Performance of Plasma Treated Polymer Macro-Fibers

J. Trejbal [1,a], J. Fládr [1], L. Kopecký [1]

[1] *Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague, Czech Republic*

Abstract: Concrix – commercial bi-components polyolefin macro-fibers (ø 0.5 mm, length 50 mm) made by BURG Group in Switzerland were plasma treated to attain the better adhesion with cement matrix. Fibers were exposed to oxygen treatment in inductively coupled plasma system by different times (from 5 to 480 seconds.). The influence of realized fiber surface treatments was observed by physical and mechanical methods: i) horizontal direct optical method enabling a measurement of fibers wettability, ii) fibers tensile strength tests, and iii) single-fiber pull-out tests from cement matrix. It turned out that fibers treated by plasma during 30 seconds reached the best ratio between their wettability and mechanical performance. While their contact angles decreased by ca. 50 %, tensile strength remained constant and cohesion with cement matrix increased by ca. 20 % in comparison with reference fibers.

Keywords: plasma; polymer fibers; reinforcement; wettability.

1 Introduction

Polymer macro-fibers used as reinforcement in cement composites are frequently applied in civil engineering. Macro-fibers as an auxiliary reinforcement can reduce the early age cracking tendency of concrete surfaces and can bestow the toughness behavior of concrete materials [1]. The principle of the fiber effect is the distribution of shrinkage into several small cracks in the case of materials based on shrinking binders, and to prevent the single crack openings after linear elastic response in the case of loaded samples [2]. Macro-fiber reinforcement also provides a compactness of materials after the crossing the material loading capacity [3]. Generally, fiber reinforced concrete is commonly used for construction of tunnels (shotcrete), fire resistance constructions, constructions exposed to dynamic loads, flat and thin construction, etc. [4, 5].

Besides a steel, polymers are an alternative material for production of fibers. Polymer macro-fibers even exhibit some material parameters better in comparison with steel fibers (tensile strength, density, corrosion resistance) [6]. In order to improve mechanical performance of composite materials containing fiber reinforcement, strong interaction between these two phases – matrix and fibers must be ensured [3]. In view of poor fiber surface wettability by water, required adhesion between their surfaces and the matrix of composite materials (containing water) is not guaranteed. Due to this reason, some different mechanical, chemical and physical modifications of fiber surfaces have been studied [7, 8]. The surface treatments must represent an affective, economic and simultaneously nondestructive method.

The treatment by low-pressure oxygen coupled plasma treatment satisfies all the requirements mentioned above and becomes popular as progressive physical method. Plasma can be defined as ionized gas (composed of electrons, ions, and neutral species) which is electrically neutral form macroscopic perspective. The principle for plasma surface modification relays on surface atoms replacement by oxygen atoms and formation of polar groups. The polar or functional chemical groups enhances the reactivity with the cement or other matrix (containing water) [1, 9].

2 Materials and Methods

2.1 Fibers and cement matrix

Polyolefin macro fibers brand named Concrix ES having diameter equal to 0.5 mm a length 50 mm were used at this study [10]. Fibers made from polyolefin composed from two parts – high strength and high modulus core guaranteeing fiber mechanical performance and shell protecting the core and ensuring good mixture processing and binding to concrete (Fig. 1). Modulus of elasticity is up to 10 GPa, density is equal to 0.91 g/cm^3.

Cement matrix samples having dimensions equal to 20×25×40 mm were prepared. The samples were composed from cement paste (CEM I 42.5 R, water to cement ratio was equal to 0.4). During the samples preparation, single fiber was submerged into each cement sample parallel to longitudinal sample axis (Fig. 2). The fiber anchor length corresponded to sample height (i.e. 40 mm). The cement samples cured and hardened 28 days in standard condition without other treatment.

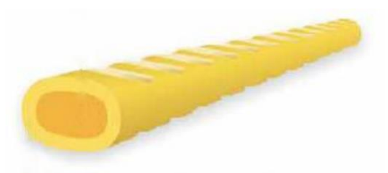

Fig. 1: Scheme of fiber Concrix ES.

Fig. 2: Cement samples prepared for single-fiber pull out tests.

2.2 Experimental methods

To improve the fiber wettability, oxygen treatment in inductively coupled plasma system was done (power 100 W, O_2 flow 50 sccm). Plasma treatment process differed only in exposition time (from 5 to 480 seconds). Plasma treatment effect was observed by direct static horizontal contact angle method enabling the measurements on fibers upright submerged into demineralized water. Treated fiber tensile strength was tested using the loading frame Web Tiv Ravestein FP100 (displacement controlled, loading speed was equal to 2mm/min). The purpose of this experiment was to verify the treatment impact on fiber mechanical performance. Based on these measurements, the most effective treatment process was defined and applied for following usage.

Reference fibers (Concrix_R) and treated fibers exposed to oxygen plasma by 30 seconds (Concrix_30) were used for single-fiber pull out tests. Principle of pull out tests consisted of pulling out of fiber free end from matrix held by static part of loading frame, carrying out by the same loading frame as is mentioned above. Displacement of pulled-out fiber free-end and loading force were monitored. Six samples of each fiber type were tested.

3 Results

Contact angle size measured on reference fibers submerged into demineralized water was equal to 54.0±6.9°, while angles measured on plasma treated fibers oscillated about ca. 26°. It was clearly shown that wettability of treated fibers does not depend on treatment exposition time, while the difference between reference and plasma treated fiber wettability was significant (Fig. 3). Fibers tensile strength measured as a force causing fiber tensile breaking was roughly constant in all cases. All fibers were broken by force equal to 95-100 N without any dependence on plasma treatment time (Fig. 4).

The average force (6 samples from each fiber) obtained during pull-out tests of reference and plasma treated fibers by 30 seconds was equal to 78.4±8.2 and 96.3±10.1 N, respectively. In the case of reference samples, all fibers were pulled out from matrix, while in the case of plasma treated fibers, only two fibers showed cohesion break in an interphase area. The remaining four fibers were broken (Fig. 5).

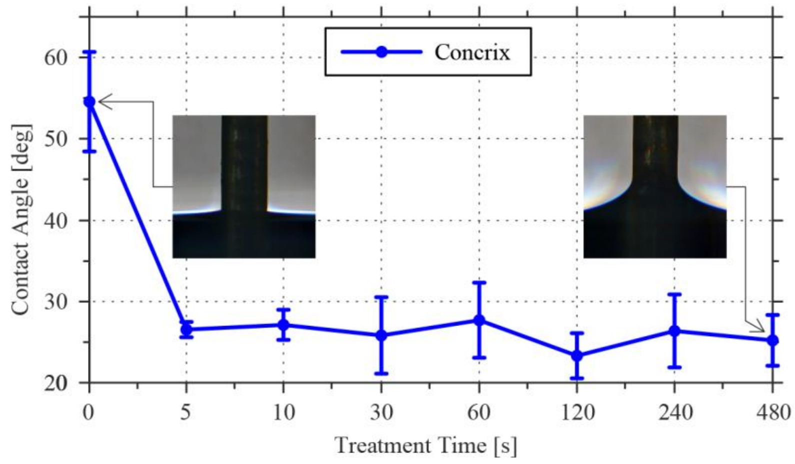

Fig. 3: Contact angle sizes depending on plasma treatment time obtained during contact angles measurements.

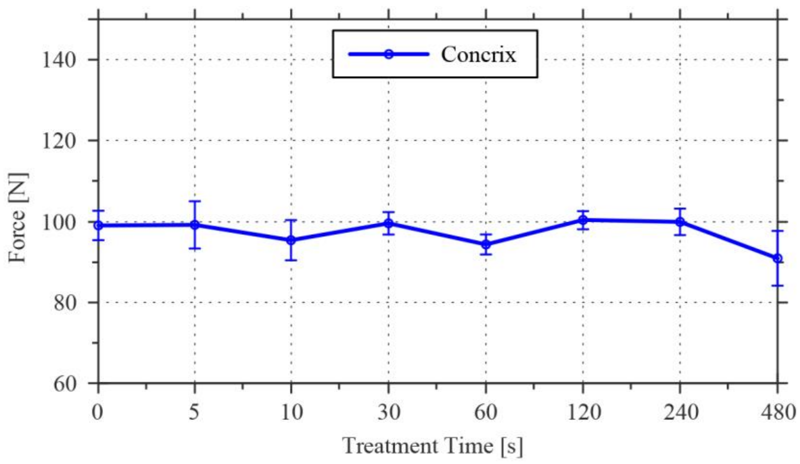

Fig. 4: Force needed to break the fibers depending on treatment time.

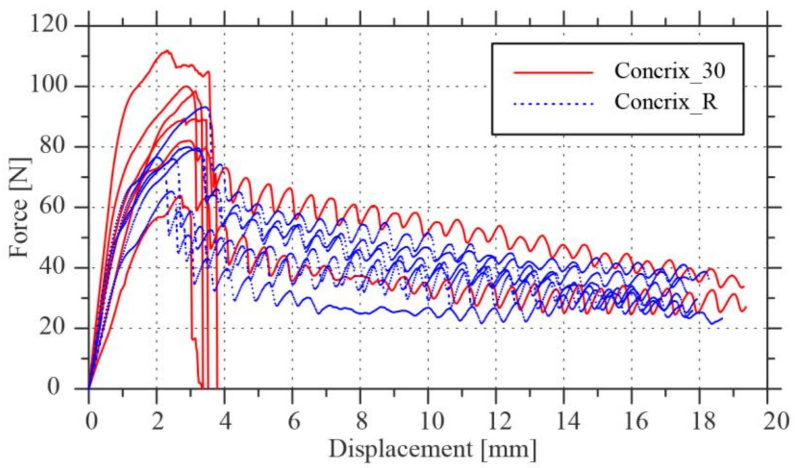

Fig. 5: Loading force depending on fiber free-end displacement obtained during pull out testing.

4 Conclusion

Polyolefin macro-fibers Concrix using as reinforcement in cement composites were plasma treated to obtain the better adhesion between their surfaces and cement matrix (CEM I 42.5 R, w/c equal to 0.4). For this purpose, oxygen treatment in inductively coupled plasma system was done. Treatment process differed in exposition time (from 5 to 480 seconds.). As a proper indicator of realized wettability treatment, horizontal direct optical method enabling contact angle measurements was used. It was found that treated fibers reached the better wettability approximately by 50 %. Tensile strength of reference and treated fibers is more or less constant. From pull-out single-fiber test from cement matrix specimens (25×20×40 mm) was shown that force needed for reference fibers pull-out was equal to 78.4±8.2 N, while in the case plasma treated fibers by 30 seconds was equal to 96.3±10.1 N.

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