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Development of Mechanical Properties of a Cement Composite Reinforced with Synthetic Fibers

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Abstract: Presented article deals with the influence of PET fiber production on the development of mechanical properties of cement-based composite during 28 days when incorporated into the fresh mortar. Cement paste samples were reinforced with 2 wt. % of primary or recycled PET fibers. Dynamic Young's and shear moduli were assessed by non-destructive resonance method and static Young's modulus was evaluated from the force-displacement diagrams obtained during compression tests. Samples with recycled, compared to primary, PET fibers exhibit a decrease in the monitored parameters but the difference not significant. The results indicate that recycled PET fibers can be used as an alternative to reinforce cement-based composites with minimal impact on their final properties.

Keywords: Cement; PET Fibers; Composite; Mechanical Properties.

1 Introduction

Fiber reinforced concrete and cement-based composites with dispersed reinforcement in a cement matrix are becoming very attractive materials in construction industry, and these are used for load-bearing and even auxiliary structures. The reinforcement has several functions depending on the type of material, diameter and length of fibers. Steel, glass or polymeric fibers are commonly used in cementitious materials, having a diameter of 0.1 – 1 mm depending on material of fibers [1]. Synthetic polymer-based fibers have become popular in recent years, because when properly designed they may increase tensile strength, ductility, reduce cracking, and even increase durability or fire resistance.

Given the global problems of waste production, it is desirable to use products made of recycled materials if possible [2, 3]. Using high quality sorting machines, fibers derived from recycled polyethylene terephthalate (PET), which is used to manufacture plastic bottles, are relatively inexpensive and easily accessible. Such fibers are mostly utilized in other industries than in production of building materials and their potential use is to be explored. There are numerous studies dealing with the use of PET fibers or PET grids in cementitious composites, demonstrating the enhancement of flexural strength, and reduction of compressive strength and modulus of elasticity. However, those studies are focused on a single type of PET fibers only, and the mechanical properties are investigated after 28 days of curing [4, 5].

2 Materials and Samples

Unlike in the above mentioned studies, the presented contribution discusses the impact of PET fiber production on the development of mechanical properties. The measurements were performed on prismatic specimens of dimensions 40 × 40 × 160 mm and made from cement paste with dispersed PET fiber reinforcement. The mixture was placed into casts in two steps and compacted after each step for 3 minutes. The samples were removed from the casts after 2 days of hardening and were cured for the next 26 days in water at the temperature of 21 ± 2 °C [6].

Portland cement CEM I 42.5 R made in Radotín plant was used for the production of the tested specimens and two types of fibers were added into the mixture. In particular fibers made of a primary PET having a diameter of about 400 μm and fibers produced from recycled PET with diameter of about 260 μm were used. Both types of fibers had the same length ranging between 10 and 12 mm. Three sets of samples were prepared:

Tab. 1: Composition of the mixtures.

mixture	cement	w/c	type of fibers	amount of fibers [wt. % of cement]
A (REF)	CEM I 42.5 R	0.4	-	-
B	CEM I 42.5 R	0.4	Primary PET	2.0 (10 - 12 mm)
C	CEM I 42.5 R	0.4	Recycled PET	2.0 (10 - 12 mm)

reference samples of the cement paste without fibers (A), samples of the cement paste with 2 wt. % of primary PET fibers (B) and samples of the cement paste with 2 wt. % of recycled PET fibers (C). All mixtures had the same water to cement ratio equal to 0.4. Composition of all mixtures is provided in Tab. 1.

3 Measurement Methods

The evolution of the dynamic Young's and shear moduli was monitored regularly at 7 days intervals for the first 28 days of hardening [7]. To that purpose the non-destructive resonance method was used, so that the measurement could be repeated on the same samples, ensuring high measurement accuracy and minimizing the number of samples required to represent each material. The measurement was accomplished using Brüel & Kjaer assembly, composed of a measuring station type 3560-B-120, an acceleration transducer type 4519-003, an impact hammer type 8206 and a control notebook. Dynamic Young's modulus was evaluated from two measurements; first based on the basic longitudinal natural frequency of the samples, and secondly by measuring the basic flexural natural frequency of the specimens. Dynamic shear modulus was determined based on the magnitude of the basic torsional frequency. The values obtained by the dynamic measurements on the 28$^{\text{th}}$ day were eventually compared to those obtained by static compression test [8,9]. The compressive strength were determined on the 28-day-old samples using the press device Heckert, model FP100. The displacement was measured by contact sensors ESSA type SM30 12-C-5.0-CAV. The testing was displacement controlled at a constant rate of 0.3 mm/s. The compression test was performed on the specimens broken during bending test with effective dimensions of 40 $\times$ 40 $\times$ 80 mm. Each set contained 12 samples.

4 Results and Discussion

Development of dynamic Young's modulus for individual fiber-types is presented in Fig. 1. The values of the dynamic Young's modulus of reference samples and samples with primary PET fibers are almost equal. The results confirm the slight reduction of the elastic stiffness when recycled PET fibers are added into the cement paste compared with reference samples and samples with primary PET fibers. The reduction is more pronounced in first measurement (7 days), compared to fully hardened material after 28 days. Development of shear modulus for individual fiber-types is presented in Fig. 2.

The results of the dynamic and static Young's moduli for individual types of samples obtained by non-destructive and destructive testing are presented in Tab. 1. Both methods indicate the same trends, and the values of the dynamic Young's modulus are about 15 % higher compared to those obtained during compression test. The difference between values of static and dynamic Young's moduli is in standard for cementitious composites.

The slight reduction of the dynamic Young's, shear and static Young's moduli can be probably attributed to a deterioration of the recycled PET fibers and their lower diameter. Moreover, as the workability decreases with the addition of fibers, the high fiber-content could lead to formation a larger amount of pores. However, the reduction of the dynamic Young's modulus of samples with recycled PET fibers compared with reference samples and samples with primary PET fibers is less than 3 %.

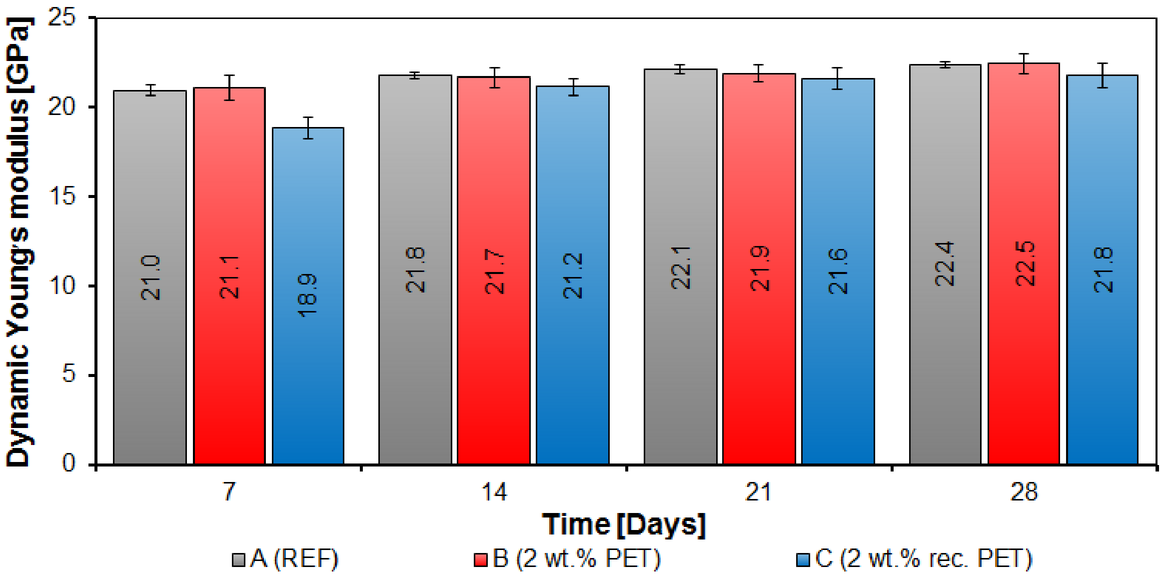

Fig. 1: Dependence of the dynamic Young's modulus of cement paste with w/c=0.4 based on type of PET fibers and time.

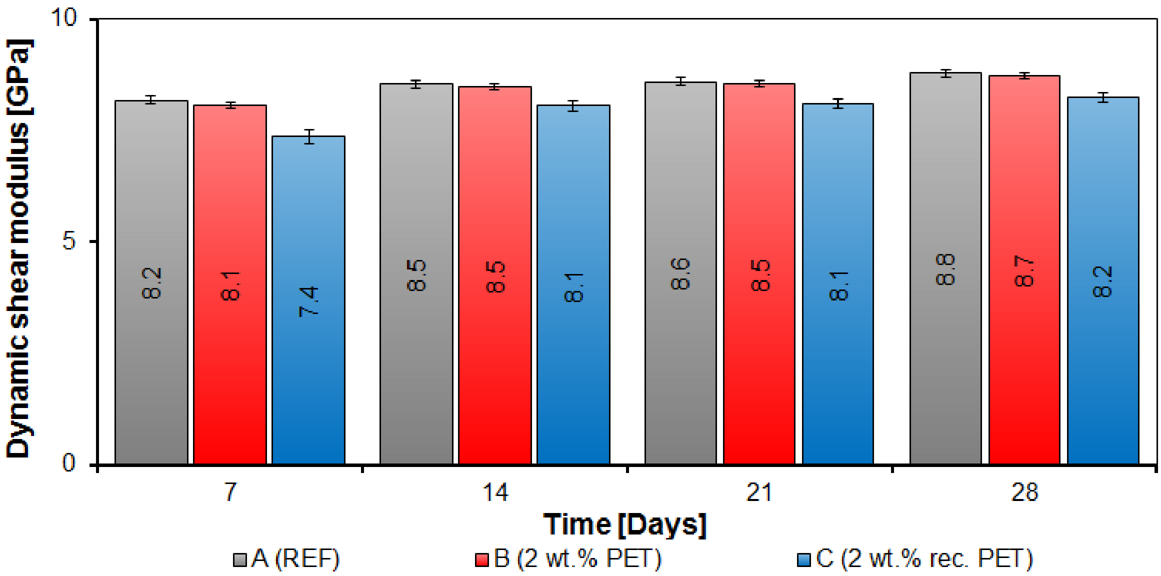

Fig. 2: Dependence of the dynamic shear modulus of cement paste with w/c=0.4 based on type of PET fibers and time.

Tab. 2: Comparison of 28^{th} days dynamic Young's modulus and static Young's modulus of cement paste based on type of PET fibers.

set	dynamic Young's modulus [GPa]	static Young's modulus [GPa]
A (REF)	22.428 ± 0.179	19.477 ± 0.179
B (2 wt.% PET)	22.456 ± 0.551	18.525 ± 0.179
C (2 wt.% rec. PET)	21.811 ± 0.686	18.235 ± 0.179

5 Conclusion

The presented work focused on the influence of PET fiber production on dynamic Young's, dynamic shear and static Young's moduli of fiber-enriched cement pastes. In addition, the development of dynamic Young's and shear moduli in time was monitored. Based on the results it can be concluded that:

- samples with primary PET fibers had almost the same mechanical properties as the reference samples without fibers,
- samples with recycled PET fibers had slightly lower stiffness than those containing primary PET fibers, which could be caused by deterioration of the recycled PET fibers or formation a larger amount of pores during hardening,
- recycled PET fibers are a good alternative for primary PET fibers used in cementitious composites, but it is necessary to obtain more knowledge about the influence of recycled PET fibers on the microstructure of cementitious composites.

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