Effect of Si-Based Waste Material on the Final Mechanical Properties of Cement Pastes

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Abstract: The article focusses on the effects of waste Si-based material on the mechanical properties of the resulting cement pastes. In this study we use Portland cement CEM I 42.5R and Si-based waste materials from the packaging industry from Recifa, a.s. The difference between individual samples was in the concentration of Si-based materials. We investigate the influence of five different amounts of SiO_2-based materials, namely, 10 wt. %, 20 wt. %, 30 wt. %, 40 wt. % and 50 wt. %. The determined mechanical properties were compressive and flexural strengths. Mechanical properties were investigated in 7 and 28 day samples with dimensions equal to 40 × 40 × 160 mm. The results showed a negative effect of Si-based materials on mechanical properties.

Keywords: Waste Si-based materials; Cement pastes; Mechanical properties

1 Introduction

Sustainability of concrete depends on its composition and origin of its components, being in general a binder, and fillers. Depletion of these natural resources hinders the sustainability of concrete structures. One of the possible strategies to mitigate the environmental impacts of concrete production is replacing quarried fillers with construction and demolition waste (CDW). The efficient utilization of CDW has become a major topic of research in civil engineering during the last decade [1]. The incorporation of larger CDW pieces (mostly aggregates, masonry, asphalt pavement, glass) has become a common practice in the construction industry, but the utilization of subsieve fractions (<0.250 mm) of silicon (Si) based materials has not been established despite the common use of microfillers, such as microsilica [2]. Si-based waste is one of the major environmental problems worldwide, because glass can be taken as non-biodegradable, when landfilled can trigger severe environmental pollution, and large deposits are not economically feasible. From the point of view of origin, it is further divided into packaging waste industry, construction industry, automotive industry, energy industry, etc. Each source brings with it different sources of micro-level additives and impurities that are likely to react in cement composites.

The use of waste Si-based materials as alternative fillers to concrete have attract interest of different researchers. However, when added in relevant amounts, the addition of these secondary materials is associated with deterioration of mechanical strength due to the formation of ITZ [3]. It turned out that more than 20 wt.% replacements of raw materials with the Si-based secondary fillers are not suitable for cementitious composites [4]. Smaller amounts are sufficient to fill pores [5] while disrupting the microstructure due to the formation of ITZs at an acceptable level. Waste Si-based materials are not optimal – their specific surface is relatively large, multiplying the negative effects. But the effects are always hard to estimate or predict, since micro-level additives exhibit complex interactions with the grains of binder, that are often larger and become coated by the filler particles. The ITZs usually formed due to transport of chemical elements [6, 7].

The present paper describes the basic effects of Si-based waste materials on a pure cement paste formed from Portland clinker cement.

2 Materials and samples

The test samples were composed of Portland cement CEM I 42.5R (Heidelberg Cement Czechia - Radotín) and different amounts of waste silica (SiO_2), which comes from waste materials from the packaging industry from Recifa, a.s. CEM I 42.5R had grain sizes up to 180 microns and contained large amounts of allite (C_3S) 74.6% and smaller amounts of other clinker minerals (C_2S 7.2%, C_3A 8.1%, C_4AF 8.5%). In contrast, the waste silica had a grain size of up to 80 microns, and therefore, the effect on the workability of the fresh mixture was investigated. Five concentrations of SiO_2 were tested: 10 wt. %, 20 wt. %, 30 wt. %, 40 wt. % and 50 wt. %. The samples were compared with reference samples composed of Portland cement only.

The amount of water was the same in all mixtures. The experiment investigated the possibility of substituting cement. Therefore, the water to binder ratio (w/b) was the same in all fresh mixes at 0.35. Compared to that, the water to cement (w/c) ratio varies from 0.37 to 0.7. The workability of the fresh mixtures was determined by flow table test during the sample production. The composition of individual mixes and the workability of fresh mixtures can be seen in Tab 1. Each set consisted of 6 samples with dimensions equal to 40 × 40 × 160 mm. The next day after production, the test samples were demoulded and stored in a water bath at temperature of 22±5 °C.

Table 1. Composition of the testing samples.

Set	CEM I 42.5R [kg]	SiO_2 [kg]	Water [kg]	Water/cement ratio [-]	Flow test [mm]
REF	3.0	0.0	1.05	0.35	205±5
S10	2.7	0.3	1.05	0.39	210±5
S20	2.4	0.6	1.05	0.44	205±10
S30	2.1	0.9	1.05	0.50	215±1
S40	1.8	1.2	1.05	0.58	205±1
S50	1.5	1.5	1.05	0.7	195±5

3 Experimental methods

Flexural and the compressive strengths were determined using the Web Tiv Ravestein devices on 7- and 28-days old samples. The resulting value was determined as the average of values excluding the lowest and highest values, and the standard deviation was determined.

The flexural strength was determined by a three-point bending test. The test is performed on a beam with dimensions of 40 × 40 × 160 mm supported on two supports 100 mm apart, which is loaded by force in the centre of the beam. Flexural strength was determined from the relationship between the maximum force achieved and the dimensions of the beam at the fracture point. Three samples of each mixture were tested. The testing was displacement controlled at a constant rate of 1 mm/min.

The compressive strength was determined by uniaxial compressive test on the half samples with dimensions of 40 × 40 × about 80 mm (broken parts of samples after bending test). The

loading area was 40 × 40 mm. Six samples of each mix were tested. The testing was displacement controlled at a constant rate of 5 mm/min.

4 Results and discussion

The results show the effect of waste Si-based materials on the flexural strength (Fig. 1) and the compressive strength (Fig. 2) of cement pastes. The results show the negative effect of SiO_2 waste on the seven-day flexural strength and compressive strength of cement pastes. In the case of 7-day strengths 50 wt. % SiO_2, there was a decrease of 33 % in flexural strength and 58 % in compressive strength compared to the reference sample.

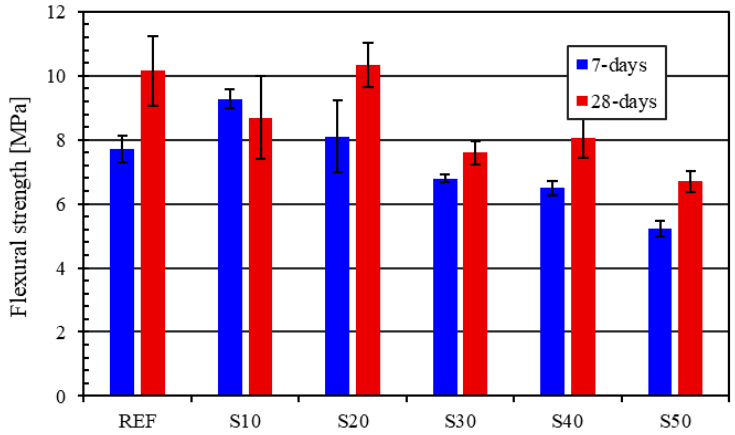

Fig. 1 Comparison of flexural strength (with standard deviations).

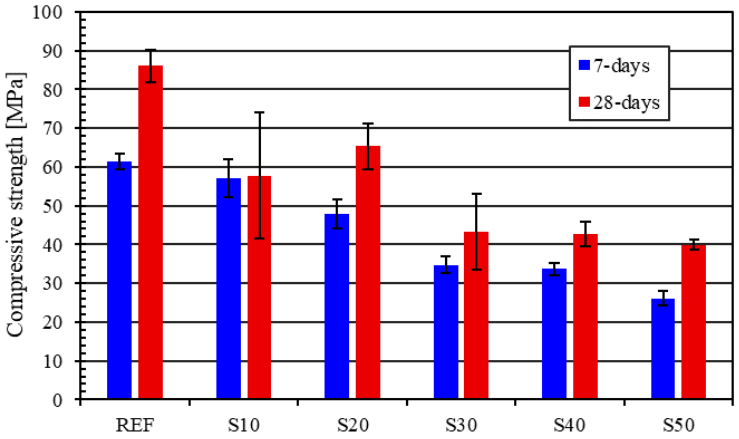

Fig. 2 Comparison of compressive strength (with standard deviations).

In the case of 28-day strengths, the difference in values is the same as in the case of 7-day strengths (flexural strength decreased by 34 %, compressive strength decreased by 54 %), which shows that the waste Si-based materials fulfills the function of a filler and does not participate in hydration [8].

Conclusions

This work was focused on the effects of waste Si-based materials on mechanical properties of resulting cement pastes. The tested samples were composed of Portland cement CEM I

42.5R and waste SiO_2 materials from the packaging industry from Recifa, a.s. The difference between individual samples was in the concentration of SiO_2. Based on the results, it can be concluded that the introduction of inert SiO_2 results in a less compact structure of cement pastes, leading to deterioration of the flexural strength and the compressive strength. A linear dependence of the decrease in strength with increasing amount of SiO_2 can be seen.

In the future, the research will focus on confirming effects of waste Si-based materials from the packaging industry on mechanical properties of cement pastes by using scanning electron microscope with X-ray microanalysis by confirms the inert effect of waste SiO_2 from the packaging industry on the phase composition of the composite.

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