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CIVIL ENGINEERING

Recycled polymer fibers in cement composites for sustainable construction

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Abstract. Innovative approaches in urban development should address all aspects, including waste management, with a strong focus on sustainability and environmental protection. Various cementitious composites can be considered a viable medium that allows waste storage. In this study, the effect of the polyester-vinyl fiber addition on the strength and microstructural properties of cement mortars was investigated to determine the optimal fiber content. The fibers were added to the composite at 1%, 2% and 4% by weight of the cement mortar mix. The fibers used were fine fraction (0–1 mm) and coarse fraction (1–4 mm). The material microstructures, particularly in relation to the properties of the fiber-cement matrix interface for the selected mortar, were then characterized using scanning electron microscopy (SEM). The results showed that, aside from the reference sample, the mortars containing 1% fibers of both the fine and coarse fractions had the highest compressive strength. In relation to the reference mix, the sample with 2% fine fraction polyester-vinyl fibers and the sample with 1% coarse fraction fibers achieved the best flexural strength, lower than the reference sample only by about 4%. The worst performance in each test was achieved by mortars containing 4% fibers. The analysis conducted was compared with findings from related studies, indicating the possibility of solving the challenges observed during the research. The solution indicated in the paper has the potential to create a procedure for the disposal of used posters and banners in cement mortar production.

Keywords: fibers; waste material; cement composite; hydration; scanning electron microscopy.

1. INTRODUCTION

Urban living comfort depends on numerous factors. An unquestionable criterion is the cleanliness and aesthetics of the surroundings. However, these aspects often conflict with the extensive use of public areas for marketing purposes (Fig. 1). The substantial number of posters made of polyester-vinyl materials is particularly noticeable during election campaigns or extensive advertising campaigns, among other things. It is estimated that the number of election posters for a single campaign is up to several thousand tons. Once their functional life ends, these materials become difficult-to-manage waste to dispose of and store, with no preferred method of recycling or reuse identified [1]. The approach of recycling and reuse of waste in the economy is defined by an EU directive [2]. The issue of utilizing waste materials in cementitious composites is widely known [3]. This is not surprising given the widespread use of concrete worldwide [4]. Many materials used as substitutes for cement or aggregate originate from waste, e.g., post-manufacturing waste. Similarly, recycled aggregate is known to be used as an ingredient for concrete.

Fig. 1. Polyester-vinyl posters

Finally, the utilization of materials in the form of fibers is also constantly being developed [5]. The effect on basic mechanical parameters like compressive and flexural strength varies depending on the fiber type [6]. The amount of fiber added is also of high importance in achieving higher compressive or flexural strength. Adding too many fibers can result in reduced compressive strength as presented in the article [7] where the addition of polyvinyl fibers to the concrete mixture in amounts of 5–30% relative to the weight of the cement led to a decrease in its compressive strength (a 5% fiber addition led to a 9.1% reduction). A similar relationship was shown by researchers studying cement mortars with the addition of recycled cellulose fibers [6].

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The addition of fibers in the amount of 0.5% by weight of the binder led to a 27% decrease in flexural strength and a 26% decrease in compressive strength. In return, a small addition of fibers (e.g., 0.3%) can result in increased strength parameters [8]. For instance, polypropylene and recycled polypropylene fibers added at 0.25–1% increased compressive strength by up to 11% [5], while PET fibers from used bottles resulted in a 38% improvement in compressive strength [9]. Despite these findings, there is a lack of research specifically addressing the effects of polyester-vinyl waste fibers on cementitious composites, making it difficult to predict their performance or define optimal use conditions. This study investigates the influence of such waste fibers on the basic properties and microstructure of hardened cement mortars. The aim is to explore a sustainable method for disposing of poster and banner waste by incorporating it into mortars, thereby improving urban environmental quality through innovative solutions.

The tested cement composites were prepared with the addition of polyester-vinyl fibers in three proportions: 1%, 2%, and 4% by total mix weight. These fiber contents (including the relatively high 4%) were selected based on findings from the literature. For example, study [10] investigated mortars containing shredded payment card fibers at a dosage of 5% relative to the aggregate, which corresponds to 3.31% of the total mortar composition in the context of this study. Similarly, research on concrete with polyvinyl fibers reported dosages ranging from 5% to 30% by cement weight [7], which translates into 0.75% to 5.1% of the total mortar composition when applied to polyester-vinyl fibers.

The novel approach in the work focuses on the use of waste fibers with a complex structure – vinyl flakes reinforced with a polyester mesh. An unconventional shredding method, easy to implement and with low process cost, was used and analyzed for its effect on the shape and size of the resulting fibers. In addition, materials were selected in order to separate polyester fibers from the vinyl fibers, knowing that the polyester part may have an adverse effect on the properties of cement composites. In comparison to many previous works on the effects of polymer fiber addition, advanced microstructure analysis, including the original procedure of segmentation and determination of the local Ca/Si ratio, was also performed to better understand the interactions between the additive and the cement matrix. Such methodology was necessary to evaluate the influence of the heterogeneous composition of the fibers on the outcome of hydration reactions and thus the microstructure of the analyzed mortars.

2. MATERIALS AND METHODS

2.1. Materials and sample preparation

The sand used for the study was Axton brand quartz sand of fractions from 0.5 mm to 1.4 mm. The amount of sand used is constant for all mortars. The cement used in the study was CEM I 42.5, which in its composition contains Portland clinker in the amount of 95–100% and secondary components of 0–5%. The early compressive strength of the cement (after 48 hours) is higher than or equal to 20 MPa, while the standard strength after 28 days is a range of 42.5 MPa $\leq \times \leq$ 62.5 MPa. In addition, the onset time of cement is more than 60 min, roasting loss is less than 5%, its volume stability is less than or equal to 10 mm, its SO_3 content is less than or equal to 4%, and its chloride content is less than or equal to 0.1%. The chemical composition of the cement consists of Si (53.0 wt.%), Al (16.5 wt.%), Ca (12.5 wt.%), and Fe (8.0 wt.%). The content of other components (Na, Mg, K) does not exceed 4.0 wt.%. Specific surface area is less than or equal to 3500 cm^2/g. (Information provided by the manufacturer). The amount of cement used was constant for all mortars. The water used comes from the city water supply system. Its quantity was the same in all the preparations, and the water-cement ratio was set to 0.5. Soudaplast MZ plasticizer from Soudal was also added to improve the consistency of the mixture. For the cement mortars, polyester-vinyl fibers (Fig. 2), made by shredding banners) were used. The structure of the banners consists of two materials – vinyl film and polyester mesh [11]. They were shredded using a mechanical cup device with a rotary blade, which turned the material into irregularly shaped fibers (Fig. 3).

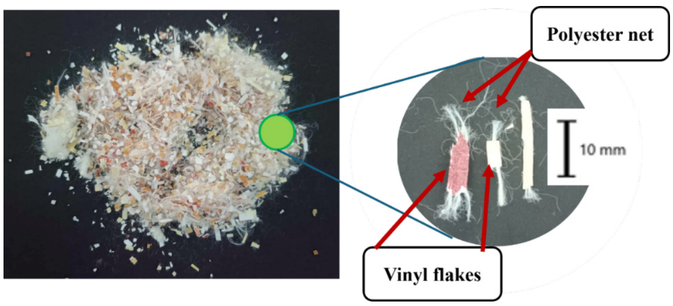

Fig. 2. Polyester-vinyl fibers after mechanical shredding

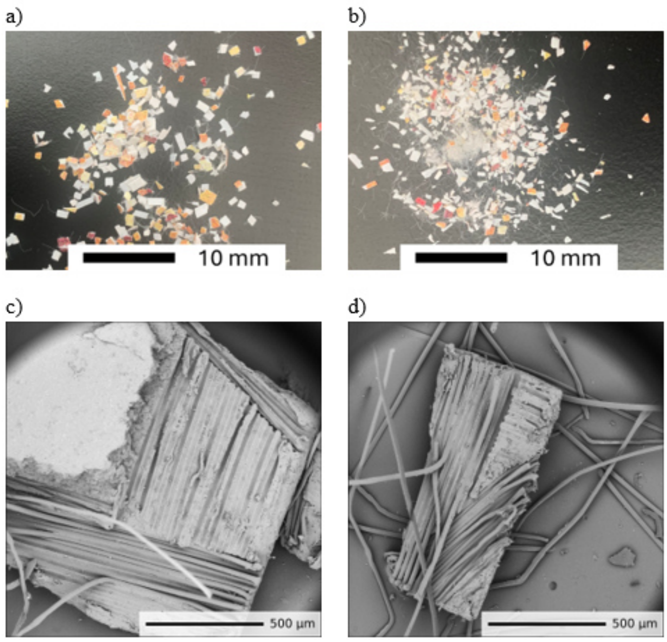

Fig. 3. Fibers used in the concrete mix: a) coarse fraction, b) fine fraction, c) micrograph of the coarse fraction, d) micrograph of the fine fraction

Resulting fibers were passed through sieves, which resulted in their selection into two fractions, which were used for the mortars. A fine fraction with a fiber size of 0 to 1 mm, designated VF, and a coarse fraction with a fiber size of 1 to 4 mm, designated CVF. The bulk density of the fibers in the loose state is 0.56 g/cm^3 for CVF fibers and 0.65 g/cm^3 for VF fibers. The specific density of the uncrushed banner is 1.30 g/cm^3 ± 0.05 g/cm^3. The polyester itself, which, when shredded, combines into clumps that resemble the wadding in appearance, was not used for the study. It would need additional processing to avoid forming clusters of polyester in the mortars, which would weaken the cement composites. Polyester-vinyl fibers were added in three proportions of 1%, 2% and 4% by weight of all components of the reference mortar mix (dry as well as wet components). Table 1 shows the proportions and wages of the ingredients needed to make one batch of mortar. The mixture components were then mixed according to the standard. The next step was to mold the 40 × 40 × 160 mm specimens, starting by preparing the molds, coating them with a release agent.

Table 1
Compositions of the tested mortars

Mortar name	Ingredients of the mortars (g)				
	Cement	Sand	Water	Plasticizer	Fibers
REF	450	1350	225	14.5	–
VF1					20.4
VF2					40.8
VF4					81.6
CVF1					20.4
CVF2					40.8
CVF4					81.6

The fresh mortar was placed in the molds in two layers, then compaction was conducted until visible air bubbles stopped coming out of the mortar. The samples were transferred to a container filled with water to continue their maturation for 28 days. Seven series of mortars were made, and three samples were obtained from each series. The volume of one series was 800 cm^3 ± 25 cm^3. A total of 21 samples were made.

2.2. Consistency

Testing the consistency of fresh mortar was performed using the spreading table method. The formed cement mixture was exposed to 15 cycles of table drop. The spread was measured, and the consistency was determined using the standard [12].

2.3. Bulk density

A bulk density test was conducted after 28 days of curing in a container filled with water. Samples before testing were dried at (105 ± 5)°C until the weight of the sample was constant. Then the samples were cooled to room temperature, weighed, and measured. Bulk density calculations were performed in accordance with [13].

2.4. Flexural strength

The flexural strength test was conducted for cementitious composites after 28 days of maturation in containers filled with water, to determine the mechanical properties of cement mortars. The test was conducted using the three-point bending method on beam specimens [14]. The specimens were placed in the testing machine, in special jaws that have two points of support (keeping the scheme of a simply supported beam) and one point of load application (in the center of the beam). The load was applied continuously, increasing the force until the failure of the beam occurred. The test was conducted on three samples for each series.

2.5. Compressive strength

The compressive strength of cement mortars was tested after 28 days of curing in containers filled with water, in order to determine the mechanical properties of cement mortars. The test according to the standard [14] was conducted in a testing machine, on specimens with an area of 40 mm × 40 mm. A load was applied to the components placed on the machine plate in such a way as to ensure uniform stress distribution. The force was increased at a uniform rate until the specimen failed. The test was conducted on six half beams for each mixture after the flexural strength tests.

2.6. SEM

Imaging in the scanning electron microscope Phenom XL (Thermo Fisher Scientific Phenom-World BV) was performed for flat cross-sections of selected cement mortar samples.

The samples were cut using a precision saw and then vacuum-embedded in low-viscosity epoxy resin (Struers EpoFix). To minimize image drift related to the charging effect [15]; while simultaneously reducing the required thickness of heavy metal coating, the resin was filled with platelet graphite in a mass ratio of 1/6. Additionally, to improve the grindability of the surface, the remaining volume of the mold was filled with glass microspheres. After the resin curing period, the embedded samples were polished to obtain flat surfaces on diamond discs (Struers MD Piano) using a developed grinding procedure. The individual grinding stages are summarized in Table 2. The polished samples were then coated with a gold-palladium layer of approximately 50–70 Å in thickness using a vacuum sputter coater. Imaging was performed using a backscattered electron (BSE) detector, with a beam current of 40 nA and an accelerat-

Table 2
The grinding and polishing procedure used in the study

Grinding disc	MD Piano				
	220	500	1200	2000	4000
Polishing time	Until the surface is fully visible	2 min	6 min	10 min	36 min

ing voltage of 15 kV. Supplementary SEM-EDS (energy dispersive spectroscopy) analyses enabled point-wise differentiation of composite phases (resin-filled pores vs. polyester fibers, cement matrix vs. vinyl foil). Additionally, quantitative analyses of the EDS data were made to investigate the Ca/Si intensity ratio of the cement matrix [16], which is a known indicator of its mechanical properties [17].

3. RESULTS AND DISCUSSION

3.1. Consistency

The results of the consistency test are presented in Table 3.

Table 3
Consistency of the cement mix

Sample	Spread of cement mortar (mm)	Decrease in workability relative to REV sample [%]
REF	180	–
VF1	169	5.9
VF2	123	31.5
VF4	107	40.4
CVF1	146	19.0
CVF2	128	29.0
CVF4	110	40.0

For both the fine fraction (VF) and coarse fraction (CVF) fibers, a relationship was observed indicating that an increase in the amount of fibers added to the cement mixture results in a decrease in its workability.

3.2. Bulk density test

The average measurement results of the bulk density of mortars are shown in Fig. 4. Mortars with the addition of a fine fiber fraction (VF) obtained the highest bulk density for sample VF1, whose bulk density was 0.06 g/cm^3 higher than the reference. The other samples obtained values lower than the reference sample, i.e., VF2 lower by 0.04 g/cm^3, and VF4 lower by 0.10 g/cm^3. The same was true for the bulk density in mortars with the addition of coarse fractioned fibers – sample CVF1 had a higher bulk density value than the reference sample by 0.02 g/cm^3. Comparing the results for mortars with the addition of fibers (fine and coarse fractions), a relationship can be seen that the higher the fiber content in the sample, the lower the bulk density value. Relative to the reference sample, the VF1 and CVF1 mortar increases the bulk density, which may have been caused by the fibers filling the free pores. Other mortars with higher fiber content do not follow this trend, which may have been caused by the formation of new pores under their surface due to the flat shape of the vinyl part of the fiber. A small addition of fibers fills more pores of the mix than the formation of new ones, so the value of bulk density increases as a result.

3.3. Flexural strength

A flexural test of the cement beams was conducted using the three-point method, from which the results shown in Fig. 5 were obtained. Cement composites with the addition of a fine fiber fraction (VF) achieved the best flexural strength for the VF2 test of 3.52 MPa. The test with the addition of 1% fibers achieved a slightly lower strength of 3.28 MPa (the difference between VF2 and VF1 is 0.24 MPa, constituting 6.82%). In contrast, the VF4 test achieved the lowest strength amounting to 2.81 MPa (the difference between VF2 and VF4 is 0.71 MPa, constituting 20.17%). In the case of composites with the addition of a coarse fiber fraction (CVF), the best flexural strength of 3.52 MPa was achieved by CVF1. The other tests yielded lower strengths, which amounted to 3.05 MPa for the CVF2 test (a decrease in strength relative to CVF1 of 0.47 MPa, constituting 13.35%) and 2.58 MPa for the CV4 test (a decrease in strength relative to CVF1 of 0.94 MPa, constituting 26.70%). The tests show that the reference test achieved the highest flexural strength relative to all tests of 3.67 MPa, while CVF1 and VF2 achieved the best strength relative to the tests with the addition of fibers, but slightly lower than the reference test (a decrease of 0.15 MPa representing 4.09% for VF2 and CVF1). The lowest strengths relative to the reference sample were achieved by samples with a fiber addition of 4%, for the fine fraction VF4, which sees a decrease of 0.86 MPa, constituting 23.43% difference, as well as the coarse fraction CVF4, which decreases even more by 1.09 MPa, constituting 29.70% lower flexural strength than reference mortar. A similar relationship was noted in [6] describing the effect of cellulose wastepaper fibers in cementitious composites. The fibers used were 0.5% by weight of filler and binder.

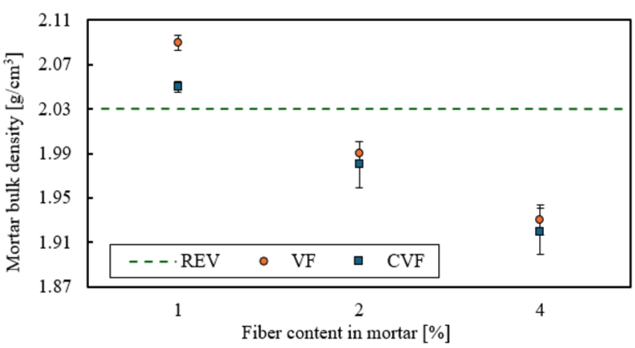

Fig. 4. Bulk densities of hardened mortar

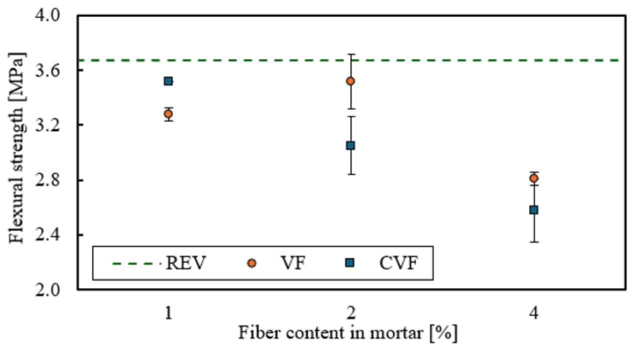

Fig. 5. Flexural strength of cementitious composites

After 28 days of curing, the best flexural strength was obtained for the reference test, and much lower for the test with cellulose fibers (about 27%). A test with cellulose fibers and plasticizer was also described, which obtained a slightly worse strength than the reference test (approximately 7% lower), but exceeded the results yielded without superplasticizer (approximately 21% higher strength). The reason may be the considerably better dispersion of the cement particles and the improved bond strength between the fiber and matrix caused by the use of the superplasticizer. It can be suspected that this mechanism worked similarly for the fibers in this paper, assuming that the polyester part can absorb water and limit its amount in the mixture, and the addition of the superplasticizer allowed for enhanced cooperation in the fiber-matrix phase.

3.4. Compressive strength

The results from the compressive strength test are shown in Fig. 6. The cementitious composites with the addition of a fine fiber fraction (VF) obtained the best compressive strength for the VF1 test, amounting to 23.55 MPa. The other VF tests achieved lower strengths, amounting to 21.07 MPa for the VF2 test (a decrease in strength relative to VF1 of 2.48 MPa, constituting 10.53%) and 15.53 MPa for the VF4 test (a decrease in strength relative to VF1 of 8.03 MPa, constituting 34.06%). Similarly, in cementitious composites with the addition of coarse fraction fibers (CVF), the best compressive strength of 21.93 MPa was achieved by the CVF1 sample. The other CVF tests obtained lower strengths for the CVF2 test, 20.33 MPa (strength lower than CVF1 by 1.60 MPa, or 7.29%), and for the CVF4 test, 14.20 MPa (strength lower than CVF1 by 7.73 MPa, or 35.25%). As in the flexural strength test, the highest compressive strength was achieved by the reference test at 24.72 MPa. Of the tests containing fiber addition, the highest strengths were achieved by VF1 and CVF1, while these are lower than the reference test (a reduction in strength of 1.17 MPa, constituting 4.73% for VF1 and 2.79 MPa, constituting 11.28% for CVF1). The lowest strengths were achieved by the samples with the addition of 4% fibers, with a decrease of 9.19 MPa, constituting 37.17% for VF4 and 10.52 MPa, constituting 42.56% for CVF4. It is presumed that such a large decrease in compressive strength could have occurred due to the higher porosity that weakens the composite. It is presumed that the increase in porosity was caused by the incorporation of polyester-vinyl fibers into the cement matrix and insufficient bonding with the binder particles [6]. As research indicates, the mortar with fine fraction of polyester-vinyl fibers achieves higher compressive strength. This correlates with the changes noted at the bulk density measurement stage. It can be surmised that the problem lies in the presence of flattened air pores, which have a much greater effect on changes in compressive strength than in flexural strength. Similar to the fibers tested, fibers extracted from shredded credit cards behaved the same way [10]. The use of a high fiber dosage (3.33% by weight of the mixture) resulted in a decrease in f_c of about 15%. In contrast, incorporating a small amount of fibers, amounting to approximately 1.67%, increased compressive strength by 7%, which highlights both the benefit of optimizing at low fiber contents and the necessity of removing the water-absorbing polyester mesh from the additive.

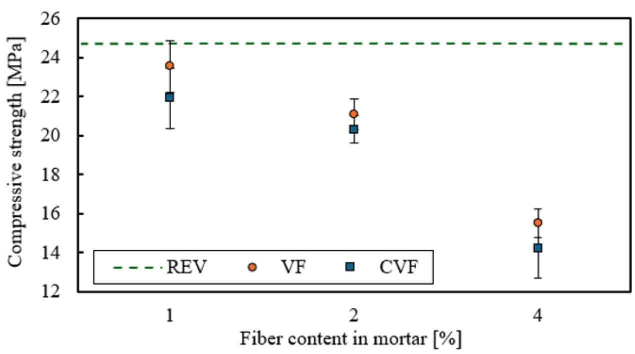

Fig. 6. Average compressive strengths of cementitious composites

3.5. SEM

The SEM analysis aimed to determine the origins of the differences in macroscopically observed mortar properties following the addition of polyester-vinyl fibers. Selected samples from the series were imaged, revealing that while the underlying mechanisms were common to all specimens up to a point, their intensity varied. Three separate types of polyester-vinyl inclusions in the mortar were identified: larger, flake-like trimmings of the vinyl foil, often bundled with polyester net, individual polyester fibers, and polyester “wool”, i.e., entangled fine polyester fibers that did not separate from each other during preparation of the mixture. The comparison between those inclusions in the matrix is depicted in Fig. 7.

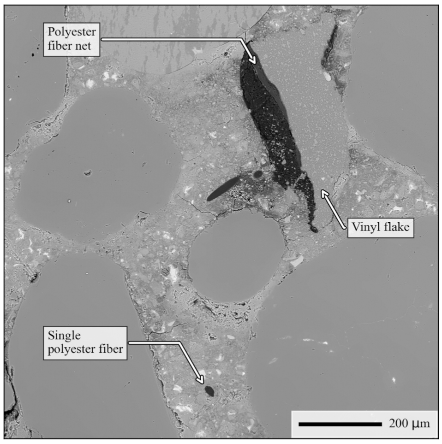

Fig. 7. Different inclusion types as found on the micrograph of the sample surface

Initially, low-magnification imaging was performed to capture an overall view of the sample surfaces. These images showed that large vinyl flakes tended to arrange themselves in a pattern similar to that of aggregate grains within the mortar, suggesting that they became integrated into the composite structure much like the natural packing of the aggregates. At higher magnifications, the images provided further insights into the behavior of the fibers and the cement matrix around them. It was observed that individual thick polyester fibers typically remained isolated rather than forming clusters, except in cases in which they were still connected to the vinyl flakes or in samples with 4% weight content of additives. Additionally, nonperfect bonding between fiber surface and cement matrix was observed, creating longitudinal micropores that in some cases propagated into microcracks (Fig. 8). The biggest observed difference between samples with coarse (CVF) and fine (VF) fibers was the occurrence of clusters of entangled, fine polyester fibers in the latter. The resulting "wool-like" structures often found their location in the narrow parts of the gaps between aggregate grains in intergranular spaces, indicating that they could influence the stress-transfer pathways in the material. The cement paste partially penetrated the space in between these fibers, leading to the creation of localized areas of alternate pore/hydration product/polyester inclusions layers. Two observed examples of such areas are presented in Fig. 9. It is worth noting that in addition to the possibility of lowering the mechanical properties of the cement matrix, the presence of those structures correlates with an increase in local porosity of the matrix and areas of uneven hydration of the cement, as indicated in the variation in grayscale intensity of the BSE image close to the location of the structures. It was also observed that vinyl flakes, especially those with polyester net still attached, tended to create additional voids of rectangular, elongated shape in the mortar. All analyzed samples containing additives exhibited those pores, while the reference sample did not. This implies that the pores are more likely to result from the air trapped beneath vinyl flakes during the addition than from the action of the aerating plasticizer.

However, it should be noted that these voids were mostly found on the side with the polyester net attached. It suggests that up to some point, they may be eliminated, given that proper separation of the polyester mesh from vinyl flakes is achieved during the additive preparation process. Selected examples of such pores, observed in different mixture types, were presented in Fig. 10. To verify the assumption that the chemical composition of the matrix may differ in the vicinity of polyester fibers and vinyl flakes, EDS analysis was conducted. Two samples were chosen for comparison: VF4, which exhibited the highest observed concentration of additive-related changes in microstructure, and REF, a reference mortar sample. In each case, an area of approximately 800×800 μm was selected for investigation. The analysis was conducted using the following procedure. First, local intensities of the appropriate characteristic X-ray lines were extracted from the EDS data (Fig. 12a),

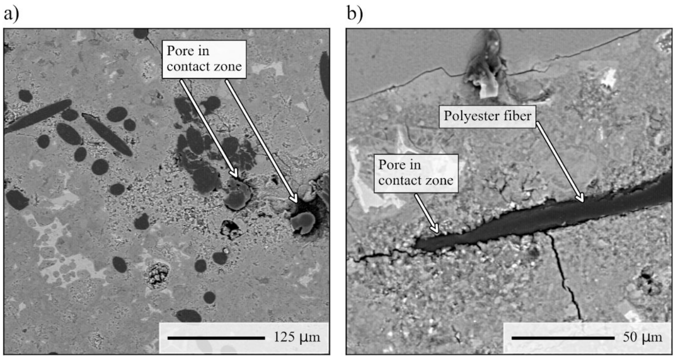

Fig. 8. Imperfect bonding between polyester fiber and cement matrix: a) bundle of fibers in sample, b) close-up of the contact zone between fiber and matrix

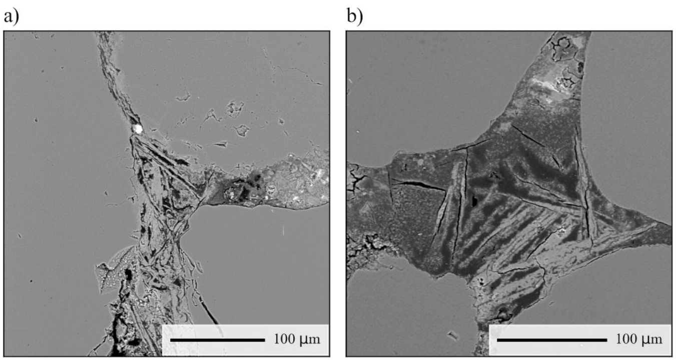

Fig. 9. Laminated structures of entangled polyester fibers and hydration products in-between aggregate: a) VF1, b) VF4

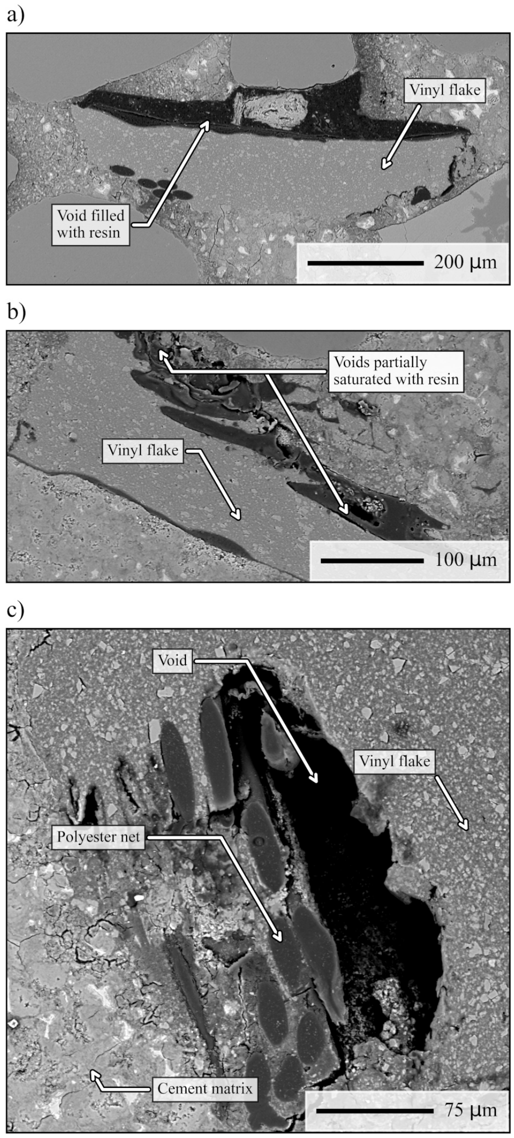

Fig. 10. Examples of voids of varied sizes under vinyl flakes as found on a) sample VF1, b) sample CVF1, c) sample VF4

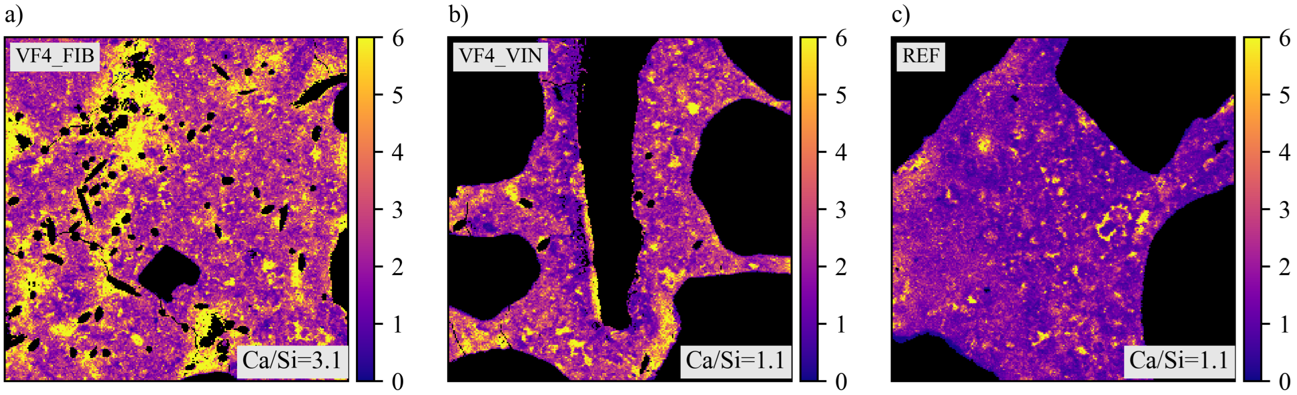

Fig. 11. Maps of Ca/Si intensity ratios as obtained via EDS analysis: a) cement matrix of sample VF4 near fiber aggregations, b) cement matrix near vinyl flake in sample VF4, c) cement matrix of reference sample

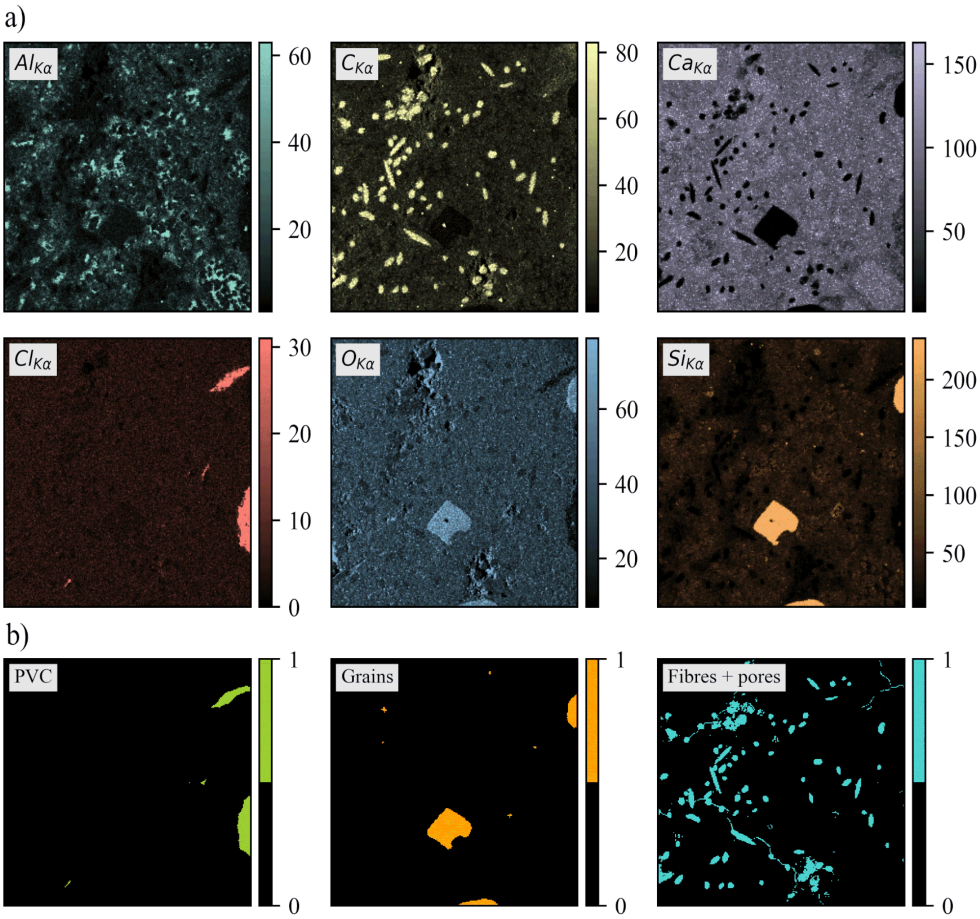

Fig. 12. Segmentation of EDS data: a) elemental intensities – sample VF4, b) identified binary masks of vinyl, aggregate and fibers/pores phases

utilizing the *exspy* library [18]. Then, a binary mask for each analyzed sample was created to isolate the locations corresponding to the cement matrix. The masks (Fig. 12b) were generated considering the following factors: the presence of chlorine (indicating PVC), silicon (indicating aggregate), fibers, and pores (identified from the BSE micrograph). Each mask was created by thresholding the appropriate elemental intensity or BSE image intensity (in the case of pore space and fibers) using the Otsu algorithm [19], followed by morphological operations (erosion and dilation with a disk kernel) to account for irregularities in the intensity data. These binary images, after aggregation via a logical OR operation, enabled filtering of the EDS data. This step made it possible to analyze Ca/Si intensity ratios in the cement matrix (Fig. 11), which may indicate the local quality of the matrix and are known to influence its mechanical properties [17]. It can be observed that the Ca/Si ratio was mostly uniform in the vicinity of the vinyl flake (Fig. 12b) and in the reference sample (Fig. 12c) but differed significantly near aggregations of polyester fibers (Fig. 12a). Overall, the mean Ca/Si ratio measured in the VF4 sample near vinyl inclusions and in the REF sample was similar (around 1.1), while in VF4 near polyester inclusions it almost tripled (3.1). This indicates that the mechanical properties of the hydrated cement in the latter case may differ, thus explaining the macroscopically observed changes in the properties of the tested composites. However, it should be noted that the Ca/Si ratios in the present study were calculated based on the intensity of the appropriate characteristic elemental lines, not on the measured mass content of calcium and silicon. Therefore, caution is advised when comparing the mean values of the ratio to those reported in the literature that are solely based on mass content or measured with different laboratory methods. In summary, imperfect contact between the fiber surface and matrix leads to an increase in local porosity of the mortar. Those places may function as a seed for the localization of microcracks. Entangled polyester fibers created layered structures of hydration products and fine fibers in between aggregate grains, which may hinder the strength and durability of the composite. Additionally, elongated, rectangular voids beneath the vinyl flakes were present regardless of the inclusion size. The pores were mostly localized near the polyester mesh; therefore, it is suggested that proper separation of the mesh from the vinyl foil may reduce their occurrence. Quantitative analysis of Ca/Si intensity ratios obtained from SEM-EDS imaging revealed that the ratios nearly tripled in the vicinity of polyester fiber aggregations, while remaining mostly unchanged near vinyl flakes as compared to the sample without any additives. A higher ratio is expected to affect the mechanical properties of the matrix near polyester inclusions, as indicated in the literature, which is consistent with the results obtained from the macroscopic evaluation of the samples.

The level of the overall influence of the negative interactions mentioned on the mechanical properties of the composite remains unknown; it is thus suggested that this topic should be studied, i.e., utilizing nanoindentation techniques [20] to map the mechanical properties in the vicinity of the inclusions.

4. CONCLUSIONS

Based on the work done, test results, and SEM analysis on cement composite samples containing polyester-vinyl fibers in the range of 1–4% by weight of the components, the following conclusions can be made:

- Cement composites containing 1% fibers achieved the highest bulk density, higher than the reference sample (an increase of 0.07 g/cm^3 for VF1 and 0.04 g/cm^3 for CVF1). The addition of up to 1% of fibers to the cement mixture can cause the filling of free pores, which contributes to an increase in bulk density, while fiber amounts higher than 1% cause a significant reduction in bulk density.
- The flexural strength for the sample containing 2% fine fraction polyester-vinyl fibers is outstanding. The addition of only the coarse fraction of fibers resulted in worsened strength parameters, so its use is not recommended.
- The best compressive strength among cement composites with the addition of polyester-vinyl fibers was achieved by the VF1 test, which scored slightly lower than the reference test (< 5%). The amount higher than 1% of fine or coarse fibers significantly weakened the cement mortar by up to 40% of the compressive strength value compared to the sample without fibers.
- Imaging in SEM revealed three distinct types of negative interactions between the inclusions and cement matrix: imperfect contact between the polyester fibers and cement matrix, changes in chemical properties of the matrix (namely Ca/Si ratio in the vicinity of the fibers), and elongated pores beneath vinyl flakes. The mechanisms were common to all analyzed sample types but varied in intensity.
- Due to changes in mortar parameters, it is recommended to use coarse or fine fibers at a maximum of 1% addition. In terms of strength parameters and aiming for the highest possible bulk density of the cement composite, this is a safe value.

4.1. Perspectives

In future studies, it is worthwhile to focus on fiber dosages in the range of 0–1% to determine their content that improves mortar properties. It is also recommended to evaluate the durability and resistance of the material after a longer maturation period (90 and 365 days) to analyze aging processes.

In addition, it is advisable to investigate alternative methods of grinding the fibers to improve their geometry and reduce air retention. Separating the polyester mesh from the vinyl flakes may reduce negative interactions with the cement matrix, such as those caused by the water absorbency of the material.

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