CEST 2021

17th International Conference on Environmental Science and Technology

Athens, Greece, 1 to 4 September 2021

Contribution to low-carbon building industry and improved durability through incorporation of waste into cement composites

ESTOKOVA A.[1*], FIGMIG R.[1] and SINGOVSZKA E.[1]

1Technical University of Kosice, Faculty of Civil Engineering, Institute of environmental engineering, Vysokoskolska 4, Kosice, 042 00, Slovakia

*corresponding author:
e-mail: adriana.estokova@tuke.sk

Abstract By using mineral waste in the production of cement composites, it is possible not only to reduce greenhouse gas emissions and carbon footprint, but by adding secondary waste such as fly ash, silica fume or slag, some properties of the resulting composites are also improved. The waste mentioned are recommended to increase the durability of cement composites against acidic corrosion. The paper presents an examination of the possible positive effects of the mineral waste to improvement of cement pastes resistance against acid rain attack. Exposition of cement pastes to experimental solutions included natural acid rain, laboratory acid rain and deionized water as reference medium during 150 days. Findings revealed that addition of fly ash, silica fume and zeoslag had improved the resistance of cement pastes to acid rain. A positive effect was seen for all additives, but the best results were found for fly ash pastes which achieved the permeability lower than the reference sample by 56 to 70%. Ion penetration testing proved to be a perspective method to estimate the actual behavior of the cement composites in real environment.

Keywords: cement paste, acid rain, fly ash, silica fume

1. Introduction

It is well known that the construction sector produces significant amounts of greenhouse gases emissions and wastes and consumes enormous amounts of primary raw materials (Zhu et al., 2020). However, it also has great potential to reduce these negative environmental impacts by introducing sustainability principles (IPCC, 2007). One way how the construction sector could help mitigate climate change is to pursue low carbon dioxide technologies and materials (Nussholz et al., 2019). The production of cement composites provides space for environmentally friendly approaches by replacing part of the cement with waste and secondary raw materials (Bilal et al., 2020; Jjun et al. 2003). In this way, three sustainability goals are achieved at the same time: the use of waste in accordance with the circular economy, the replacement of high-carbon-emissions cement with lower-carbon materials and, last but not least, increasing the durability of cement composites by strengthening their resistance to long-term aggressive environments (Prajna et al.,2021). Acid rains are an increasingly common dangerous phenomenon, posing a serious threat not only to natural ecotopes but also to degrading inanimate systems such as buildings and equipment (Zeng et al., 2018). Pollutants released from stationary or mobile sources, especially sulfur and nitrogen oxides (SOx, NOx) are converted into sulfuric acid (H_2SO_4) and nitric acid (HNO_3) in the atmosphere, leading to the formation of acid rain. Although the composition of acid rain varies depending on the conditions of its formation, climate and the degree of air pollution, in general the concentrations of sulfate and nitrate anions $SO_4^{2-} > NO_3^- > Cl^-$ predominate while the ammonium cation NH_4^+ is the most represented of the cations (Zabawi et al., 2008).

The objective of the paper was to evaluate the positive effect of waste as cement replacement in cement pastes regarding the pastes resistance against the acid rain attack.

2. Materials and methods

2.1. Studied materials

Four types of cement pastes with the same content of selected wastes were subjected to acid rain resistance testing. Ordinary Portland cement CEM I 42.5 R (CRH Turňa nad Bodvou, Slovakia) without replacement was used in the comparison sample (CP-Ref), other cement pastes contained 15% replacement of cement by silica fume (CP-SF), fly ash (CP-P), and commercially available product with combination of 80% slag and 20% zeolite (CP-ZS). The used mineral admixtures are recommended as to increase the resistance of cement composites in an acidic environment (STN EN; Wang et al., 2016). After demolding, the prepared samples were treated in $Ca(OH)_2$ solution for 28 days and then each sample was labeled, dried to constant weight and weighed. The $Ca(OH)_2$ solution was chosen to prevent leaching of the resulting portlandite, as recommended in ASTM C511 procedure. Various properties were analyzed on cement pastes before and after the experiments: changes in weight and water absorption, penetration of aggressive ions, and pH of the material. To obtain the value of each studied parameter, two samples were tested in each case and the resulting values are presented as average values from two measurements.

2.2. Experimental

The cement pastes were subjected to acid rain attack through static tank testing in experimental solutions. Experimental solutions included: acid rain collected in locality of the eastern Slovakia with pH = 5.6 (NR); laboratory solution simulating the acid rain (LAR), consisted of the sulphuric and nitric acids solutions with pH = 5.6, and as a reference solution, a neutral deionized water (DV). The volume of the solution was 10 times the volume of the immersed samples. The solutions were checked regularly during the experiment and the pH was adjusted to the starting value. The experiment took place over the period of 150 days.

3. Results and discussion

The parameters of cement pastes measured before the corrosion experiment are given in Table 1.

Table 1. Water absorption, ion penetration and pH of cement pastes prior to exposition in model solutions

Parameter	Sample			
	CP-ref	CP-P	CP-ZS	CP-SF
Water absorption (%)	26.9	28.8	28.6	24.9
Ion penetration I-max (A)	0.53	0.60	0.49	0.36
pH	12.8	12.6	12.6	12.6

Based on the measured parameters before the corrosion experiment, the CP-P paste was estimated to be the least resistant against the acid rain attack. The CP-P sample achieved the highest values in water absorption and ion penetration.

The comparison of the measured values of the water absorption and ion penetrations of the cement pastes before and after simulation of acid rain attack are presented in Figures 1-2. The water absorption (WA) values decreased after the acid rain experiment for the CP-ZS and for the CP-ref sample whereas increased for the CP-SF (3.6-4.0%) samples and slightly for CP-P (0.1-0.5%) samples. The decrease in water absorption can be explained by the ongoing hydration processes, which evidently prevailed over the deterioration processes due to acid corrosion. On the opposite, the increase in water absorption could point to the leaching of portlandite (Amenta et a., 2020). However, the water absorption values may not reflect the realistic resistance of the cement pastes, as the cement composites are usually not completely immersed in an aggressive medium. The permeability of the samples to the penetration of aggressive ions appears to be a better parameter.

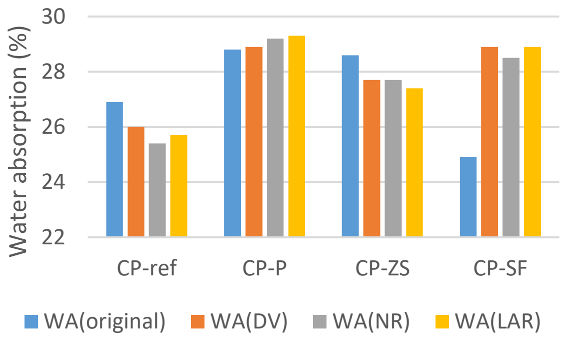

Figure 1. Changes in water absorption

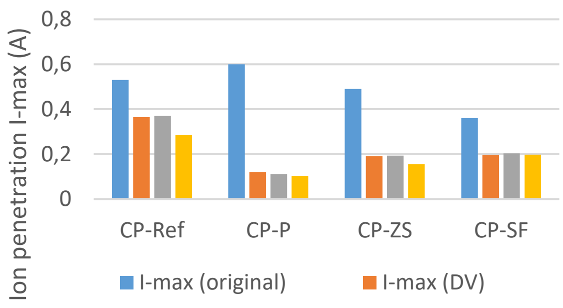

Figure 2. Changes in ion penetration

Maximum values of ion penetration through cement pastes after exposure to acid rain I_{max} were used to compare the effectiveness of added waste in cement paste to resist the acid rain. The values measured for the individual samples were related to the values of the reference sample. The influence of individual additives on the decrease of the permeability of the sample compared to the reference sample is illustrated in Fig. 3. As can be seen in Fig. 3, all cement pastes with incorporated waste showed a positive effect of the admixture in reducing the permeability of the sample compared to the sample without admixture. This positive effect was manifested to an approximately equal extent in the environment of deionized water and natural rain (45-71%). Additives were less effective in laboratory-simulated acid rain, where the effect of reducing the permeability of the paste was in the range of 16-56%. This difference is probably related to the chemical composition of the model solutions. In the case of natural and model rain, despite the same pH value, the content of sulphates was different, and in the case of LAR there was not only acidic but also sulphate corrosion and thus this solution was more aggressive (Estokova et al., 2016). When evaluating the impact of individual additives, it can be stated that the sample with fly ash proved to be the most effective, despite the initial assumptions. Despite the increase in water absorption and ion penetration compared to the initial value, this sample probably had the highest degree of hydration of the cement paste compared to other samples. Cement paste with fly ash achieved the permeability lower than the reference sample by 68, 70 and 56 % in DV, NR and LAR, respectively.

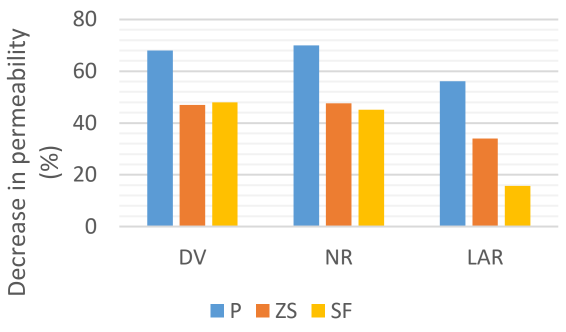

Figure 3. Effect of the additive to the permeability of cement paste

4. Conclusions

The paper presents an examination of positive effect of mineral waste incorporating into cement composites in terms of the increased durability of cement pastes under acid rain attack. The results of the study confirmed that the addition of wastes such as fly ash, silica fume and zeoslag had improved the resistance of cement pastes to acid rain. A positive effect was seen for all additives, but the best results were found for fly ash pastes. To evaluate the effectiveness of added mineral wastes, the approach of comparing the permeability of cement pastes based on measuring the transition of aggressive ions by means of the RCP (rapid chloride penetration) test was used. Ion penetration testing seems to be a perspective method to estimate the actual behavior of the cement composites in real environment.

Incorporating waste in cement and concrete production thus could contribute not only to the better performance of the cement materials in acidic environment but also to reducing the carbon dioxide emissions connected to the building sector.

Acknowledgment

This research was funded by Scientific Grant Agency of the Ministry of Education, science, research and sport of the Slovak Republic and the Slovak Academy of Sciences, grant VEGA 1/0230/21.

References

Amenta M., Karatasios I., Psycharis V., Maravelaki P., Kilikoglou V. (2020), The leaching mechanism of hydraulic mortars as part of autogenic self-healing process, *Journal of Cultural Heritage*, **46**, 1-10.

Bilal M., Khan K.I.A., Thaheem M.J., Nasir A.R. (2020), Current state and barriers to the circular economy in the building sector: Towards a mitigation framework, *Journal of Cleaner Production*, **276**, 123250.

Estokova A., Kovalcikova M., Luptakova A., Prascakova M. (2016), Testing Silica Fume-Based Concrete Composites under Chemical and Microbiological Sulfate Attacks, *Materials*, **9**, 324.

IPCC (2007), Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nußholz J.L.K., Rasmussen F.N., Milios L. (2019), Circular building materials: Carbon saving potential and the role of business model innovation and public policy, *Resources, Conservation and Recycling*, **141**, 308-316.

Prajna S.P., Anjum M.I., Lakshmi P.S., Gayathri G., Beulah M., Sudhir M.R. (2021), A comprehensive investigation of the effect of mineral additives to bituminous concrete, *Materials Today: Proceedings*, in press.

STN EN 206+A:2017-05 (2017), Concrete. Specification, performance, production and conformity (in Slovak); Slovak Institute of Technical Standardization: Bratislava, Slovakia.

Wang, Z., Song, Y., 2016. Adsorption properties of CFBC ash–cement pastes as compared with PCC fly ash–cement pastes. *International Journal of Coal Science & Technology*, **3**, 62–67.

Yajun, J. Cahyadi, J.H. (2003), Effects of densified silica fume on microstructure and compressive strength of blended cement pastes, *Cement and Concrete Research*, **33**, 1543-1548.

Zabawi A.G.M., Esa S.M., Leong C.P. (2008), Effects of simulated acid rain on germination and growth of rice plant, *Journal of tropical agriculture and food science*, **36**, 1-6.

Zeng, X., Li, Y., Ran, Y., Yang, K., Qu, F., Wang, P. (2018), Deterioration mechanism of CA mortar due to simulated acid rain. *Construction and Building Materials*, **168**, 1008–1015.

Zhu W., Feng W., Li X., Zhang Z. (2020), Analysis of the embodied carbon dioxide in the building sector: A case of China, *Journal of Cleaner Production*, **269**, 122438.