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The hygrothermal assessment of cement-ash-based mortar

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Abstract. Cement is the second most consumed substance by weight in the world, after water. The growing demand for reduced emissions of CO_2 urges the cement industry to find materials with a low CO_2 footprint, which calls for cement substitution. An assumption of the study has been that sewage sludge ash (SSA), an industrial by-product, can be applied as a potential cement substitute in cement-based materials without compromising material performance. The study investigated the effect of partial replacement of cement by SSA in mortar on hygrothermal properties of mortar. Two sewage sludge ashes originated from wastewater treatment plants located in the Greater Copenhagen area, Denmark. SSAs consisted of larger particles compared to cement particles; thus cement-ash-based mortar resulted in more porous structures compared to cement-based mortar. The higher porosity was responsible for a decrease of the thermal conductivity of the mortar. Significant differences were recognized in sorption isotherms of individual components, i.e. cement and ashes. However, their effect on the sorption isotherms of the mortars was minor.

1. Introduction

Negative environmental effects and overexploitation of available resources is a prevailing and extensive problem faced by the construction industry. Specifically, cement is the second most-consumed substance by weight in the world, after water [1], and during its production 900 kg of CO_2 are emitted per ton of cement [2]. The growing demand for reduced emissions of CO_2 urges the cement industry to find materials with a low CO_2 footprint, which calls for cement substitution. In order to achieve feasible rates of cement substitution, it is necessary to introduce new supplementary cementitious material (SCM), which is readily and possibly locally available. Sewage sludge ash (SSA) could be such a viable resource. The assumption of the study states that SSA, as an industrial by-product, can be applied as a potential cement substitute in cement-based materials without any compromise on the material performance.

2. Materials and Methods

2.1. Sewage sludge ashes (SSAs)

Two SSAs were used as a substitute for cement in the study. They originated from two major Danish incineration plants located in Avedøre (AVE) and Lynetten (LYN) in the Greater Copenhagen area. The effect of different ratios of cement substitution in the mortar was investigated. The ash was pre-treated by a 30-sec grinding process (G) as the grinding of ash has a positive effect on mortar quality [3].

2.2. *Mortar recipes*
Reference mortar samples based on cement were prepared according to the standard DS/EN 196-1 [4]. For the mortars containing SSA, the same basic recipe was used, but part of the cement content was replaced by SSA (see Table 1).

Table 1. Basic mortar recipes.

Substitution ratio [%]	Cement [g]	SSA [g]	Sand [g]	Water [g]
0 (Ref)	450	0	1350	225
10	405	45	1350	225
30	315	135	1350	225

3. **Results and Discussion**

3.1. *Open porosity and thermal conductivity*
SSAs were characterized by larger grains compared to cement [5]. The open porosity of the mortar was clearly affected by larger particle size and different morphology of ash grains. Increased ash content yielded higher open porosity and resulted in decreased thermal conductivity and increased water vapour permeability (see Figure 1). With 30% cement replacement, a reduction of 15% of thermal conductivity was measured. This complies with the fact that pores filled with air contribute to the thermal insulation property. Depending on mortar application, this may positively contribute to energy savings and the carbon footprint of building constructions.

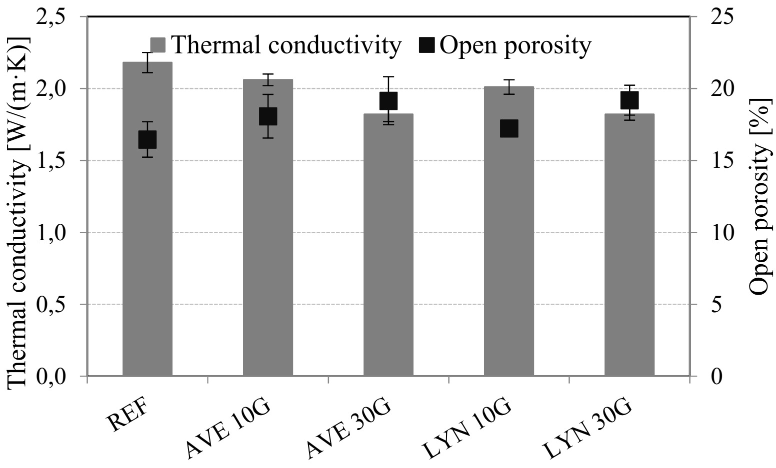

Figure 1. Graphical relation of average values and standard deviation of three duplicates for thermal conductivity and porosity.

3.2. *Water vapour adsorption*
The moisture adsorption/hydration of cement is higher than that of the SSAs when exposed to identical conditions and the steepest increase of the adsorption curve was observed above 70% RH (see Figure 2). Cement did not reach equilibrium for the conditions at 94% RH, while the ashes did so at the set

time period. This may be due to the reactions of the cement with water, which proceed slower when water is present in the vapour state compared to water in the liquid phase [6], while SSA may not hydrate itself and only bonds with water in its pores [7]. Differences between the individual components are clearly visible, while the measurements of the mortars were only to a minimal extent affected by the replacement of 30% of the cement content. In general, with decreased cement to ash ratio, the ability to adsorb water vapour decreased. This indicates that the sorption ability of the mortar samples may be affected by the potential reactivity of cement/ash with water, which is clearly higher for cement.

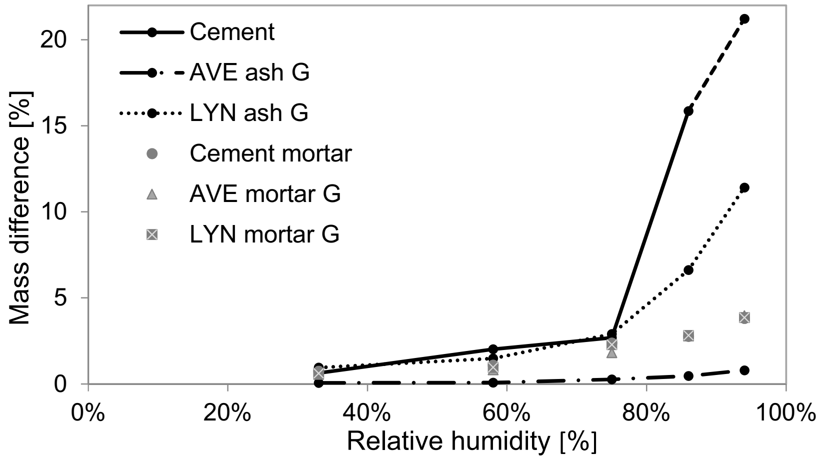

Figure 2. Sorption isotherms of the cement, SSAs, cement-based mortar and mortar with 30% cement replacement by ground ash.

4. Conclusion

Generally, it can be concluded that the partial replacement of cement by SSA has an effect on the hygrothermal properties of mortar, especially thermal conductivity that is directly related to mortar structure (i.e. porosity), and at higher cement replacement ratios (i.e. 30%). However, replacement of cement by SSA of up to 10% affects hygrothermal qualities of mortar only to a minimal extent and it can be a good compromise between mortar's environmental impact and material quality.

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