TOWARDS MORE SUSTAINABLE 3D PRINTED CONCRETE BY THE USE OF LC^3 BINDERS

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Additive manufacturing of concrete is able to enlarge the freedom of design and to reduce manual labor and resource consumption during construction. The usually high clinker content of additively manufactured concrete [1] dampens the positive effects of 3D printing partially, as cement clinker is responsible for the main CO_2 emissions related to concrete production. Thus, in order to allow for a more sustainable construction with concrete, the replacement of the clinker with supplementary cementitious materials (SCMs) is essential. For the use in conventional building techniques, the combination of calcined clays (CC) and limestone powder (L) as partial replacement of cement in concrete has shown promising results with regard to compressive strength and durability [2]. While the workability reducing effect of CC is mostly undesirable in traditional casting [3], it might be of advantage in 3D printing. After deposition, the layers need to keep their shape and harden fast enough in order to bear the load of the next layers to be extruded on top of them (commonly referred to as buildability). In this study, we investigated the impact of varying L and CC dosages on reactivity – including synergetic effects – and rheological properties of selected model cements.

We investigated composite cements consisting of 55 wt.% CEM I 52.5 R (HeidelbergCement), and various ratios of limestone powder (Warsteiner Kalksteinmehl, HeidelbergCement) and metakaolin (Metapor, Poraver) as shown in Table 1. In addition, a sample containing only CEM I (C) was used as a reference for all samples.

Table 1: *Mix design of cements investigated in this study, in [wt.%].*

Sample name	CEM I	L	CC
C (ref)	100	-	-
L	55	45	-
LCC 1:1	55	22.5	22.5
LCC 1:2	55	15	30

For the preparation of the pastes, a water-to-solid ratio of 0.51 was used for all samples. The development of the early hydration of the paste samples was monitored for 7 days by isothermal heat flow calorimetry at 25 °C. In addition, the phase assemblage of the hydrated pastes was investigated by thermogravimetric analysis on hydration-stopped samples after 7 and 28 days of sealed curing at 25 °C. As a second step, we are currently assessing the printability of the paste samples by rotational rheological tests, determining their yield stress as a function of time and allowing the prediction of workability and buildability.

The results of the heat flow calorimetry confirm the previously reported effects of L and CC on the hydration of Portland composite cements [4]. When normalizing the results to the amount of CEM I in each sample (Figure 1), the filler effect of L becomes visible, and the additional heat contribution from CC, due to its pozzolanic reaction, becomes more obvious. However, it should be noted that no clear difference between the CC-containing samples LCC 1:1 and LCC 1:2 can be observed. This suggests that the very reactive metakaolin used in this study is not able to react to its full potential in sample LCC 1:2, and probably not even in sample LCC 1:1. This also becomes obvious when looking at the portlandite (CH) content determined in the samples (Figure 2). There are no significant differences between LCC 1:1 and LCC 1:2. A small amount of CH is present in all samples even after 28 days. This is potentially due to spatial inhomogeneities of metakaolin within the samples. The similarity in heat of hydration and CH content of samples LCC 1:1 and LCC 1:2 therefore show that a part of the CC added only acts as a filler. Still, the reaction slightly accelerates due to the addition of more CC compared to

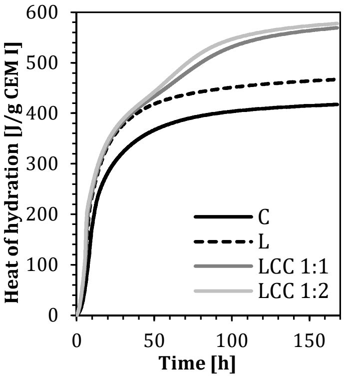

Figure 1: Heat of hydration of the paste samples measured with isothermal heat flow calorimetry for 7 days at 25 °C.

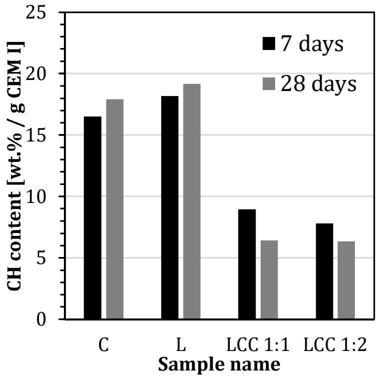

Figure 2: CH content in the paste samples determined with TGA after sealed curing for 7 and 28 days at 25 °C.

samples containing less or no CC (Figure 1). This might cause a potential advantage for the buildability of sample LCC 1:2 compared to LCC 1:1. However, a high CC content is known to reduce the workability of cementitious materials [3]. The amount of metakaolin needs to be optimized for application in additive manufacturing taking both effects into account. Furthermore, a detailed optimization is needed with regard to the CEM I replacement ratio and the L/CC ratio depending on the reactivity of the clay used. Therefore, rheological parameters are currently investigated. Preliminary results show an increase in yield stress with increasing CC content of the mix. This is beneficial for the buildability of the material, which means that higher loads can be applied on the base layers without causing a plastic collapse [5], which in turn enables faster building rates.

Our methodology enables us to assess the critical steps in the process of 3D printing. Further research will investigate the suitability of different binder compositions for concrete extrusion determining maximum building rates. Furthermore, the addition of admixtures at the concrete scale will be investigated with the objective to control and adjust the rheology both, for the conveying and the layer-wise construction phase. The overall goal is to combine material reduction enabled by additive manufacturing and CO_2 emissions reduction by replacement of clinker with SCMs.

Keywords: SCMs, 3D printing, calcined clays, limestone, early hydration

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