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Development of self-leveling screed based on calcium sulfoaluminate cement: Modelling of curling due to drying

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ABSTRACT

The development of cement-based screed unbound to its support is still limited because of the curling that occurs at the corners and perimeter of the screed. This phenomenon is mainly due to the moisture gradient that appears within the thickness of the screed: the upper surface dries and shrinks, whereas lower regions dry less and stay wetter. This paper demonstrates this phenomenon can be mitigated through the use of calcium sulfoaluminate cement instead of ordinary Portland cement. Experiments utilizing an original, specially designed device, show that curling is 3.5 times lower when calcium sulfoaluminate cement is used compared to ordinary Portland cement. The moisture gradient within the thickness of the screed is also lower.

A model based on simplified poroelasticity theory describes both fluid transfer and hydro-mechanical coupling. The comparison between experimental and calculated results shows that the model gives a good estimation of the kinetics of the mass loss, and that the numerical simulation is an effective tool to predict curling due to drying.

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1. Introduction

Some concrete slabs curl upward at their corners and perimeter. This condition is particularly common with slabs-on-grade [1,2]. When this occurs, corners and edges are unsupported and tend to break under load. This phenomenon is especially marked in screeds that are not bound to their support. As the thermal and acoustic insulation regulations become more and more stringent in Europe, this phenomenon is expected to appear more often. The new regulations require use of a layer of insulating material between the support slab and the screed. Therefore, the bond between the support and the screed is broken, and the latter is able to curl more readily.

The curling phenomenon is mainly due to the moisture gradient present within the thickness of the screed, which in turn leads to differential shrinkage between the top and the bottom of a slab or screed. The top surface dries and shrinks, while the bottom stays wet and undergoes a much smaller amount of change in dimensions [3]. The curling of screeds utilizing Portland cement is very common and, therefore, the development and use of these screeds is limited. One solution to limit curling is to use calcium sulfoaluminate cement, as shown in a previous paper [4]. Use of such cement leads to lower drying shrinkage compared with the use of Portland cement.

The present paper is divided into two parts: in the first part, an experimental study is reported, using an original, specially designed, device to compare the behavior of screeds based on:

- Portland cement (OPC).
- Calcium sulfoaluminate cement (CSA).
- Calcium sulfoaluminate + anti-shrinkage agent (CSA + polyol).

In the second part, a model is developed to better understand the physical mechanisms involved within the CSA screed undergoing desiccation. Theoretical basis for the modelling used to describe both fluid transfer and hydro-mechanical coupling is presented. A simplified poroelasticity approach is used based upon the numerical results obtained by several authors [5–8].

2. Experimental

2.1. Materials and mixture proportions of screeds

The mixture proportions of the screeds were based either on ordinary Portland cement (OPC) or calcium sulfoaluminate cement (CSA) (Table 1).

OPC was a CEM I 52.5 Type according to the European Standard ENV 197-1. Limestone powder was used as supplementary fine material. Its influence on shrinkage at early age has been studied by Bouasker et al. [9]. The system of chemical admixtures in the OPC screed was composed of: a liquid polycarboxylate as

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Table 1
Mixture proportions of screeds (kg/m^3)

Material	OPC	CSA
OPC CEM I 52.5	300	20
CSA		300
Limestone powder	100	80
Sand (0/5 mm)	1350	1350
Viscosity Modifying Agent (VMA)	0.45	1.25
Superplasticizer (SP)	8	6
Water	320	320

superplasticizer (SP), to get the desired fluidity; and, a viscosity modifying agent (VMA), a modified starch stable in the high-pH basic environment of OPC [10,11].

The CSA cement was composed of 80% CSA clinker and 20% recrystallized gypsum (RG). RG is a by-product of the manufacture of phosphoric acid by the Prayon PH2 process, with two hemi-hydrate stages followed by a di-hydrate process producing co-crystallized gypsum with low P_2O_5 content [12]. The pure gypsum content of RG determined by DTA-TGA was 89.4%. The composition of CSA clinker was as follows:

– $Ca_4Al_6O_{12}SO_4$ (yeelimite): 75.5%
– β-Ca_2SiO_4 (belite): 11.1%
– $Ca_3Fe_2TiO_9$ (perovskite): 9.2%
– $Ca_{12}Al_{14}O_{33}$ (mayenite): 2.6%

OPC was added to the recipe of the CSA screed in order to get shrinkage compensation, by forming swelling ettringite from the reaction of CSA, OPC, and water. The system of chemical admixtures was composed of:

- A superplasticizer (polycarboxylate) to get the desired fluidity for three hours, which is required for on site-applications.
- An anti-shrinkage agent: a polyether polyol. The influence of polyol on the drying and curling of self-leveling screeds based on calcium sulfoaluminate cement was described in a previous paper [13]. When polyol was added to the mixture (0.63% of the cementitious material content), curling was reduced by 23%. Polyol also reduced drying shrinkage by 40%, but did not affect the mass loss of the screed and the porous distribution.
- A viscosity modifying agent (polyvinyl alcohol + Welan gum) to avoid sedimentation and bleeding.

The quantities of SP and VMA were adjusted to keep the water content constant in both types of screeds at 320 L/m^3.

The fluidity of the mortar was measured by means of the static spread of a truncated cone having the following dimensions: $Ø_{inf}$ = 95 mm; $Ø_{sup}$ = 55 mm; h = 70 mm. Mortar was considered as self-leveling when the spread reached 250–270 mm.

2.2. Measurement of the curling of screeds

A special measuring device was developed to simulate the curling phenomenon, which is shown in Figs. 1–3 [14] and composed of the following:

- A mold, in which a mortar slab with dimensions 330 × 330 × 30 mm can be cast. The sides of the mold had 1° relief angle in order to permit the vertical displacement of slab corners and the perimeter. All the faces of the mold are treated (teflon coating deposited at high temperature) in order to prevent bond between the mold and the mortar. The thickness of the mold is very close to that typically used at a construction site in France, 40–50 mm.

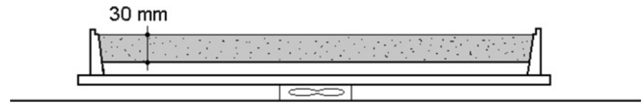

Fig. 1. Cross-section of the equipment showing the sample on the balance.

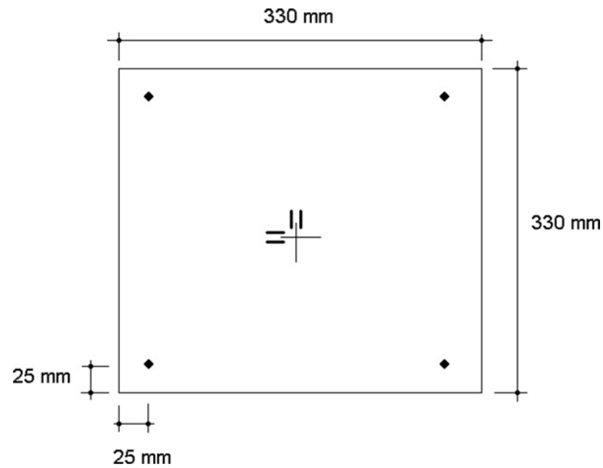

Fig. 2. Top view of the equipment showing the position of the LVDT sensors: two for horizontal shrinkage measurement and four for vertical displacement of corners.

- A balance to continuously measure the mass loss of the whole system.

Twenty-four hours after casting the screed, the slab was equipped with four vertical LVDT sensors placed in the corners measuring the vertical displacement; and two horizontal LVDTs measuring the shrinkage occurring at the centre of the slab (Fig. 3). The LVDT's precision was 0.5%. The mold and measuring equipment was stored at 20 °C and 50% RH after casting the screed. Data were recorded automatically each hour after casting. During the first 24 h, the curing regime was maintained at 20 °C and 50% RH.

The mass loss (water-mass) of screeds is shown in Fig. 3. At 28 days, the mass loss of the CSA screed (with and without polyol) was about 20% lower than that of the OPC screed. This can be explained by the higher consumption of mixing water necessary to produce ettringite:

$$4CaO \cdot 3Al_2O_3 \cdot SO_3 + 8[CaSO_4 \cdot 2H_2O] + 6[Ca(OH)_2 + 74H_2O \Rightarrow 3[3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O]. \quad (A)$$

This reaction may explain the lower value of drying shrinkage observed in the CSA screed (Fig. 4). At 20 days, the OPC screed developed shrinkage of 890 μm/m. At the same age, the shrinkage of CSA was only 545 μm/m, or 39% less. The presence of polyol had additional beneficial effect on the shrinkage of CSA screed: the maximum value recorded was only 435 μm/m. Polyol reduced CSA screed shrinkage by 20%, which is less than the value reported in a previous study for a different mixture proportion of the mortar [14].

The curling of screeds is shown in Fig. 5. All the results were obtained when curing the screeds at 20 °C and 50% RH, after having sprayed a curing compound on the top surface of the screed. In Fig. 5, the time scale begins with the time of casting the screed. OPC screed started to curl after 4 days of hydration while CSA-based screeds started to curl after two days of hydration. After 20 days of hydration at 20 °C and 50% RH, the curling of the CSA screed was 3.5 times lower than that of the OPC screed. The curling of (CSA + polyol) screed was nearly seven times lower than that of

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