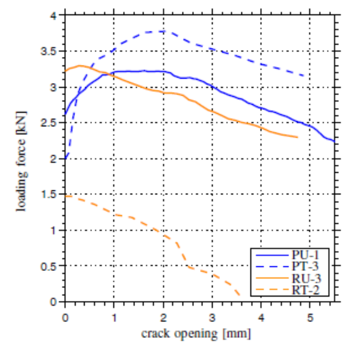

Fig. 17. Relationship between loading force and the crack opening measured with virtual extensometer 1.

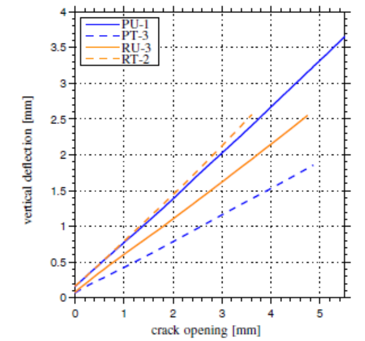

Fig. 18. Relationship between the deflection of the specimen measured with virtual extensometer 2 and the crack opening measured with virtual extensometer 1.

6. Conclusion

The investigation of the morphology and performance of primary and recycled PET fibers when untreated and after the oxygen plasma treatment provided valuable findings to be considered in the design of fiber-reinforced cementitious composites. Oxygen plasma treatment proved to be very efficient in altering the surface of PET fibers as demonstrated by microscopy observations and with wetting angle measurements. Surface roughening with ion bombardment together with the activation of polar groups on fiber surfaces resulted in better adhesion of the fibers to the cementitious matrix and stronger interfacial bonding.

Based on the results presented here, it can be concluded that:

1. Plasma surface treatment of both fiber types, primary and recycled, significantly increased their roughness, as demonstrated by microscopy images,
2. The change of surface morphology made the fibers hydrophilic and led to a reduction of the wetting angle,
3. The elastic stiffness of cementitious pastes reinforced by plasma-treated fibers was lower than those reinforced by untreated fibers due to higher water retention for such fibers and a consequently higher porosity of the composite,
4. Reinforcement with plasma-treated fibers contributed to elevated compressive and flexural strength for primary fibers,
5. Compressive strength was not enhanced by the addition of recycled plasma treated fibers to the reference paste and flexural strength was, if fact, reduced — these phenomena can be attributed to an excessive reduction in the cross-sectional areas of the recycled fibers, which were thinner than the primary ones,
6. Plasma treatment of primary fibers ensured better activation and increased hardening after reaching peak load during the four-point bending tests, and

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Abstract

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Impact of surface plasma treatment on the performance of PET fiber reinforcement in cementitious composites (Article)

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