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Cement Based Composite with PVA: Development of Mechanical Properties

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Abstract. Main goal of this article is monitoring the development of the mechanical properties of composite based on cement and PVA. A resonance method was used to determine dynamic Young's modulus and dynamic shear modulus of the samples during the curing. Measurements were performed for a period 161 days. Individual samples of the composite were modified by different amount of PVA. Unlike the studies already published, in this article there were studied mechanical properties of the samples cured on air, not in water.

Introduction

Many types and forms of the polymers were used for cement modification. Best results in cement composites were achieved by adding latex and polymer resins. Due to massive consumption of cement composites in the construction industry, increasing demands on the mechanical properties and the high price of latex and resins the other alternative polymers as water soluble polymers are interested [1].

The water soluble polymer used in this paper is polyvinyl alcohol (PVA). There are known attempts to improve workability by using of a small amount of PVA (less than 1 wt. % of cement). R. Morlat [2] and Jae-Ho Kim [3, 4] made attempts to improve the mechanical properties of the cement paste by adding a higher amount of PVA (less than 3 wt. % of cement). But improvement of mechanical properties due to reinforcement bond in cementitious composites containing PVA is not so clear. The addition of PVA to cement has resulted in increase of total porosity, increase of flexural strength, reduction of Young's modulus and reduction of compressive strength. In these experiments, the influence of the curing was not taken into account at the time of hardening of the tested samples, because both authors cured the samples in water. Due to solubility of the PVA in water, this approach of curing may cause a negative effect on the mechanical properties of samples. Moreover, in the mentioned studies the mechanical properties of the samples were investigated only at the age of 28 days. For a better understanding of this composite, it is necessary to monitor the long-term development of mechanical properties.

Materials and Samples

The samples were made of Portland cement CEM I 42.5 produced in Radotín, CZ. PVA was added into the fresh cement as a water solution SLOVIOL® R with PVA concentration equal to 16 ± 1.5 % and molar mass from 60 000 to 80 000 g/mol. Water and PVA were mixed in such proportion to achieve desired content of PVA (as wt. % of weight of cement) in mixture with water/cement ratio (w/c) equal to 0.35. A homogeneous mixture was prepared by manual mixing, from which five sets of prismatic specimens having the standard dimension 40 × 40 × 160 mm were prepared. Four sets represent different PVA content in sample increasing from 1.4 to 5.6 wt. % (the samples denotes as B – E). One set is reference without PVA content in cement (the samples denote as A). The prepared mixture was placed into casts and then was compacted for 3 minutes. The samples were removed from the casts after 2 days of hardening. For a better understanding of the PVA influence in a cement paste, the cement/PVA samples were cured in a laboratory conditions at temperature 21 ± 2 °C and a relative humidity of 50 ± 5 %. Identification of sets depending on PVA content, bulk density, and total porosity are shown in Table 1.

Table 1. Properties of tested cement/PVA samples.

Set	w/c	Amount of PVA [wt. % of cement]	Bulk density [kg/m³]	Total porosity [%]
A (ref.)	0.35	0.0	1841 ± 15	23 ± 0.6
B	0.35	1.4	1543 ± 16	35 ± 0.7
C	0.35	2.8	1512 ± 2.5	36 ± 0.1
D	0.35	4.0	1443 ± 19	39 ± 0.8
E	0.35	5.6	1366 ±7.8	41 ± 0.3

Measurement Method

Development of mechanical properties was determined by using a resonance method, which is based on measuring appropriate basic natural frequency of a sample. Mentioned method was used for long-term determination of dynamic Young's modulus and dynamic shear modulus of cement/PVA composite [5]. These mechanical properties were measured continuously for 161 days.

The measurement was performed by a measuring assembly Brüel & Kjaer containing the measuring station type 3560-B-120, the acceleration transducer type 4519-003, the impact hammer type 8206 and a control notebook. It was necessary obtain dimension and weight of each sample before starting the measurement by resonance method.

The measuring station recorded excitation signal and response signal. Using the Fast Fourier Transform the signals were transformed from the time domain to frequency domain. Software PULSE LabShop version 14.0.1 evaluate graph of Frequency Response Functions (FRF) as a ratio of a response and an excitation force in the frequency domain. From the FRFs the appropriate basic natural frequencies were evaluated. They were used in the calculation of dynamic Young's modulus and dynamic shear modulus [6].

After substituting basic natural frequencies, dimensions and weight of samples into the standard equations, the dynamic Young's modulus and dynamic shear modulus were determined [7]. Dynamic Young's modulus was evaluated by measuring the basic longitudinal natural frequency of the samples. The sample was supported by a soft and elastic pad at the midpoint of its length, which is fundamental longitudinal nodal point. The acceleration transducer was placed in the middle of the vertical side perpendicular to the length of the sample and the impact hammer strikes were performed in the middle of an opposite side (Fig. 1a). This measurement of a dynamic Young's modulus was checked by measuring the basic flexural natural frequency of the samples. In this case the sample was supported by two soft and elastic pads at the fundamental bending nodal lines, which are placed at a distance of 0.224×l (l – length of the sample) from each end of the sample. The acceleration transducer was placed on the edge of the top side of the sample and the impact hammer strikes were performed on the edge of the same side of the sample (Fig. 1b).

Dynamic shear modulus was evaluated by measuring the basic torsional natural frequency of the sample. The sample was supported as in case of measuring longitudinal natural frequency of the samples. The acceleration transducer was placed in the corner of the vertical side parallel to the length of the sample and the impact hammer strikes were performed diagonally on the same side (Fig. 1c) [8]. Results of a dynamic Young's modulus are shown in Table 2 and results of a dynamic shear modulus are shown in Table 3.

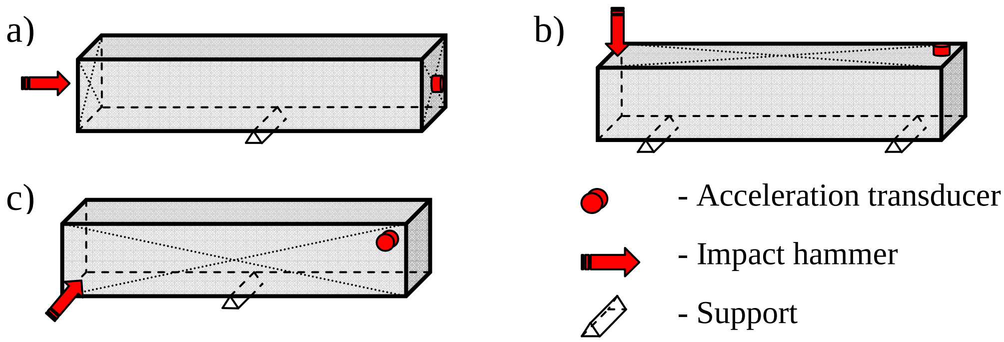

Fig. 1. Scheme of measuring of the basic natural frequency: a) longitudinal, b) flexural, c) torsional.

Results and Conclusions

The results of the dynamic Young's modulus (Table 3) show decrease of the dynamic Young's modulus of the samples with PVA (B to E) compared to the reference sample (A) in the early stages of hardening (7 days). It is caused by an increase of porosity (about 10-19 %) in the samples with PVA. However, for the samples B to E there is also seen an increase of the dynamic Young's modulus depending on the increasing content of PVA. In the late stages of hardening (between 28 to 161 days) the beneficial effect of PVA in cement paste outweighs the negative effect of increasing the total porosity and better results are achieved than in the conventional cement.

Table 2. Time dependence of the dynamic Young's modulus of cement/PVA composite.

Set	Dynamic Young's modulus [GPa]					
	7 days	14 days	21 days	28 days	42 days	161 days
A (ref.)	15.7 ± 1.0	15.6 ± 0.7	15.8 ± 0.7	16.6 ± 0.7	15.1 ± 0.6	14.5 ± 0.6
B	12.9 ± 0.3	13.1 ± 0.2	13.0 ± 0.3	14.1 ± 0.3	14.7 ± 0.1	14.5 ± 0.7
C	13.4 ± 0.4	13.5 ± 0.4	13.6 ± 0.4	14.8 ± 0.5	14.1 ± 0.1	14.9 ± 0.1
D	14.3 ± 0.6	14.7 ± 0.6	15.0 ± 0.6	16.4 ± 0.7	14.6 ± 0.4	16.0 ± 0.1
E	14.8 ± 0.3	15.3 ± 0.4	15.5 ± 0.4	17.0 ± 0.5	16.2 ± 0.7	17.8 ± 0.3

A similar trend is also evident in case of dynamic shear modulus (Table 3). There is a decrease of the modulus of the samples with PVA (B to E) compared to the reference sample (A) in the early stages of hardening (7 days) through an increased total porosity (Table 1). It's also seen an increase of the dynamic shear modulus for the samples with higher concentrations of PVA (D and E), which leads to better results in the late stages of curing (between 28 to 161 days).

Table 3. Development of the dynamic shear modulus of cement/PVA composite.

Set	Dynamic shear modulus [GPa]					
	7. day	14. day	21. day	28. day	42. day	161. day
A (ref.)	6.3 ± 0.3	6.3 ± 0.3	6.4 ± 0.2	6.7 ± 0.2	6.8 ± 0.2	6.7 ± 0.2
B	5.2 ± 0.1	5.2 ± 0.1	5.2 ± 0.1	5.7 ± 0.1	6.0 ± 0.1	6.1 ± 0.1
C	5.4 ± 0.2	5.5 ± 0.2	5.5 ± 0.2	6.0 ± 0.2	5.9 ± 0.1	6.4 ± 0.1
D	5.8 ± 0.3	6.0 ± 0.3	6.1 ± 0.3	6.7 ± 0.3	6.1 ± 0.1	6.8 ± 0.1
E	6.0 ± 0.1	6.1 ± 0.1	6.3 ± 0.2	6.9 ± 0.2	6.4 ± 0.1	7.4 ± 0.1

The addition of a higher PVA content (more than 4 wt. %) has resulted to improvement of the dynamic Young's modulus and the dynamic shear modulus in the later stages of hardening (42 days and more) compared with reference cement. Experiments also showed that PVA in cement has impact on increase of porosity which led to deterioration of the composite's mechanical properties.

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