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Micromechanical Characterization and Modelling of Recycled Concrete

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Abstract. The purpose of this contribution is to outline a basic framework of identification of phases, determination of elastic properties, and micromechanical modeling of cementitious composites based on recycled concrete. It was found that micromechanical modelling can help to understand the role of individual phases, establish relationships between input materials and effective properties of the hardened composites, and assess the impact of individual phases.

Introduction

During the past century, concrete became the most widely used construction material [1]. The production of Portland cement is energetically very demanding [2] and largely contributes to the global CO_2 emissions [3, 4]. For that reason, combined with economic benefits, the partial substitution of cement with recycled reactivated concrete is very appealing. The effect of such recycling would be twofold as the use of the disposed of material would also help to reduce waste production. In the Czech Republic alone, over 23 million tons of concrete were disposed of in 2012, while European Union produced over 2.5 billion tons of concrete waste.

To maximize the incorporation of the recycled material into newly produced mixes, one has to understand the mechanisms and consequences. If, e.g., some minor component of the disposed of material appears to deteriorate mechanical strength or durability of the newly produced concrete, it can be eliminated or modified.

To investigate the behavior of the reactivated particles at the microscale, grid indentation and scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM, EDX) were employed. Also, we formulated a simple micromechanical model based on Mori-Tanaka scheme, validated by macroscopic measurements.

The individual components of the recycled concrete can deteriorate, but also enhance the properties of the newly produced composites in two ways. First, fine powder can act as an inert micro-filler that contributes to the reduction of porosity and supporting agent for clinker hydration. Second, the non-hydrated phases can further contribute to the matrix strengthening. These mechanisms were revealed recently by Chen et al. [6] or Kim et al. [7].

Materials and Experimental Methods

An epoxy resin bonded samples of finely ground old concrete from disposed of railway sleepers. Such an approach allowed polishing, microscopy investigation, and consequent nanoindentation.

The Scanning Electron Microscopy (SEM) was accomplished using a MIRA II LMU (Tescan corp., Brno) microscope. The chemical composition of each phase characterized by a distinct level of grayscale (Fig. 1). The micrographs were taken using EDX (Bruker Corp. Berlin). The SEM EDX analysis revealed five main phases present in the recycled material. These are low- and high-density C-S-H gels, calcium hydroxide, non-hydrated clinker, and aggregate fragments (Fig. 2).

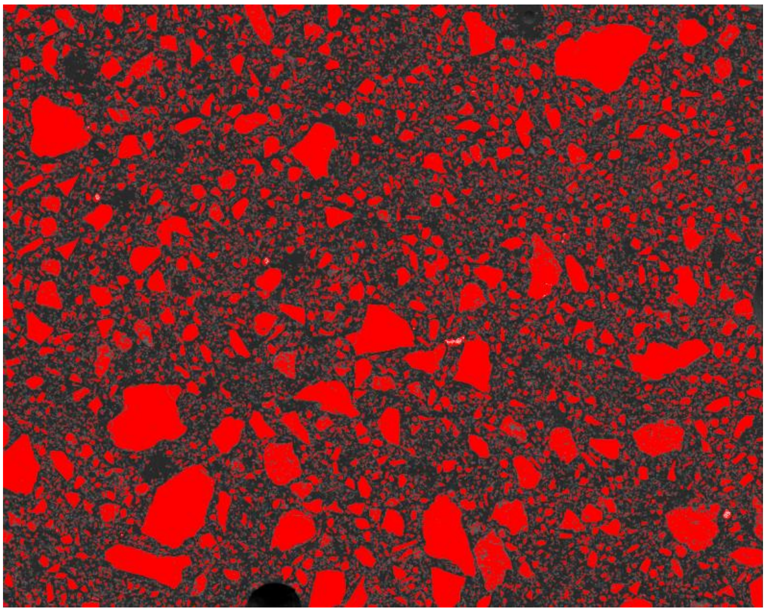

Fig. 1 Mapping of phases in SEM EDX images of micronized recycled concrete

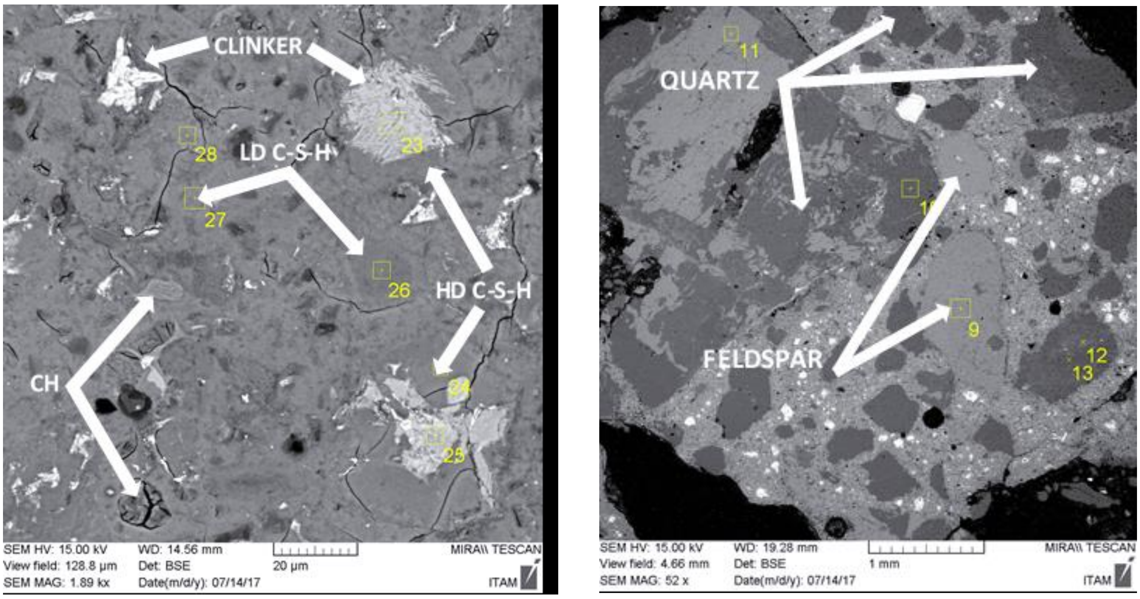

Fig. 2 Micrographs at distinct scales and identification of individual phases

Quasi-static nanoindentation was addressed to accomplish mapping of elastic stiffness of the pastes within selected areas. To that purpose, we used nanoindentor Ti 7500 (Hysitron Inc.). The measurement was performed at two scales (Level I and II), corresponding to further micromechanical modeling. At Level I the nanoindentation grid consisted of 25 by 25 indents with the spacing of 2 μm. Such a setting allowed to investigated the phases constituting the matrix at Level II. At Level II, a displacement-controlled quasi-static grid indentation was performed in the 21 by 21 raster with the spacing of indents equal to 5 μm.

After deconvolution of indentation distribution functions the stiffness of individual phases was established as follows: low-density C-S-H 19.17 ± 3.54 GPa, high-density C-S-H 39.75 ± 5.98 GPa, calcium hydroxide 58.59 ± 6.34 GPa, aggregate 79.78 ± 3.11 GPa, clinker 118.35 ± 16.85 GPa. The map of distribution of Young's moduli is presented in Fig. 3. The results are consistent with previously published research, e.g., [7-9].

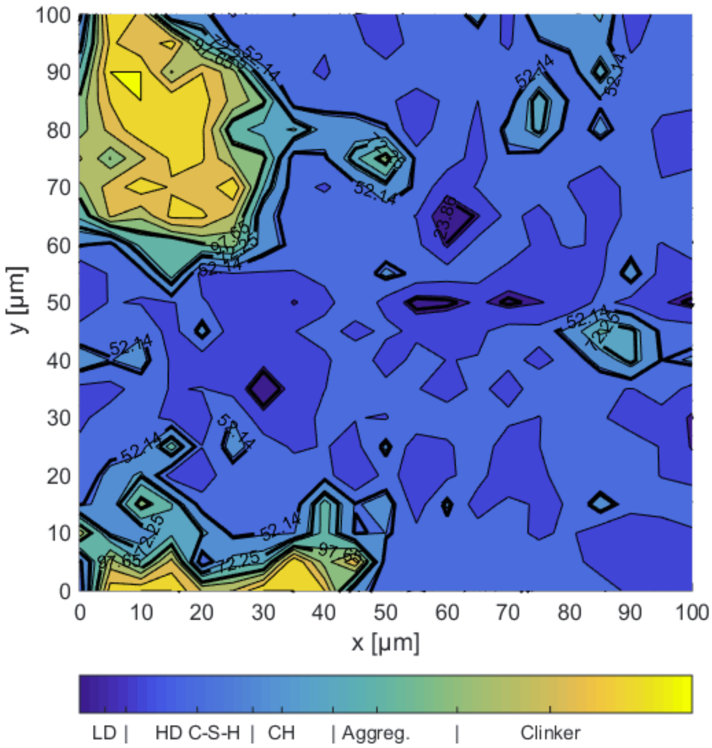

Fig. 3 Contour maps of Young's moduli distribution over the indented area at Level II

Micromechanical Modeling

Micromechanical modeling will be employed to confirm the assumptions about the impact of weak transition zones formed around inert phases and assess the impact of finely ground recycled material. The model will be based on Mori-Tanaka scheme with coated inclusions and combined with von Mises failure criterion to estimete the compressive strength at macro scale. Such an approach was recently used for micromechanical characterization of cement pastes with marble powder [10]. Unlike in that study, the model will operate at two scales as in the case of nanoindentation.

A preliminary study was carried out on pastes containing micronized recycled concrete (Level I). The study revealed that if the model does not take into account improvement of ITZ or the matrix itself by the presence of unhydrated reactivated clinker, it underestimates the elastic stiffness, especially in the pastes rich in recycled concrete powder (see Fig. 4). Further research is needed to establish the effect of recycled concrete on macroscopic properties of cementitious composites containing recycled concrete.

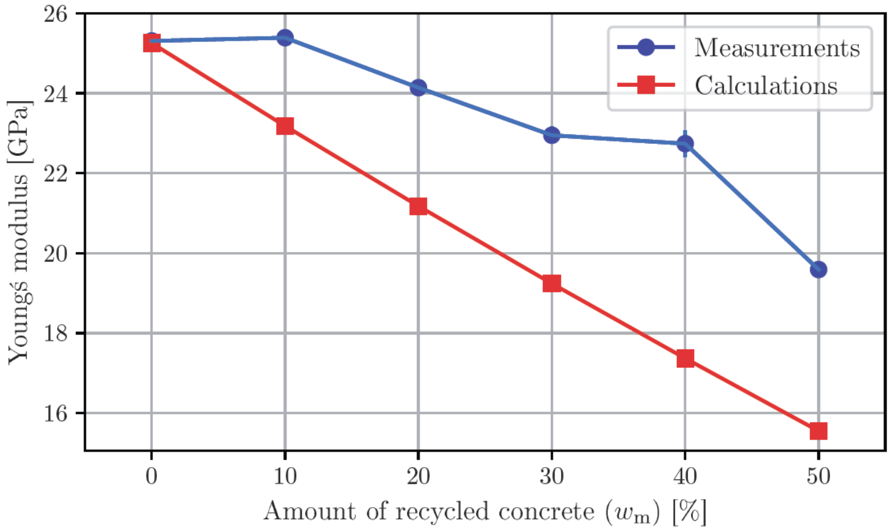

Fig. 4 Preliminary outcomes of micromechanical modeling of cementitious pastes containing recycled concrete powder; the model underestimates the elastic stiffness, indicating that the unhydrated phases present in the recycled concrete can be activated and improve the mechanical properties of cementitious composites by means of ITZ or matrix strengthening

Conclusion

Measurements at micro scale were carried out to assess the elastic properties of individual phases in cementitious composites containing recycled concrete. The material was finely ground to allow secondary hydration of unhydrated clinker. Micromechanical model was suggested to revaeal the role of unhydrated phases and weak interfacial transition zones.

After the model validation, it can be used for designing mixes with a suitable volume/mass ratio of individual components. However, the issue cannot be addressed only from the point of view of micromechanics, but study on chemical processes in recycled and finely ground concrete will be needed..

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