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Influence of Different Admixtures on Hydration Process and Mechanical Properties of Cement Paste

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Abstract. Sustainable developments requires massive use of recycled materials but recycling of fines part of cementitious materials, which mostly composed of cement paste, proves to be very complicated. Therefore reactive properties of recycled concrete powder due to presence of non-hydrated cement grains are investigated. To eliminate influence of larger nucleation area (caused by presence of fine particles) on hydration process the inert micro-milled silica sand was used to comparison. Calorimetric measurement proves the presence of exposed non-hydrated particles in recycled concrete powder that can react again. But lower density of old cement paste in RCP overweight the mentioned potential of recycled concrete powder and mechanical properties are decreased compared with reference cement paste and cement paste with micro milled silica sand.

Introduction

Sustainable developments requires massive use of recycled materials. Due to high consumption of cementitious materials in construction is necessary to focus on complete recycling of it. Recycling process of fines part of cementitious materials, which mostly composed of cement paste, proves to be very complicated. In previous papers where the recycled concrete powder (RCP) is used as partial cement replacement and microfiller the reactivity and hydration properties are examine [1,2]. The aim of this paper is to compare hydration and mechanical properties of RCP with inert filler with similar granulometric curve. Micro-milled silica sand was chosen to comparison. Due to his crystalline character, the pozzolanic activity of SiO_2 should be minimal compared with amorphous SiO_2, which is used as reactive additive [3,4]. Thanks to this comparison, the possible binder properties of RCP could be highlighted.

Measurement of heat flow during hydration were supplement by testing of mechanical properties. This results should be helpful to understand influences of changes in hydration process on final mechanical properties of cement paste with different admixtures.

Materials and Samples

The Portland cement CEM I 42.5 used in this experiment was produced in Radotín (Czech Republic). Old railway sleepers of type PB2 and SB8 were used to produce recycled concrete powder (RCP) by high speed mill from LAVARIS Ltd. As micro-milled silica sand (MSS) was used product ST2 from company Sklopísek Střeleč, Inc.

For calorimetric measurement, three different mixtures were made. First mixture (denote as CEM) was reference cement past. Second mixture (denote as CEM+RCP 50) contained 50 % of cement and 50 % of RCP and third mixture (denote as CEM+MSS 50) contained 50 % of cement and 50 % of MSS. For this measurement had those three samples same water/mixture ratio equal to 0.45.

One reference cement paste without any admixture and four mixtures with different admixtures were made for measurement of mechanical properties. Two mixtures contain cement with 10 and 50 % of recycled concrete powder. Last two mixtures contain cement with 10 and 50 % of micro-milled silica sand. Mixtures had different water/mixture ratio from 0.35 to 0.40 to compensate the deteriorated workability caused by increasing amount of RCP and MSS. Composition of the samples is shown in Table 1. Each set contained 6 prismatic samples having dimensions of 40 × 40 × 160 mm. The samples were removed from their casts after 2 days. After that the samples were cured for 28 days in water at the temperature of 21 ± 2 °C.

Tab. 1: Composition of the tested samples.

Mixture	Cement [g] (CEM I 42.5 R)	Recycled concrete powder (RCP) [g]	Micro-milled silica sand (MSS) [g]	Water/mixture ratio
CEM (ref)	1500	-	-	0.35
CEM+RCP 10	1350	150	-	0.36
CEM+RCP 50	750	750	-	0.40
CEM+MSS 10	1350	-	150	0.36
CEM+MSS 50	750	-	750	0.40

Experimental methods

Calorimetric measurement was conducted on an isothermal TAM Air calorimeter for measurement of heat flow. Mixtures were tested for 7 days at a constant temperature of 20 °C and were stored in sealable plastic containers, each containing from 32 g to 36 g of mixture. Based on the weight of each sample (measured before testing) the results of the heat flow were related to 1 g of cement for a better detection of changes caused by admixtures.

Dynamic Young's modulus were monitored by using the non-destructive resonance method. This method is based on measuring the natural frequency of the prismatic 40 × 40 × 160 mm samples. For evaluation of dynamic Young's modulus the basic longitudinal and flexural natural frequency, dimension and weight of the samples were used.

Flexural and compressive strength were determined on 28 day old samples using a model FP100 Heckert device. The testing was displacement controlled at a constant rate of 0.1 mm/s in the case of three-point bending and 0.3 mm/s during the compression test.

Experimental results

Results of calorimetric measurement are shown in Fig. 1. By relating heat flow to 1 g of cement and not an entire RCP or MSS mixture it was possible to highlight differences in the hydration process caused by RCP. In case of mixture CEM+MSS 50 the increase of heat flow compared with reference cement is caused by larger nucleation area due to MSS addition. Increase of heat flow of mixture CEM+RCP 50 is partly (as CEM +MSS 50) caused by larger nucleation area, but mostly by presents of non-hydrated cement grains in RCP. Increase of heat flow of mixture with RCP compared with mixture CEM proves that exposed cement grains in RCP can react again and comparison with CEM+MSS 50 proves that increase of heat flow wasn't caused only by larger nucleation area.

Bulk density of the samples was measured before dynamic Young's modulus testing. Reference cement samples had bulk density 1919 ± 9 kg/m^3. Bulk density of the samples with 10 % RCP was 1851 ± 1 kg/m^3 and with 50 % of RCP was 1566 ± 3 kg/m^3. Bulk density of the samples with 10 % MSS was 2026 ± 11 kg/m^3 and with 50 % of MSS was 1964 ± 3 kg/m^3.

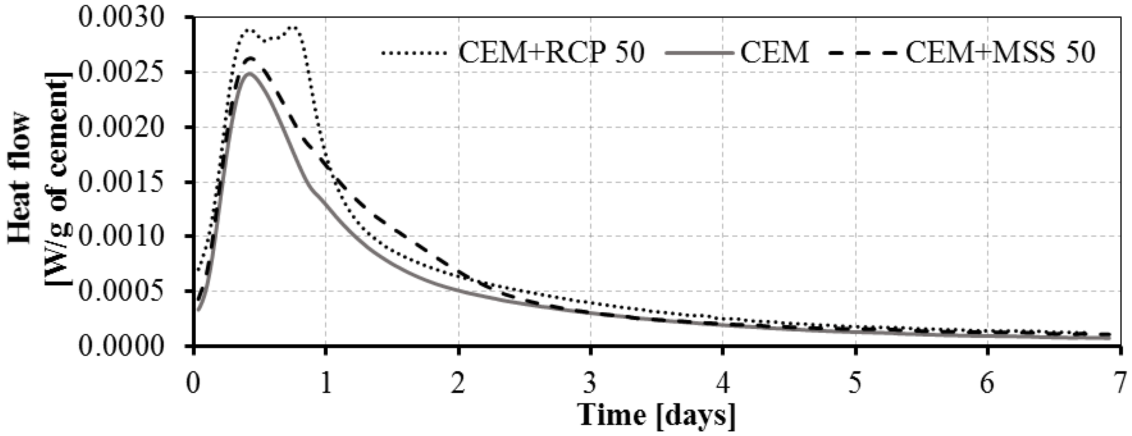

Fig. 1: Heat flow of cement paste and cement with 50 wt. % of recycled concrete powder (CEM+RCP) and micro-milled silica sand (CEM+MSS).

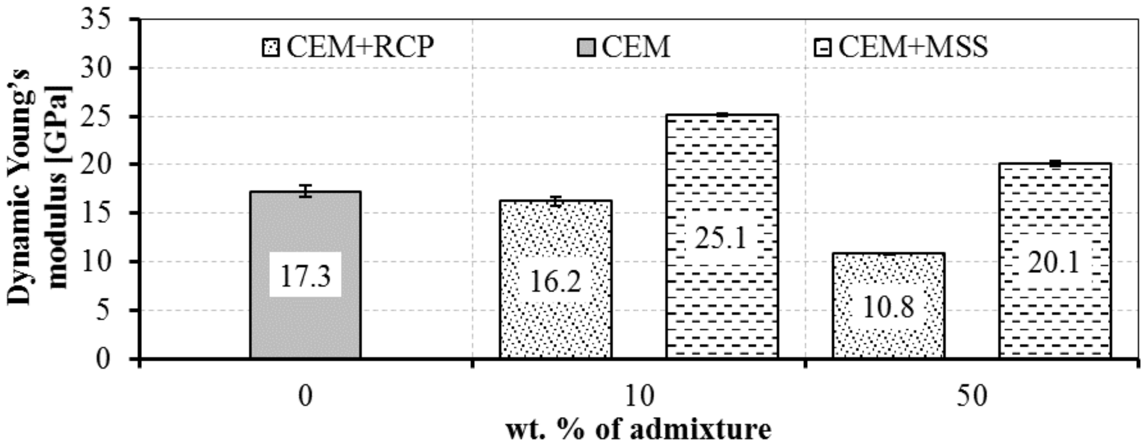

Fig. 2: Dynamic Young's modulus of cement paste and cement with 10 and 50 wt. % of recycled concrete powder (CEM+RCP) and micro-milled silica sand (CEM+MSS).

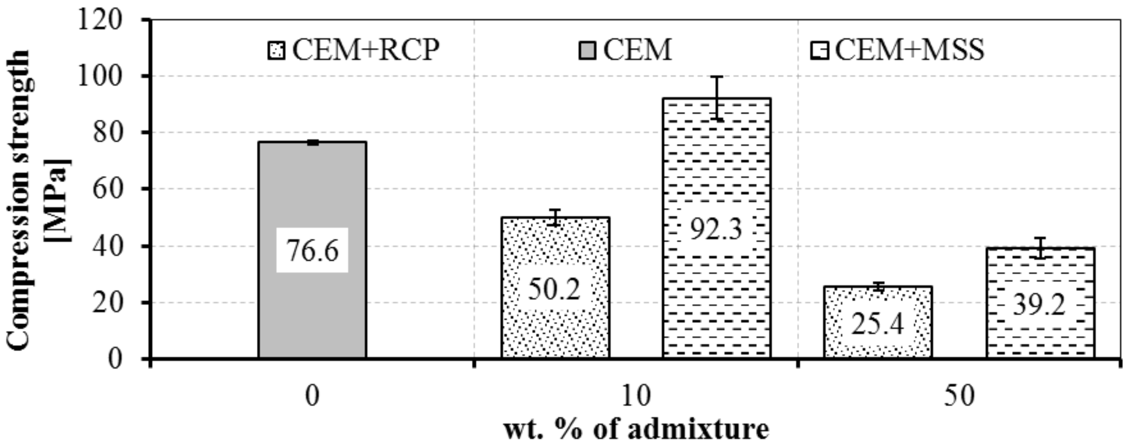

Fig. 3: Compression strength of cement paste and cement paste with 10 and 50 wt. % of recycled concrete powder (CEM+RCP) and micro-milled silica sand (CEM+MSS).

Dynamic Young's modulus of the samples illustrated in Fig. 2 and compression strength illustrated in Fig. 3 are proportional to bulk density. As can be seen, the mechanical properties of samples with RCP are despite the hydration of cement grains in RCP decreased compared with other samples. This decrease is probably caused by lower density of old cement paste in RCP compared with MSS and new hydration products.

Based on this results, the potential improvements of mechanical properties could be achieved by using small amount of RCP in cement mortars or concrete where aggregate is present. In this combination, the RCP would be fulfills the role of micro filler and partially the role of binder and lower density of RCP would not be obstacle as in case of cement paste. Those experiments will follows in further research.

Conclusions

This paper is focused on hydration and mechanical properties of cement paste with addition of RCP (filler and possible binder replacement) and MSS (inert filler). Based on results the following findings are summarized:

- Based on heat flow during hydration process, the presence of exposed non-hydrated cement grains in RCP has been proved and influence of larger nucleation area was define as minimal thanks to comparison with influence of MSS.
- Despite the additional hydration of cement grains in RCP, the mechanical properties of cement paste with RCP were negatively influenced by lower density of cement paste in RCP compared with MSS and new hydration products.
- Probably only solution how micro filler and binder properties of RCP could be utilized to improve the mechanical properties is combination of small amount of RCP with cement composites where aggregate is present. Then the RCP would be fulfills the role of micro filler and partially the role of binder and lower density of RCP would not be obstacle.

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