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EXPERIMENTAL STUDIES ON DUST-MODIFIED CEMENTITIOUS COMPOSITES

The problem of collecting waste containing plastics is increasing in significance in today's world. This paper presents the results of a study of the effect of adding dust from air purification filters installed at a plant producing plastic construction materials on selected properties of a cementitious composite. The elemental composition of the dusts was analysed using an energy dispersive X-ray fluorescence spectrometer and the grain size distribution using a laser particle size analyser, and the dusts were then added to the cement composite in amounts of 1-6% by weight of the cement. The effect of the amount of dust was evaluated in terms of changes in rheological characteristics (consistency), mechanical characteristics over a period of up to 12 months (compressive and bending strength), water absorption, and frost resistance after 50 freeze-thaw cycles. The addition of the applied dust has been shown to positively alter some mechanical properties.

Keywords: Cement composites; filter dust; chemical composition; strength; frost resistance

1. Introduction

The development of science, technology and industry brings both benefits and risks to the environment, especially in the case of materials that are difficult to manage. Today's society is faced with a constant increase in the amount of waste from various industries, such as metallurgy and energy. A major problem is plastic waste, the production and consumption of which is steadily increasing, and the use of waste from this material can improve the quality of the environment. The global production of plastics has increased dramatically since 1950 – according to [1], in the last 65 years, the production of plastics increased from 2 million tonnes per year to over 400 million tonnes in 2015. According to Plastics Europe in its report "Plastics – the Facts 2021" [2], global production of plastics in 2020 was 376 million tonnes. This waste is a significant problem and a challenge for scientists who are looking for novel methods to recycle or dispose of it in order to reduce environmental pollution. The use of waste in concrete production could be a sustainable solution to environmental contamination [3-5]. The use of plastic waste in concrete composite technology has been extensively investigated. There are many publications in the literature on research into the use of plastics as a substitute for aggregate in concrete. Research is being conducted to determine their effects on the properties and durability of composites with cementitious matrices [6-10]. The authors of papers [11-13] modified concrete by adding PET (polyethylene terephthalate) waste from beverage bottles. They shredded the bottles into flakes or filaments of 5 to 15 mm in length. In works [11,12], filaments were covered with a mixture of fly ash, volcanic lava and slag. Filaments prepared in this way were used to replace part of the sand in different proportions: 0%, 25%, 50% and 75%. The authors showed that the modification of the concrete had a beneficial effect on its plasticity, which made it possible to reduce the amount of water required in the concrete mix. In [13], in turn, it was shown that concrete modified in this way had good properties attenuating dynamic impacts. In [14], the effect of using polypropylene as a substitute for some of the coarse aggregates in concrete in amounts of 20%, 40% and 60% by weight was evaluated and it was noted that the compressive strength decreased with increasing polypropylene content in concrete samples. However, the strength values for samples with 20% polypropylene content in concrete were found to be comparable to samples without polypropylene. Similarly, in [15], the authors investigated the waste of ground polyethene plastics in concrete with a partial replacement of ½ kg and 1 kg by volume of coarse aggregate. They found that concrete with 1 kg of plastic content achieved the highest compressive strength. Similarly, concretes in which EPS (expanded polystyrene) granules were used as aggregate replacement were examined in [16]. The effect of plastic waste on the properties of cement mortars

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was investigated in [17]. The researchers used waste polyethene in sand volume proportions of 0%, 1%, 2%, 3% and 4%, respectively. They found that as the amount of waste polyethene increased, the compressive strength decreased. However, the use of ground granulated blast furnace slag in the mortar formulation allowed the authors to achieve the preservation of the mechanical properties of the concrete for a proportion of waste polyethylene at 2%, and blast furnace slag replacing cement at 10%. Many researchers are evaluating the possibility of using plastic waste as a lightweight aggregate in cement composites by combining two waste materials, PET waste and quartz sand [18], or PET waste with granulated blast furnace slag [19,20].

The present study analysed the effect of adding dust from air purification filters installed at a plant producing plastic construction materials on selected properties of a cementitious composite on consistency, compressive and bending strength up to 12 months, water absorption and frost resistance after 50 freeze-thaw cycles.

2. Plan of experiment

The experiment aimed to test the suitability in cementitious matrix composites of dust taken from air purification filters installed at a plant producing plastic construction materials. The effect of the test dust on the characteristics of the cementitious matrix composites was evaluated using the following tests: consistency of the freshly made composite, compressive and bending strength testing after 28 days and change in strength over 1 year, absorption test, durability test performed using a salt spray chamber and frost resistance after 100 freeze-thaw cycles. The test programme consisted of a reference series of the composite, which was then modified with a dust addition of up to 6%. In this way, seven series were obtained, the composition of which is shown in TABLE 1. The S0 series in the study refers to the control series, obtained without any additional components.

From each series, 36 cubes of 40×40×160 mm were cast. CEM I 42.5 R Portland cement was used to make all the series tested; the control series had a water-cement ratio of W/C = 0.6. The superplasticiser used in the tests was CHRYSO®Optima 294, which is produced based on modified polycarboxylates, and fine aggregate with a grain size of 0 to 4 mm and the grain size distribution shown in Fig. 1.

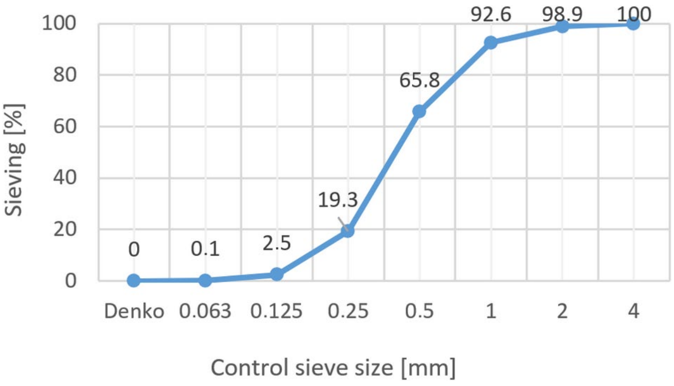

Fig. 1. Sieving curve of the used fine aggregate

The particle size distribution of the dust was also analyzed using the Analysette 22 laser analyser (Fig. 2) and its chemical composition was determined using the ED-XRF X-ray spectrometer.

TABLE 1

Composition of test mixtures for making 36 bars for each series

Component	Series						
	S0	S1	S2	S3	S4	S5	S6
Cement CEM I 42.5R [kg]	5.42						
Sand 0/4 mm [kg]	16.26						
Tap water [kg]	3.25						
Dust [kg]	0.00	0.054	0.108	0.163	0.217	0.271	0.325
Superplasticizer [ml]	0	0	0	10.84	13.55	16.26	18.97

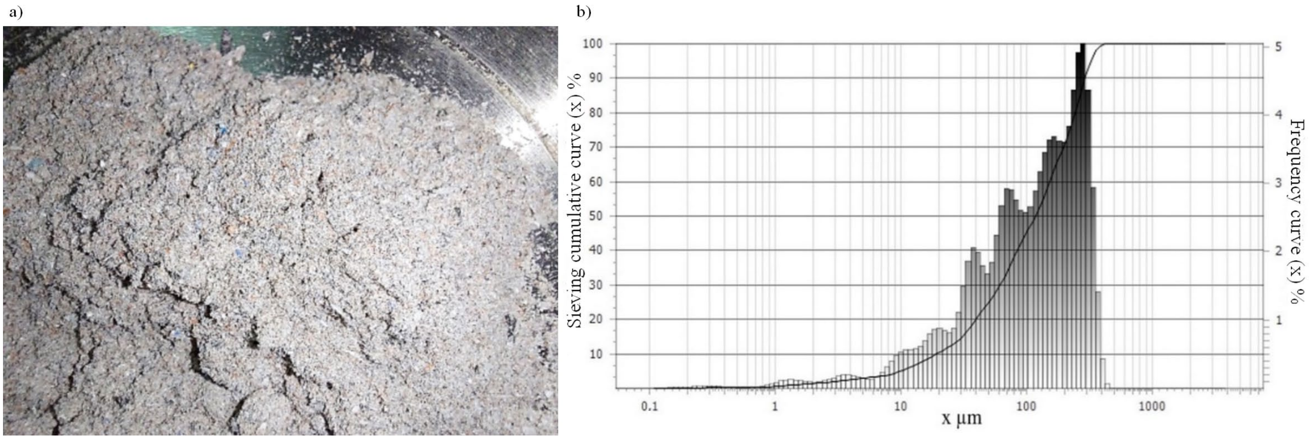

Fig. 2. Grain size of the dust used: a) sample photo, b) sieving curve

Based on the particle size distribution of the examined dust, it was found that 100% of the dust particles were smaller than 520 µm. The chemical composition analysis revealed that the main component was silicon dioxide at 38.89%. The remaining components included calcium oxide – 18.60%, calcium – 13.29%, magnesium oxide – 12.48%, digaluminum trioxide – 10.15%, phosphorus pentoxide – 5.39% and titanium – 1.20%.

3. Research results

3.1. Consistency of fresh mortar

Consistency tests for all series were performed using two methods: the flow table method according to [20] and using a penetrometer [21]. The consistency test results are presented in Fig. 3.

It can be observed that even an addition of just 1% of the dust used (S1 Series) had a negative impact on the consistency of the composite. Larger amounts also caused noticeable deterioration in consistency.

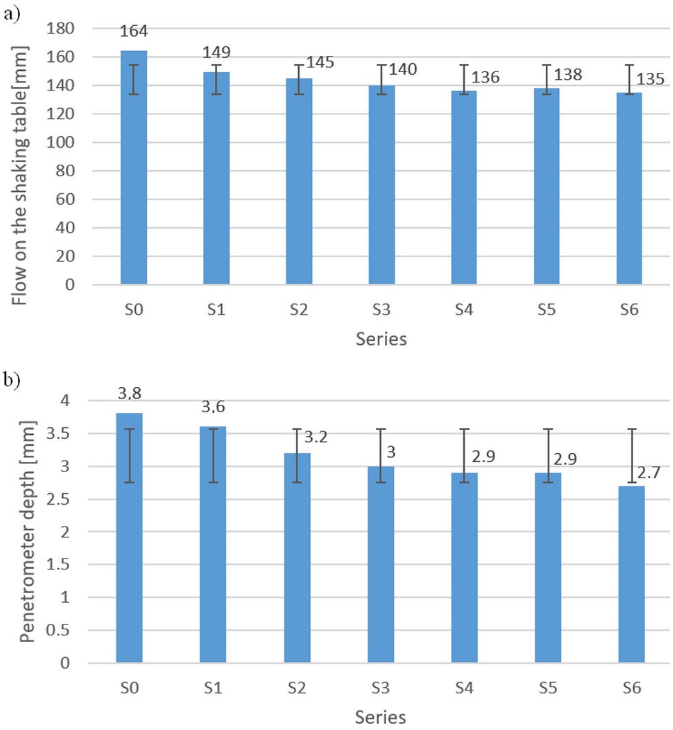

Fig. 3. Composite consistency test results: a) using the flow table method; b) using a penetrometer

3.2. Bending and compressive strength

The bending strength tests were carried out on 40×40×160 mm rectangular specimens in a three-point bending test, while the compressive strength was tested on cube halves obtained in the bending strength test [22]. The specimens were stored for 7 days at 20°C in a polythene bag, of which 2 days in the mould and 5 days after removal of the mould. The specimens were then stored in a room with a relative humidity of approximately 65% until tested. Strength assessments were carried out after 28, 56 and 90 days and after 6 and 12 months. For each series, three bars were made for the bending strength test, and the halves of the bars were then subjected to compressive strength testing. The samples during the tests are shown in Fig. 4. The average bending strength after 28 days is shown in Fig. 5.

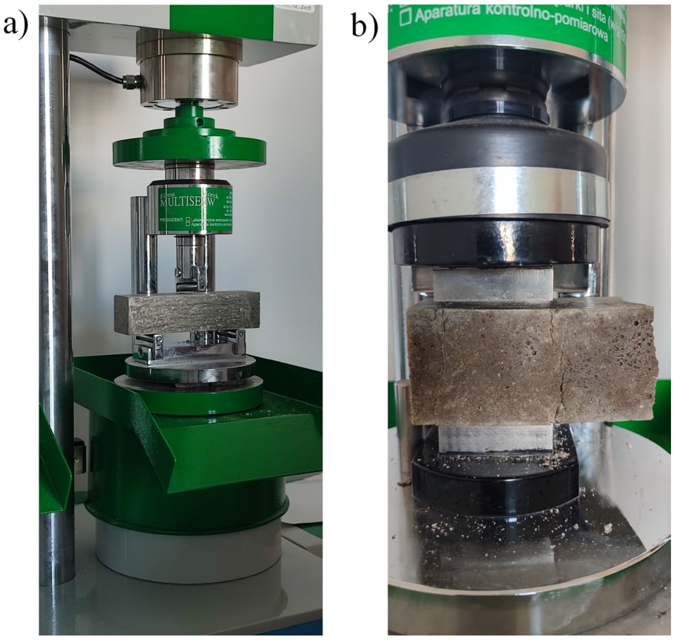

Fig. 4. Testing the strength for a) bending, b) compression

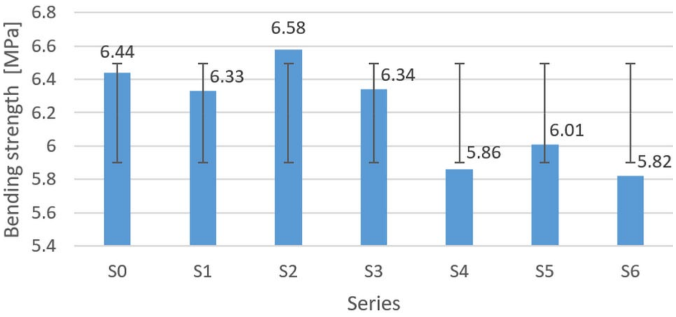

Fig. 5. Average bending strength after 28 days

In the bending strength test after 28 days, the reference series achieved 6.44 MPa. In the range up to 3% of added dust, no significant change was observed. However, at 4% dust contents and above, a decrease in bending strength was noted. The greatest reduction occurred in the series with the maximum dust content (S6 series), which showed a 10% decrease compared to the reference series (S0).

The average compressive strength for the tested reference series was 40.3 MPa (Fig. 6).The addition of 1% dust (S1 series) did not affect the strength, which remained at the same level. In the other series, a gradual decrease in strength was observed, with the lowest strength recorded for S6 series at 33.5 MPa, representing a decrease of about 17% compared to the reference series.

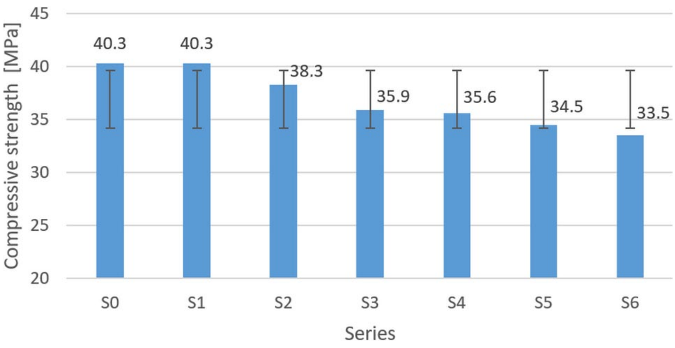

Fig. 6. Average compressive strength after 28 days

The bending and compressive strength tests of the composite over a longer period of time are presented in TABLES 2 and 3. The green colour indicates an increase in the tested strength in percentage terms compared to the previous test, while the red indicates the percentage decrease compared to the previous test.

TABLE 2

Average bending strength of the tested composites up to 1 year

Series	Bending strength up to 1 year [MPa] and the change expressed in [%]					
	28 days	56 days	90 days	6 months	9 months	12 months
S0	6.4	7.7↑16.6	7.9↑2.6	7.9 --	7.8↓1.3	7.9↑1.3
S1	6.3	7.6↑20	7.8↑2.6	7.7↓1.3	7.6↓1.3	7.4↓2.6
S2	6.6	7.6↑18.8	7.7↑1.3	7.5↓2.6	7.4↓1.3	7.2↓2.7
S3	6.3	7.3↑15.9	7.4↑1.4	7.2↓2.7	7↓2.8	6.9↓1.4
S4	5.9	6.9↑11.3	7.0↑1.5	7.0 --	6.9↓1.4	6.7↓2.9
S5	6.0	6.7↑11.7	6.9↑3	6.8↓1.4	6.7↓1.5	6.4↓4.5
S6	5.8	6.5↑10.2	6.6↑1.5	6.5↓1.5	6.3↓1.5	6.2↓1.6

The test results obtained for all series indicate an increase in bending strength up to 90 days of hardening, with the most significant increase observed up to 56th day, ranging from 10.2% for S6 series to 18.8% for S2 series.

TABLE 3

Average compressive strength of the tested composites up to 1 year

Series	Compressive strength up to 1 year [MPa] and the change expressed in [%]					
	28 days	56 days	90 days	6 months	9 months	12 months
S0	40.3	45.4↑12.7	50.2↑10.6	50.6↑0.8	50.6 --	50.7↑0.2
S1	40.3	45.2↑12.2	49.1↑8.6	49.0↓0.2	47.9↓2.3	47.5↓0.8
S2	38.3	43.7↑14.1	47.7↑9.2	47.2↓1	46.7↓4.7	45.1↓3.4
S3	35.9	40.1↑11.7	42.3↑5.5	42.3 --	42.1↓0.5	41.7↓0.9
S4	35.6	39.8↑11.8	41.7↑4.8	41.6↓0.2	41.3↓0.7	41.0↓0.7
S5	34.5	40.0↑15.9	40.9↑2.3	40.9 --	39.9↓2.4	39.4↓1.2
S6	33.5	39.8↑18.8	40.2↑1	39.3↓2.2	38.7↓1.5	38.1↓1.5

Similarly, the compressive strength of the tested composites increased up to 90 days of hardening with a more significant increase between 28 and 90 days. By day 56, the highest increase was recorded for S6 series (18.8%), and the lowest for S3 series (6.1%). Between days 56 and 90 the greatest strength gain was noted in S2 series (9.2%) and the smallest for the S6 series (1%). After 90 days, all series with added dust showed slight decreases in compressive strength.

3.3. Water absorption of composites

The water absorption test of the composites was carried out using the water saturation method under atmospheric pressure in accordance with [23]. For each series, the test was performed on 3 bars of 40×40×160 mm after 28 days of hardening. Fig. 7 shows the samples during water saturation. The obtained average water absorption values are shown in Fig. 8.

Fig. 7. The water absorption test

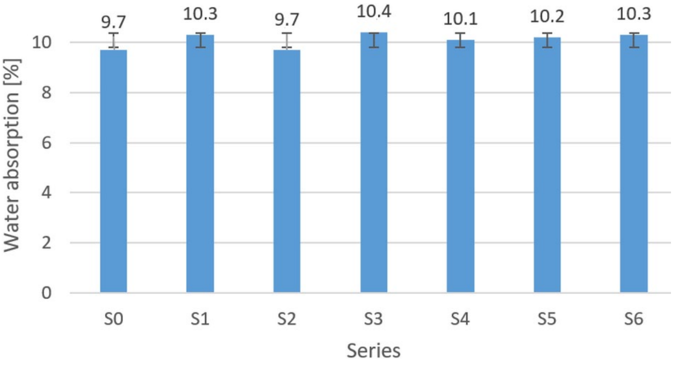

Fig. 8. Composite water absorption test results

The water absorption for all tested series was about 10% and was comparable. No significant impact of the added dust on this feature of the composite was observed.

3.4. Frost resistance

The frost resistance test was carried out on 40×40×160 mm cubes after 28 days of setting. For the determination, 12 cubes were prepared, of which 6 were subjected to 50 freeze-thaw cycles after saturation with water, while the remaining 6 were stored in water until the control strength test. Assessment of frost resistance was based on percentage weight loss and percentage loss of bending and compressive strength. The results are shown in Fig. 9.

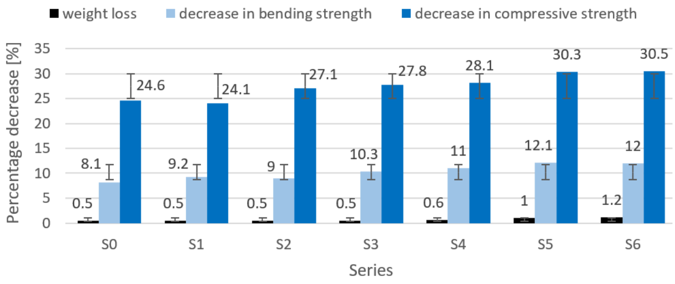

Fig. 9. Mass loss and change in mechanical properties of the composite expressed in % after the frost resistance test

In the weight loss test, as a result of cyclic freezing and thawing, a decrease of 0.5% was obtained for the control series, which was similar for series S1 to S4. For the S5 and S6 series, a greater weight loss was recorded, at 1 and 1.2%, respectively. When assessing the bending strength, a decrease of 8.1% was found in the reference series, which showed an increasing trend with the increased amount of added dust, to a value of 12% for the S6 series. In the case of compressive strength, an upward trend in strength reduction was found, similar to that found for bending strength. In the S0 series, the strength decrease was 24.6% and increased to 30.5% for the S6 series with the highest amount of dust tested.

3.5. Durability in chloride corrosion

Chloride ions rapidly penetrate the cementitious matrix composite, resulting in rapid corrosion progression of the chloride-treated composite. Chloride aggression lowers the pH of the composite and causes the formation of expansive compounds that can cause cracking. The effect of the corrosive environment was simulated in an artificial atmosphere of sprayed salt mist in a corrosion chamber. The salt solution for the test was prepared by dissolving pure sodium chloride in pure water at a weight ratio of 5% sodium chloride to 95% water. The solution was sprayed in the chamber at a temperature of 35°C. The test lasted 48 h and was carried out on three 40×40×160 mm cubes from each batch of composite after 90 days of setting. The stand prepared for testing the durability in chloride corrosion is shown in Fig. 10.

The corrosion resistance of the cubes subjected to the salt mist test at elevated temperatures was assessed through compressive and bending strength tests, comparing them with the strengths of the samples obtained after 90 days of setting.

Fig. 10. Testing the durability in chloride corrosion

The bending strength test of the cubes subjected to salt spray at 35°C compared to the 90-day strength showed an increase in strength in each series (Fig. 11). The effect of this behaviour of the composite could result from the temperature treatment of the specimens but requires microscopic testing to confirm such a claim, especially as no such strength improvement was achieved in the compressive strength test (Fig. 12).

In S0 series, a decrease in the average compressive strength of 17.1% was noted, with increasing amount of dust in the composite mix, the decreases were as follows: S1 series – 16.7%, S2 series – 12.2%, S3 series – 17.1%, S4 series – 10%, S5 series – 7.1%, and S6 series – 15.4%. Figure 13 shows the decrease in strength after testing in the salt mist chamber.

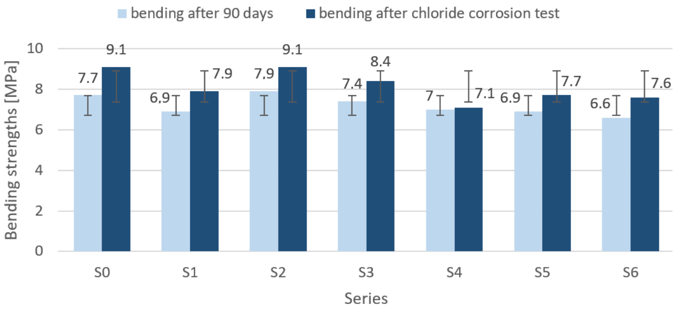

Fig. 11. Average bending strengths of control series and those subjected to salt mist corrosion

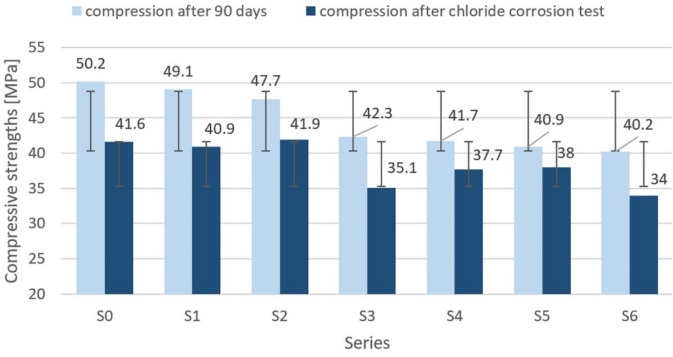

Fig. 12. Average compressive strengths of control series and those subjected to salt mist corrosion

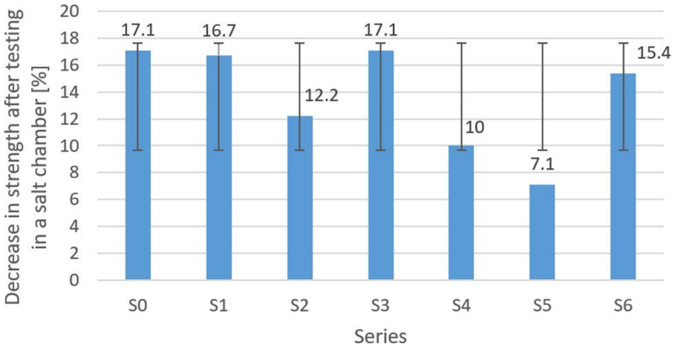

Fig. 13. Decrease in strength after testing in a salt chamber

Between series S0, S1 and S2, a trend of decreasing compressive strength loss can be observed, which was broken by S3 series. In the subsequent series S4 and S5 the decreasing trend returned. In S6 series, another increase in strength loss was recorded, but it should be noted that the decrease was lower than in the reference series.

4. Conclusion

This paper presents the results of a study of the properties and durability of a cementitious matrix composite containing the addition of dust from air purification filters installed at a plant producing plastic construction materials. The study showed that the dust in question can be used in cementitious composites as an additive in small quantities. However, the primary justification for its use lies in environmental considerations, specifically in reducing industrial waste. The key findings from the study are as follows:

- **Consistency:** The addition of dust negatively affects the consistency of the mortar, leading to reduced workability. To maintain proper workability, the use of a superplasticizer is necessary.
- **Water absorption:** The presence of dust had no significant impact on the water absorption of the composite – values remained comparable across all tested series.
- **Mechanical properties:** Increasing the amount of dust resulted in a gradual decrease in both compressive and flexural strength.
- **Durability in chloride corrosion:** In the series exposed to chloride aggression, the addition of dust improved flexural strength. This effect requires further investigation to fully understand the underlying mechanisms. Additionally, compared to the reference series, the samples with added dust exhibited smaller losses in compressive strength after testing in a salt spray chamber.
- **Long-term durability:** In tests carried out from 28 days up to 12 months, samples with dust showed a slight decline in strength during the second half of the curing period. In contrast, the reference series maintained a stable strength level throughout the entire period.

In summary, exploring simple and effective methods for processing and utilizing industrial waste is a crucial part of sustainable development strategies. In the case of dust from air filtration systems used in plastic construction material production, further research and experimentation are necessary to fully confirm its practical applications in building material technologies.

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