EAN 2018
56th conference on experimental stress analysis

Effect of Cement/Water Ratio on Mechanical Properties of Cement Pastes Containing Recycled Micronized Concrete Powder and Chemical Additives

TESÁREK Pavel[1,a], PROŠEK Zdeněk[1,b], RYPAROVÁ Pavla[1,c], HRŮZA Jaromír[1,d], NEŽERKA Václav[1,e] and FLÁDR Josef[1,f]

[1] Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague, Czech Republic

[a]tesarek@fsv.cvut.cz, [b]zdenek.prosek@fsv.cvut.cz, [c]pavla.ryparova@fsv.cvut.cz, [d]jaromir.hruza@fsv.cvut.cz, [e]vaclav.nezerka@fsv.cvut.cz, [f]josef.fladr@fsv.cvut.cz

Keywords: Micronized Recycled Concrete, Water/Cement Ratio, Recycling, Cement Pastes, Mechanical Properties.

Abstract. Cement pastes containing recycled concrete powder (RCP) from an old road drainage channel in 3/2 weight ratio were prepared and their basic and mechanical properties macroscopically tested. These were in particular composed of standard Portland cement CEM I 42.5 R (locality Radotín, Czech Republic), a micronized road drainage channel, and additives to improve workability. Namely, we used one plasticizer and two different solidification accelerators. The main goal of this research was to reduce the amount of kneading water while ensuring sufficient workability of the fresh cement pastes. The performance of individual additives was assessed in terms of selected material parameters as bulk density, being an indicator of weathering resistance and durability, and mechanical strength (compressive strength and bending strength) of hardened 28 days old specimens. To that purpose, a comparison with the reference, untreated pure cementitious paste, was done. The results indicate that additives should assist the production RCP-rich cementitious composites to avoid compromising their mechanical performance.

Introduction

Incorporation of recycled cement powder (RCP) into fresh concrete mixes leads to higher demands on kneading water and the higher water-to-cement ratio (*w/c*), resulting in deterioration of mechanical properties. However, methods to reduce the needed amount of water in fresh concrete exist. Soares et al. [1] investigated two types of aggregate to – natural and recycled of high quality. The concrete mixture containing recycled aggregate was modified by plastificators or superplastificators. It was shown that such a modified mix exhibited up to 40 % higher compressive strength, compared to a reference mix. The *w/c* resulted in the formation of a matrix having higher density, rendering the mix more durable and less susceptible to weathering. Pereira et al. [2] designed several concrete mixes with concrete recycled aggregate and outlined a self-cleaning system for such aggregates. They found that newly make the concrete with such a recycled aggregate exhibited the same mechanical compressive strength and mechanical strength as one with natural (extracted/quarry) aggregate. Çakır [3] modified properties of concrete mixes with the use of natural and recycled aggregate with other additives, such as microsilica or slag. To improve workability and reduce the amount of kneading water in the fresh mix, he used superplastificator. Some specimens containing recycled components exhibited better durability than those containing only natural aggregate. However, their mechanical strength was compromised. The same effect as plastificators or superplastificators can also have a micronized marble or rock powder. However, the upper limit of applications is 10 % of weight additions, since higher amounts have a negative effect on mechanical properties of the cementitious composites [4, 5]. These findings and outcomes of other studies were exploited when designing the cementitious mixes with micronized concrete recycled materials for applications in the construction industry in different ways, e.g., as interior or exterior plasters, masonry blocks or pastes [6, 7, 8].

Materials and Samples

Pastes made of Portland cement (C) or Portland cement with RCP mixed were prepared. The cement CEM I 42.5R was produced in Radotín, Czech Republic, while RCP was prepared by micronizing an old road drainage channel. A high-speed mill manufactured by LAVARIS Ltd. was used for micronizing. To enhance the properties of the pastes containing RCP, we used one plasticizer (P3) and two distinct solidification accelerators (U1 and U2). These additives were carefully chosen from 3 distinct plastificators / superplastificators and three distinct accelerators of hardening – these acts also as plastifying agents.

The experimental samples were denoted by the code name "XX YY," which included a type of a binder, respectively samples with and without the micronized concrete material (RCP), and type of used additives. The samples with cement CEM I 42.5R without RCP were denoted as "C" and ones with cement and RCP with a weight ratio 60/40 (cement/RCP) were denoted as "CR." These both materials were used as reference material, and they contained no additives. The water/cement ratio for samples C was 0.29 and for CR was 0.31, a higher ratio of water/cement for sample CR is due to added RCP. Other samples contained additives. The water/cement ratio for samples CU1 and CU2 was 0.29; both samples contained added additives, in this case, 1.5 wt. % of solidification accelerators from the cement of cement/RCP. The water/cement ratio for samples CRU1 and CRU2 was 0.31; both samples contained the same values od additive as CU1 and CU2. For samples, CP3 and CRP3 with plasticizer were the reduced water/cement ratio 0.21, respectively 0.25. Amount of additives (g) was 1.0 wt. %. Values of bulk density depended on added RCP and a type of used additives; the higher values were achieved for samples without RCP, namely 2054 ± 28 kg/m^3 for CP3. For other samples from this group were the values in a ranking from 1923 ± 31 to 1962 ± 22 kg/m^3. The bulk density of the sample with cement and RCP was 1749 ± 28 to 1768 ± 18 kg/m^3.

Experimental Methods and Results

The six prismatic 40×40×160 mm specimens were prepared to represent each sample. The specimens were stored at standard laboratory conditions with temperature 22 ± 1 ° C and relative humidity 50 ± 2 %. The 28-days old specimens were tested.

Bulk density was calculated from the measured dimensions and weight of the individual samples, resulting values were averaged from six specimens. Compressive strength was calculated from the contact stress on measured samples, where the load area of the press has dimensions of 40 × 40 mm. From the resulting force and contact stress on the samples, the compressive stresses in the samples were calculated. Twelve samples (12 sample halves) were tested for each set. The bending strength, three-point configuration, was calculated from the exact dimensions of each sample measured immediately before the destructive test. The strength is calculated from a linear dependence of the bending moments, which are based on the strength at the breach limit, and the section modulus, which is based on accurately measured dimensions of the samples.

Comparison of bending and compressive strengths is presented in Figure 1, including standard deviations of the measured values. From the obtained results it is obvious that the plasticizer P3 has a positive impact on bending strength when compared to the reference cement paste samples without any additives. The effect of the solidification accelerators was found similar. There was a slight increase in bending strength compared to the reference mix. On the other hand, the increase of compressive strength was observed only in the case of plastificators; the use of accelerators resulted in 50% reduction of compressive strength compared to the reference mix.

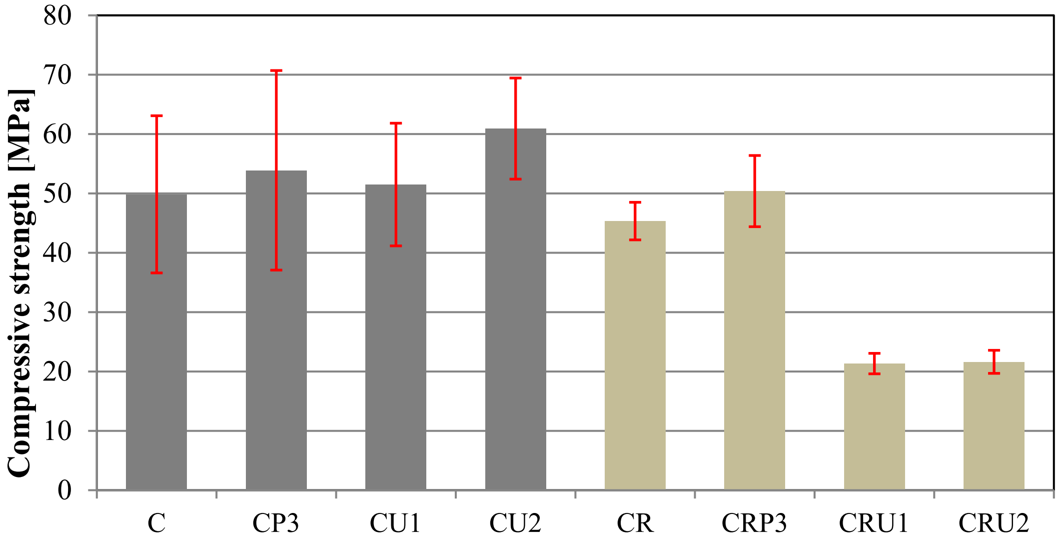

Fig.1 Comparison of bending strength (with indicators of standard deviations)

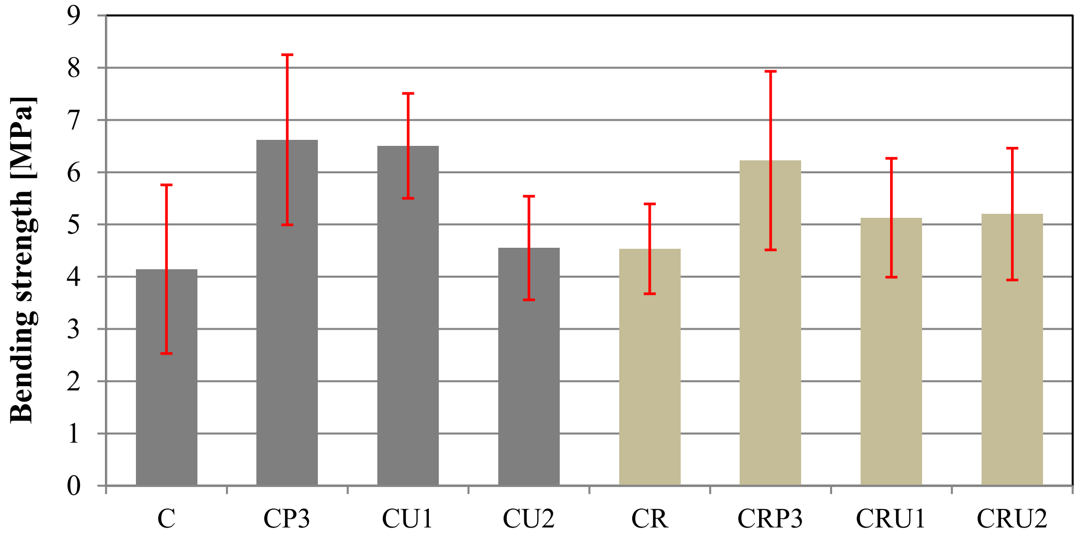

Fig.2 Comparison of bending strength (with indicators of standard deviations)

Conclusions

The results indicate the RCP can be efficiently utilized in the production of concrete, making the concrete construction more sustainable. However, agents improving the workability of the mixes must be used to minimize the needed amount of kneading water. The agents must be selected carefully. The use of suitable plastificators results in a significant reduction of *w/*c, making the cementitious matrix denser and the composite stronger. This is reflected mainly in bending strength. The following research will be focused on the study of the microstructure. To that purpose, scanning electron microscopy combined with nanoindentation will be addressed. Such approach will allow establishing the impact of micronized concrete on macroscopic properties of the cementitious composites [9, 10].

The presented results will be used for calibration of a new micromechanical model. A comprehensive study will be consisting of a microstructure investigation, nanoindentation, and micromechanical modeling was performed to identify phases and assess their impact on macroscopic properties of cement pastes containing waste marble powder. The proposed model, built on the Mori-Tanaka scheme, will be used to estimate the effective Young's modulus and compressive strength at a low computational cost. After model validation, the effects of an interfacial transition zone (ITZ) and increased porosity of marble powder rich-pastes were quantified. The study revealed a fundamental role of the ITZ formed around stiff marble powder inclusions, responsible for performance deterioration. These findings indicate that elimination of the ITZ and reduction of porosity would considerably enhance the strength of cement-based materials containing waste marble powder. As a consequence, larger amounts of waste marble could be incorporated as a cement replacement without sacrificing structural performance.

Acknowledgment

This research was supported by the GA ČR research a project under the number 17-06771S and by Czech Technical University in Prague – project under the number SGS16/201/OHK1/3T/11. The authors thank the Center for Nanotechnology in Civil Engineering at the Faculty of Civil Engineering CTU in Prague, and LAVARIS Ltd for providing the micronized concrete.

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