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DOI: 10.1515/sspjce-2018-0026

Frost resistance of cement composites prepared on the basis of waste water from a concrete plant

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Abstract

This article presents the results of a research dealing with the use of waste water from concrete industry as a possible substitution of mixing water during the production of cement composites. This experimental research involved the preparation of two recipes of cement composites, named R1 and R3. Mixing water in these recipes was replaced with waste water from a concrete plant in the amount of 25, 50, 75 and 100%. Samples of recycled waste water, which were tested for the content of sulphates, chlorides and alkali according to ČSN EN 1008, were taken in order to determine the properties of waste water from a concrete plant. The prepared test specimens were tested for frost resistance after 100 freezing cycles according to ČSN 73 1322. The results of the frost resistance test showed that the required value of the frost resistance coefficient of 0.75 according to ČSN 73 1322 was achieved only in case of recipe R1 based on Portland cement CEM I 52.5R and 75 and 100% substitution of the mixing water with recycled water from a concrete plant.

Key words: cement composites, sludge water, concrete,

1 Introduction

This article presents the results of frost resistance tests of cement composites prepared on the basis of waste water from a concrete plant. The aim of this research is to find the ideal ratio of pure and sludge water from a concrete plant used as the mixing water so as to preserve or improve the properties of cement composites. Replacing pure mixing water with sludge water from a concrete plant will result in material cost savings of the mixing water. The current trend in the area of building materials is to develop new cement composite materials based on by-products with an emphasis on preserving or improving their properties. A comparative study of long-term sorption behaviour of composite reagent with water and with chemically modified hemp hurds in three samples has confirmed the usability of this material [1]. The study of fungistatic properties and the potential application of fly ash from fluid combustion presumes that the incorporation of fly ash can increase the antimicrobial properties of building materials. The potential applications of fly ash include building industry, i.e. the production of cement mixtures, binders, geopolymers, mortars and concretes [2]. The objectives of sustainable development represent the basic principles of management for the development of innovative materials in building industry. Natural fibres are interesting as an alternative reinforcing material due to their good mechanical properties that can improve the final cohesion of cement composites [3]. The results from the use of glass bottles indicate that glass waste used as aggregate in concrete does not adversely affect the strength properties of cured concrete [4]. The cement production industry has always been dealing with environmental issues. Some cement materials contain heavy metals, which are among the dominant pollutants in building materials with toxic effects on the environment and human health. That is why the cement recipe designing is important in relation to the environment the resulting material will be intended for [5]. For example, the production of a cement mix with antibacterial effects is suitable for applications that are in contact with drinking water. The article of The Modification of Cement Mortar Microstructure: Effects on Capillarity and Frost-Resistance, presents the results of capillary, frost-resistance and microstructure parameter tests for four cement mortars with modified microstructure using superplasticizer, silica, and aeration additives in order to determine their effect on the structure of the sample and the monitored properties. Cyclic freezing and defrosting is one of the worst environmental conditions for the concrete structure [6]. Microstructure characterization using the measurement of pore size distributions is examined before and after the exposure to frost damage by means of porosimetry [7]. The examination of the composite cement materials was also aimed at the following studies. The results of the relative dynamic modulus of elasticity and weight loss tests have shown that the samples of natural and synthetic fibres remain stronger after 300 freezing and defrosting cycles in comparison with the comparative samples. That is why the results of the freezing and defrosting tests have revealed that mixing natural and synthetic fibres with cement composites is highly effective as far as the frost resistance is concerned [8]. An experimental study of The Impact of Cyclic Degradation of Frost on the Sorption of Water from Cement Composites is based on the measurement of water sorption of mixtures made with mineral admixtures with different chemical components after their exposure to cyclic freezing and defrosting in accordance with the standards. The results have shown that the effects of frost up to the end of 150 cycles have caused a decrease of material sorption due to self-healing in microcracks, depending on the composition of the mixture. However, after the following 150 freezing and defrosting cycles, the self-healing effect was worse and the sorption of the material (composite) increased [9]. Other experimental results show that the size and quantitative characteristics of the pores exceeding 0.35 nm in diameter can be obtained by combining these methods of mixture preparation. Since a simple improvement in the degree of strength tends to reduce the porosity, which further increases the volume of empty air and the number of harmful pores in the macroeconomic scale, it does not necessarily contribute to the improvement of the resistance of concrete to frost [10]. The studies also included the effects of the substitution of Portland cement (PC) with magnesium oxide on the properties of mortars based on PC, mortar, and concretes. The research also included a determination of the mechanical properties and frost durability, except for the microstructure study. The replacement of PC with magnesium oxide had adverse effects on the mechanical properties and frost resistance. Magnesium oxide reduces microscopic coupling matrices compared to pastes containing only PC. The interaction of magnesium oxide and PC caused, in addition to compacting of the microstructure, an increase in capillary porosity, resulting in lower frost resistance [11]. Based on the microstructure research, further studies confirm that frost causes damage within the cement paste. The resistance of cement paste to frost is determined by the type of cement and the used components [12]. These studies show that the use of alternative or recycled components for the production of cement composites has positive effect on the final product. However, it is always necessary to determine the acceptable amount of added components in order to obtain the best possible final results.

2 Material and methods

The preparation and determination of the strength of cement composites was carried out according to ČSN EN 196-1 [13]. The cement composites were prepared using waste sludge water generated during the recycling of concrete waste water from a concrete plant according to the requirements of ČSN EN 1008 [14]. The determination of the frost resistance of cement composites was performed according to ČSN 73 1322 [15].

2.1 Designed cement composite recipes

Two recipes named R1 and R3 were designed for the tests of experimental verification of the possibility of replacing mixing water with waste water from a concrete plant in the production of cement composites. The composition of the designed recipes is described in Table 1. The composition of the cement composite mixture complies with the standard requirements. The percentage substitution of sludge water from the amount of pure mixing water was determined in the recipes. The production of the test specimens for compressive and flexural strength tests and frost resistance test was based on a procedure complying with ČSN EN 196-1 [13].
Tab. 1 presents the individual components of R1 and R3 recipes. The substitution of mixing water was performed in both recipes in the percentage amount from pure mixing water. The percentage amounts were: R¼ - 25%, R½ - 50%, R¾ - 75% and (R1) 100% substitution with sludge water.

Table 1: Composition of the designed recipes

Recipe	**R1**					**R3**				
Substitution of mixing water	**K**	**1/4**	**1/2**	**3/4**	**1**	**K**	**1/4**	**1/2**	**3/4**	**1**
Portland cement CEM 52.5 R EN 197-1 [g]	450	450	450	450	450	-	-	-	-	-
Mixed Portland cement CEM II/B-LL 32.5 R EN 197-2 [g]	-	-	-	-	-	450	450	450	450	450
Pure mixing water [g]	225	168,8	112,5	56,3	-	225	168,8	112,5	56,3	-
Sludge water [g]	-	56,25	112,5	168,8	225	-	56,25	112,5	168,8	225
Sand CEN 196-1 [g]	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350

2.2 Properties of pure and mixing water

The mixing water has been tested according to ČSN EN 1008 for the purpose of experimental verification of the possibility of replacing the mixing water with waste water from a concrete plant in the production of cement composites [14]. The resulting water properties are shown in Table 2. It is clear that the standard limits stipulated in ČSN EN 1008 [14] have not been exceeded in the sample of pure mixing water or the sample of sludge water from a concrete plant.

2.3 Determination of frost resistance of cement composites

Test specimens in the form of beams (dimensions of 40x40x160 mm) have been subjected to frost resistance tests with the total number of 100 freezing cycles in accordance with ČSN EN 73 1322 standard [15]. The prepared test specimens were stored in aqueous environment for 28 days. The frost resistance test was performed using KD20 instrument from EKOFROST, s.r.o. company.

2.4 Determination of strength characteristic

Flexural strength and compressive strength tests at the end of the beams have been performed in accordance with ČSN EN 196-3 standard [16]. Flexural strength and compressive strengths were determined on comparative samples after 28 days of aging and on frozen specimens after 100 freezing cycles.
Tab. 2 clearly shows that the monitored analyte of pure and waste water from a concrete plant comply with the concentrations for mixing water as specified in ČSN EN 1008 standard. The tested pure mixing water has complied with all the parameters for use according to the requirements defined in ČSN EN 1008 standard [14]. Furthermore, it is also obvious that the monitored analyte concentrations in waste water from a concrete plant are approximately 20 times higher, for example, in case of sulphates, and almost 13 times higher in case of chlorides when compared to pure mixing water.

Table 2: Mixing water properties

TESTED PROPERTIES	PURE MIXING WATER FROM A CONCRETE PLANT	WASTE WATER FROM A CONCRETE PLANT	LIMIT CONCENTRATIONS ACCORDING TO ČSN EN 1008
pH	6.78	12.45	> 4
Temperature	17.0°C	17.0°C	-
Conductivity	335.10 µS/cm	14.90 µS/cm	-
Humus substances	acceptable	acceptable	paler than yellow-brown
Chlorides	12.30 mg/l	156.5 mg/l	< 600< 2000< 4500 mg/l
Sulphates	40.268 mg/l	875.3 mg/l	< 2000 mg/l
Nitrates	9.4 mg/l	-	< 500 mg/l
$CHSK_{Cr}$	5.236 mg/l	-	- mg/l
Na	31.326 mg/l	135 mg/l	< 1000 mg/l
Pb	0 mg/l	0.1821 mg/l	< 100 mg/l
Zn	0.0655 mg/l	0.0232 mg/l	< 100 mg/l
Ca	33.47 mg/l	1108.5 mg/l	-
Glucose = sucrose	< 100 + < 100 mg/l	< 100 + < 100 mg/l	< 100 + < 100 mg/l

3 Results

3.1 Comparison of flexural strength results

Fig. 1 and 2 present the measured flexural strength values. The testing has revealed a decrease in strength after 100 freezing cycles. The decrease in flexural strength was also measured for the comparison recipe. The beams from R3 recipe have shown visible microcracks and light layering on the surface after the frost resistance test.

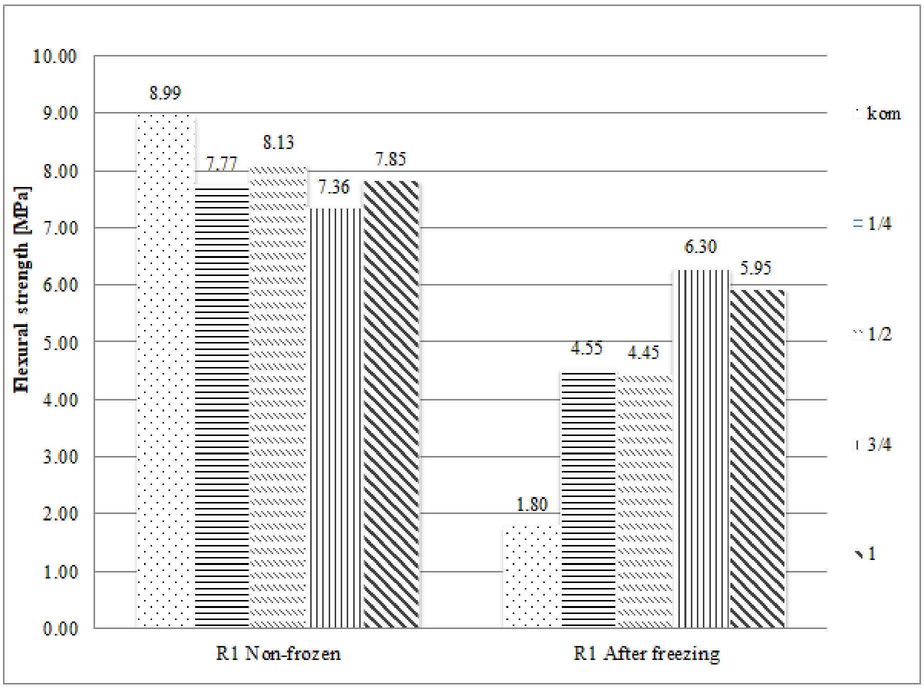

Figure 1: Flexural strength of R1 recipe

The above presented figure comparing the results of flexural strengths of the R1 partial recipes before and after freezing of the samples clearly show that the comparative recipe named R1 kom has the strength values after freezing lower by 80.0% than those of the non-frozen samples. The values of strengths after freezing of R1 ¼ recipe are lower by 41.4% than the values of non-frozen specimens. Additionally, the values of strengths after freezing of the R1 ½ recipe were lower by 45.3% than those of the non-frozen samples. The values of strengths after freezing of R1 ¾ recipe were lower by 14.4% than those of the non-frozen samples, and in case of the last R1 1 recipe, the values of strengths after freezing were 24.2% lower than those of the non-frozen samples of the same recipe.

When comparing the values of flexural strengths of partial recipes R3, see Fig. 2, before and after 100 freezing cycles, it can be seen that the value of flexural strength of comparative recipe R3 kom after freezing is lower by 94.9% compared to the value of flexural strength before freezing. Another recipe R3 ¼ shows a decrease of the value of flexural strength after freezing by 87.6%, while R3 ½ recipe also has the value of flexural strength lower by 73.5%, and in case of R3 ¾, it is by 86.1%, and in case of R3 1 by 62.9%.

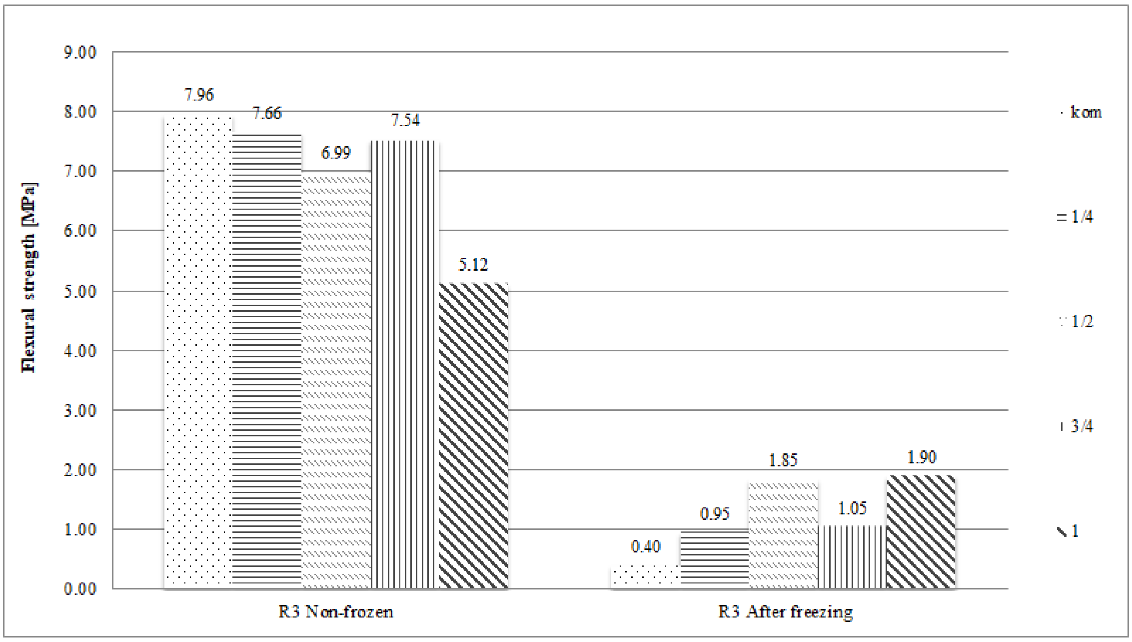

Figure 2: Flexural strengths of R3 recipe

The samples not subjected to freezing cycles had higher values of flexural strengths for both recipes. Fig. 2 clearly shows a significant decrease in flexural strength for the samples subjected to freezing cycles. These results can be affected by the used CEM II / B-LL cement interacting with the substances contained in sludge water. However, it is surprising that even the comparative recipe has shown such a substantial decline in strength. A significant decrease of flexural strength values in case of recipes R1 and R3 after freezing can be explained by a disruption of the internal structure of the frozen test specimens after 100 freezing cycles. In our opinion, the dimensions of the test specimens (40x40x160 mm), which are not in compliance with ČSN EN 73 1322 standard [15], also influence the decrease of flexural strength.

3.2 Comparison of compressive strengths

The tests of compressive strengths of the test beams of R1 and R3 recipes were performed before and after the frost resistance test consisting of 100 freezing cycles. The resulting average values are presented in Fig. 3 and 4.

When comparing the results of compressive strengths of recipe R1, see Fig. 3, before and after freezing, it can be clearly seen that the comparative recipe R1 has achieved the largest drop by 68% compared to the non-frozen recipe. The increase in the strength of recipes R1/2 was in the order of percent, the increase in strength of R3/4 recipes was 10%, and R1 recipe also witnessed an increase of strength of several percent in comparison with the non-frozen samples.

The compressive strengths at the end of beams of recipe 3 are presented in Fig. 4. We have achieved almost ideally lower values of the strength of the comparative specimens after freezing cycles, however, the remaining recipes have shown a slight increase in compressive strength after the freezing cycles. We have reached a conclusion that the flexural strength of the samples is significantly affected when exposed to 100 freezing cycles, while the impact on the compressive strength values is not so significant.

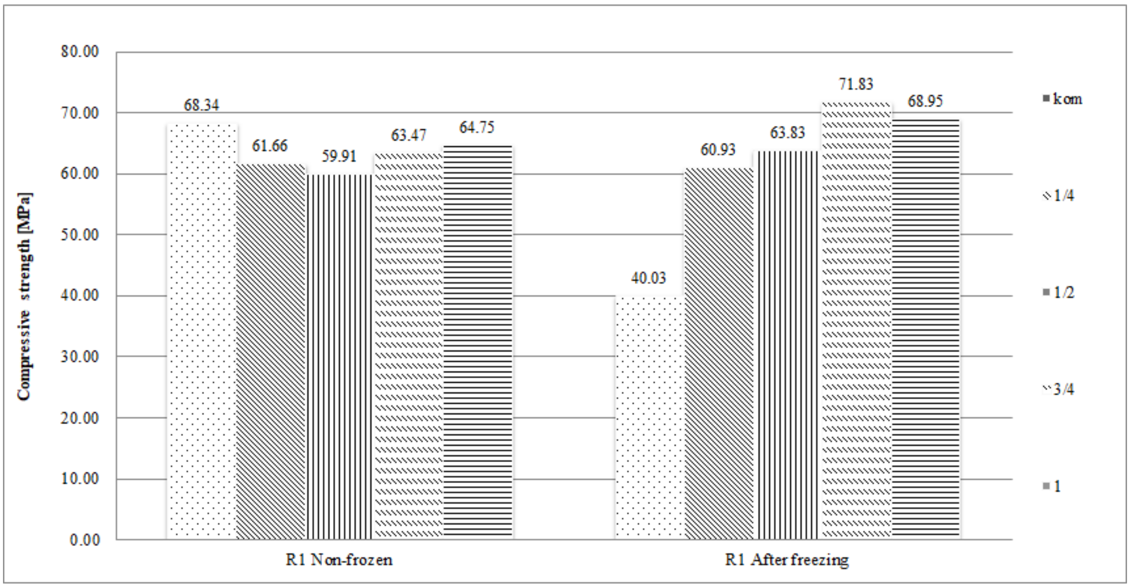

Figure 3: Compressive strengths of recipes R1

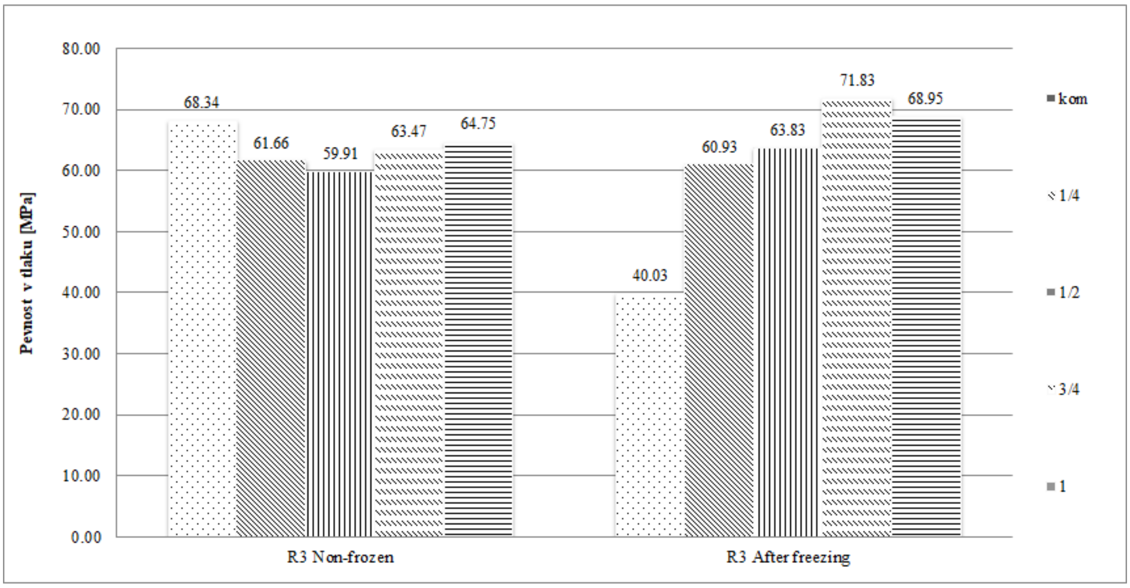

Figure 4: Compressive strengths of recipes R3

3.3 Frost resistance coefficient

The values of frost resistance coefficient of the experimental recipes R1 and R3 of the cement composites are presented in Fig. 5.

The values of frost resistance coefficient have been calculated as the ratio of the arithmetic mean value of the flexural strength of the frozen specimens and the arithmetic mean value of the flexural strength of the comparison beams. The standard says that the samples are frost-resistant for the number of cycles in which the frost resistance coefficient is not below 75% [15]. The figure clearly shows that only two R1 ¾ and R1 1 recipes have met this condition.

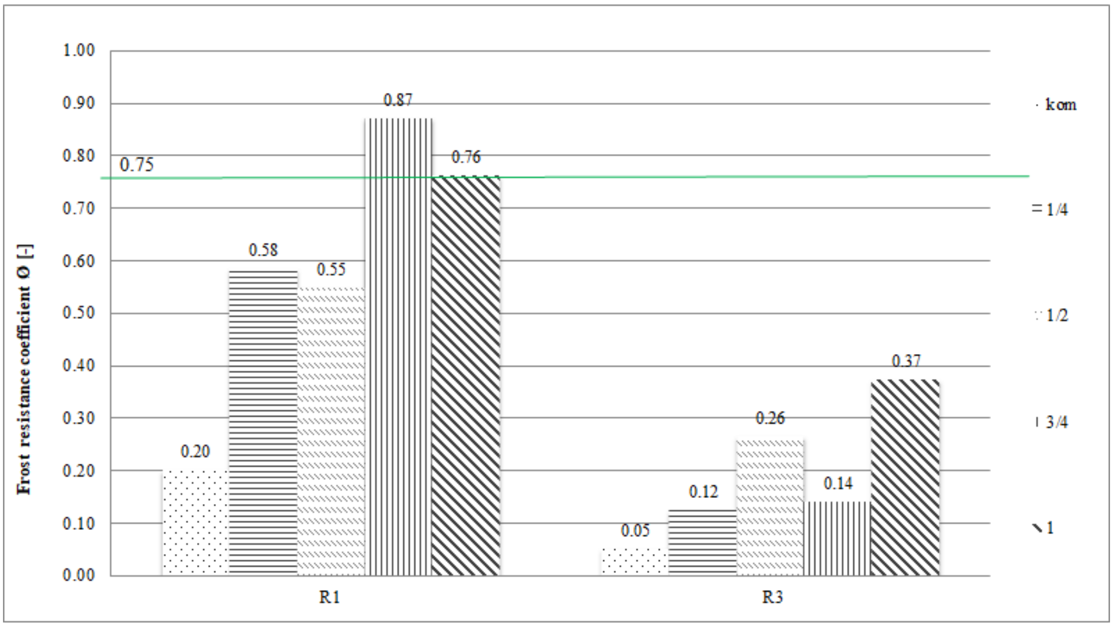

Figure 5: Results of frost resistance tests

4 Conclusion

The results of the frost resistance tests of cement composites prepared on the basis of waste water from a concrete plant as a substitute for pure mixing water have confirmed the possibility of using sludge mixing water in the amount of 75% and 100%, without lowering the water coefficient below 75%, as defined by EN 73 1322 standard [15]. The remaining recipes have not shown frost resistance for 100 freezing cycles. It should be noted that the test specimens in the form of beams with dimensions of 40x40x160 mm do not meet the requirements of EN 73 1322 standard [15]. For further research, we assume the production of test specimens - beams - with the dimensions of 100x100x400 mm from concrete, whose aggregate composition will consist of fractions of 0/4, 4/8, 8/16 mm in the volume ratio of 40:30:30, and will contain substituted sludge water at the same percentage as presented in this article. The reason for the preparation of these test specimens will be to verify whether the dimensions of the test specimens affect the results of the frost resistance tests.

Acknowledgements

This article was written in connection with project SV511889 and project Institute of clean technologies for mining and utilization of raw materials for energy use - Sustainability program. Identification code: LO1406. Project is supported by the National Programme for Sustainability I (2013-2020) financed by the state budget of the Czech Republic.

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