FIRE-PROTECTION WITH ALKALI-ACTIVATED CEMENT BINDER

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Abstract

Fire resistance of unprotected steel structures is very low and steel elements must be protected from fire. One possibility is to create a protective layer of a cement-based material. Most types of cement have a low resistance to high temperatures, reducing mechanical properties. In flammability tests, cement activated with alkaline compounds showed better properties compared to conventional types of cement. This paper represents the determination of the properties of two H-Cement mortars with experlite or fireclay sand. Experiments carried out in a small kiln simulating a 1D load showed differences between elements in terms of heat transfer to the tested elements. The calculation model created to predict the course of the experiments has been validated and the unknown properties of the material have been calculated based on the data collected. The samples were tested in a small fire furnace. Finally, the thermal conductivity pattern was determined depending on the temperature.

Keywords: fire safety, alkali-activated cement, fire-protection, modelling, material properties

1 INTRODUCTION

Protection of the steel members by a layer of the thermal insulation material is traditional solution of passive fire safety. Most materials in cement bases do not behave well exposed to high temperatures, due to the formation of cracks in the protective layer. It offers the use of a new alternative alkaline-activated hybrid cement, H-Cement, which has better properties at higher temperatures than conventional types of cement.

The composition of H-Cement, as opposed to conventional cement, consists of the use of metallurgical slag along with an alkaline-activated inorganic geopolymer with a base of precipitated sewage in the production of bauxite. Portland cement's share of the H-Cement mix is 20 %. The production of H-Cement reduces CO_2 emissions by 80 % compared to the production of OPC (Martauz, 2016).

H-Cement exhibits properties like ceramic material at high temperatures, i.e. when H-Cement is heated to high temperatures due to the transformation of crystalline aluminosilicate phases to high melting points, and at temperatures above 800 °C there is a transformation into a ceramic form, so there is no significant development of cracks (Panias, 2014). Transformation and geopolymer water contained is an endothermic material that is very resistant to the effects of fire. When designing the protective layer of an H-Cement-based steel element, it is possible to use the heat transfer prevention property due to the thermal conductivity of hybrid cement, which ranges from 0,1-0,3 W/m/K when using experlite as a filler (Šmilauer, 2011).

Preliminary results (Daxner, 2016) demonstrated the excellent resistance of H-cement lightweight mortars to those of gypsum or alumina cement equivalents. Pilot tests for the larger experiment were performed (Šulc, 2021) on a laboratory burner and baseline values for thermal conductivity were determined.

This contribution aims to determine the thermal characteristics of the H-Cement layer at 20 mm thick on the steel sheet. The adhesion of H-Cement to steel has not yet been studied.

2 EXPERIMENTS

Two types of mortar were considered to verify the properties of the H-Cement coating for fire purposes, namely, a mortar not lightweight with fireclay sand and PVA fibres and a lightweight mortar of H-Cement with experlite and plating. The formulation used to make the mortar is given in

Table 1. The thickness of the 20 mm protective layer of H-Cement is chosen to ensure a fire resistance of at least 45 min.

Table 1 Composition of H-Cement mortar for 1 m^3

<table>
<tr><th rowspan="2">Mortal</th><th rowspan="2">H-Cement [kg]</th><th colspan="2">Fireclay [kg]</th><th rowspan="2">water [kg]</th><th colspan="2">Experlite [kg]</th><th rowspan="2">Plasticizer [kg]</th><th rowspan="2">PVA fibres [kg]</th></tr>
<tr><th>0-1 mm</th><th>1-2 mm</th><th>0-1 mm</th><th>1-2 mm</th></tr>
<tr><td>Regular</td><td>119,62</td><td>119,62</td><td>239,24</td><td>44,21</td><td colspan="2">-</td><td>-</td><td>0,31</td></tr>
<tr><td>Light weight</td><td>72,10</td><td colspan="2">-</td><td></td><td>9,17</td><td>12,13</td><td>1,11</td><td>-</td></tr>
</table>

The experiment was carried out for both a non-lightweight mortar and a lightweight mortar. For one test, four samples measuring a steel sheet 180 × 100 × 12 mm were produced with a protective layer of 20 mm with the additional protection of the sides from mineral wool to ensure heat is applied to the sample from one side at a time. The protective layer was also applied from the sides of the steel element to simulate part of the bottom of the strip of the steel profile. Thermocouples for measuring steel temperature were placed on the non-heated side of the sample. The geometry of the sample is shown in Figure 1.

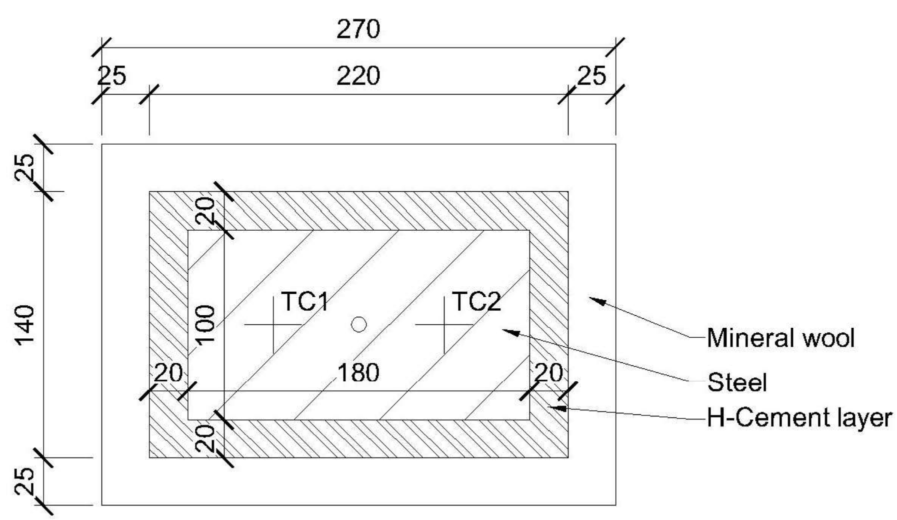

Fig. 1 The geometry of a sample and the position of the thermocouples

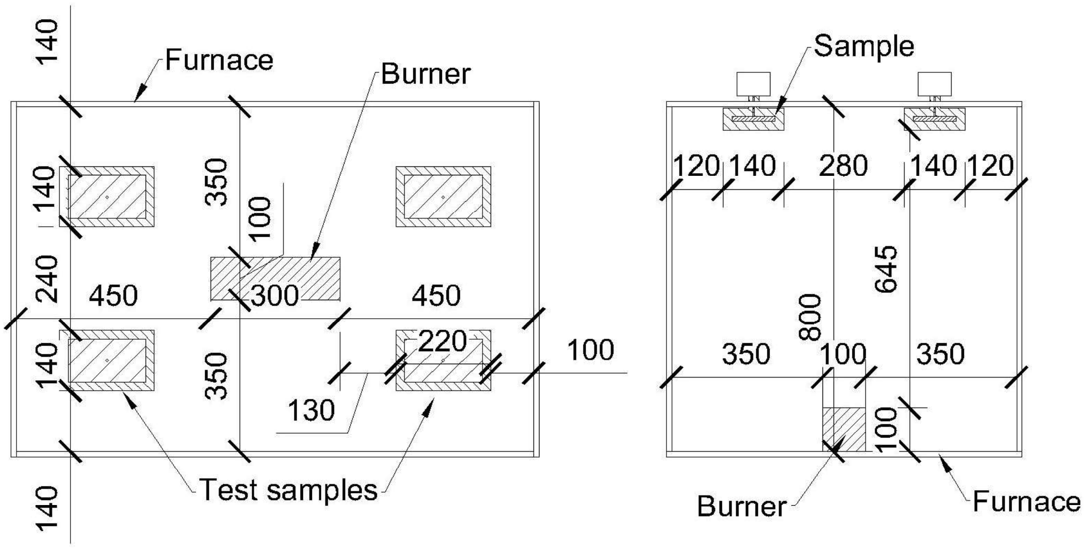

Fig. 2 Distribution of samples in furnace floor plan, and section of furnace

The experiment took 60 min, 45 min of faze heating, and 15 min of faze cooling. No significant cracks in the protective layer were evident when the samples were removed from the test furnace after the experiment. By the influence of cooling, these fissures were advancing in-depth and widening. All variants of H-cement-based lightweight mortars withstood exposure to high temperatures without causing visible cracks. For the lightweight variant of H-cement, cooling caused the edges of the test samples to fall off. Samples protected by a layer of H-cement, chamotte sand, and PVA fibres resisted waste even after cooling. Compared to the lightweight variants, however, there was a partial separation of the protective layer from the steel sheet due to the different cooling of steel and concrete.

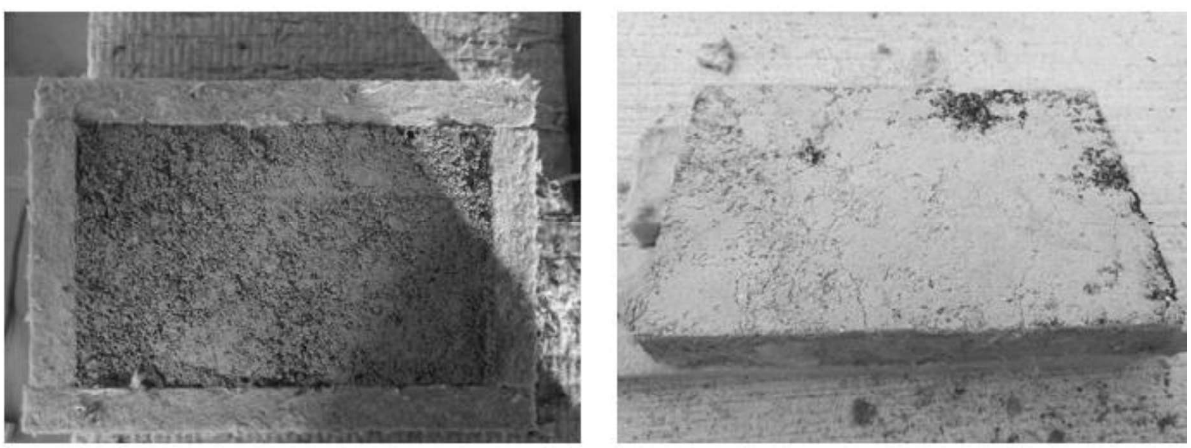

Fig.3 The samples before and after the test

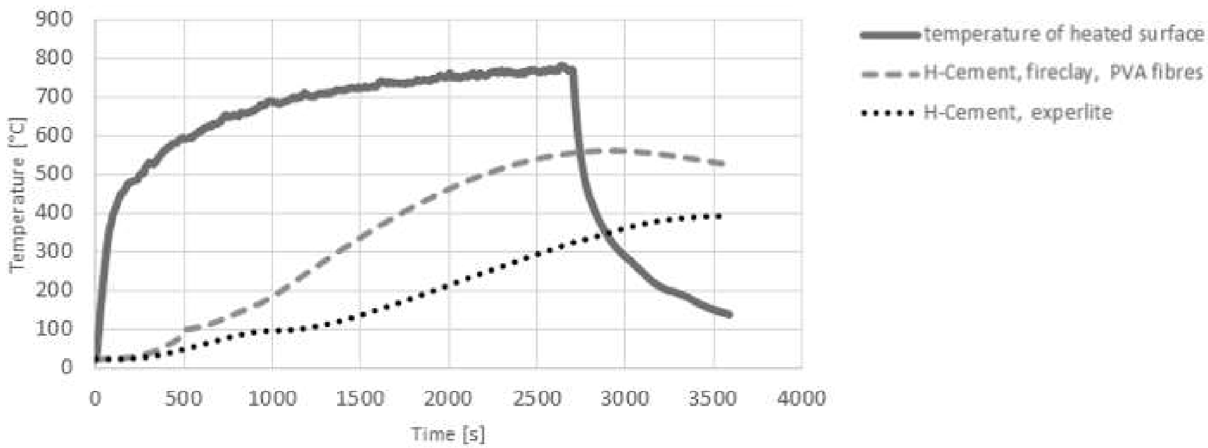

Fig.4 Test furnace temperature compared to steel temperature

Tab. 2: Comparing the predictions of the evolution of temperature and temperature achieved in the experiment on unprotected steel (H-Cement with experlite)

Time [min]	Temperature forecast [°C]	Experimental temperature [°C]
15	44,43	40,1
30	162,39	130,9
45	330,59	262,3

Fig.5 Destroyed sample after cooling

3 MORTAL CHARACTERISTICS

Model (Wang et al., 2013) was used to predict the material properties of H-cement with experlite. In many cases, however, there are no values available to describe the material. A prediction equation has therefore been used to describe the thermal conductivity of the porous material of H-cement with experlite, which can be applied in these very cases.

$$\lambda^* = C_1 + C_2 T^3 \tag{1}$$

The determination of the coefficients C_1 and C_2 was considered to be for vermiculite. Thus, the coefficient C_1 can be replaced by the thermal conductivity at 20°C and the coefficient C_2 by a formula considering the influence of volume weight.

$$C_1 = \lambda_0^* = A \frac{\rho}{1000} = 0{,}27 \frac{\rho}{1000} \tag{2}$$

$$C_2 = B\frac{(1000-\rho)}{1000} = 0{,}18\frac{(1000-\rho)}{1000} \quad (3)$$

A lower value was achieved than the original assumption, where a thermal conductivity of 0,12 W/K/m was predicted for mortar at 20 °C. The improved thermal conductivity can be attributed to the effect of drying the sample and its low volume weight. The thermal conductivity is calculated using the data measured in the experiment. By the method of least squares, the values of coefficients A and B were determined for H-cement with experlite.

$$y = 0{,}09221 + 1{,}586E^{-11}x \quad (4)$$

$$\lambda_0^* = A\frac{\rho}{1000} \rightarrow A = \lambda_0^*\frac{1000}{\rho} = 0{,}09221\frac{1000}{406} = 0{,}22712 \quad (5)$$

$$C = B\frac{(1000-\rho)}{1000} \rightarrow B = C_2\frac{1000}{(1000-\rho)}1000^3 = +1{,}586 \times 10^{-11}\frac{1000}{(1000-406)}1000^3 = 0{,}0267 \quad (6)$$

Resulting H-cement thermal conductivity equation with experlite:

$$\lambda^* = 0{,}22712\frac{\rho}{1000} + 0{,}0499T^3 \quad (7)$$

The effect of temperature on the change in volume weight and specific heat capacity was neglected for small samples. The change in the density of protective materials is due to the evaporation of the moisture content in the test samples. The samples were dried in a drying furnace when weight loss due to evaporation of the bound water in the samples was measured. Constant values were taken for basic models for concrete with a perlite filler that corresponds to the bulk weight of H-cement concrete with experlite. Values for basic modelling are given in Tab. 3.

Tab. 3: Material properties H-Cement with experlit

Material characteristics		H-Cement with chamotte	H-Cement with experlit
Density		1930 kg/m³	406 kg/m³
Specific thermal capacity		1050 J/kg/K	1150 J/kg/K
Thermal conductivity (W/m/K)	20°C	1,1000	0,097425
	100°C	0,9697	0,098100
	200°C	0,8508	0,099312
	300°C	0,7433	0,101686
	400°C	0,6472	0,104763
	500°C	0,5625	0,109002
	600°C	0,4892	0,114456
	700°C	0,4273	0,121282
	800°C	0,3768	0,129738
	900°C	0,3377	0,139827

Resulting H-cement thermal conductivity equation with fireclay:

$$\lambda_p = \left[\mathrm{d}_p\frac{V}{A_p}C_s\rho_s(1+\emptyset/3)\frac{1}{(T_{fi}-T_s)\Delta t}\right]\left[\Delta T_s + \left(e^{\emptyset/10}-1\right)\Delta T_{fi}\right] \quad (8)$$

$$\lambda_p = 1{,}1 - 0{,}136 \times 10^{-2}T + 0{,}0057 \times 10^{-4}T^2 \quad (9)$$

4 CONCLUSIONS

H-cement is an excellent bonding agent for fire-fighting materials, whether in compact or lightweight variants. Compared to the reference alumina cement, H-cement exhibits lower weight loss in temperatures above 300 °C in thermal insulation mortars. This is explained by the mild reaction of H-cement to experlite. This property is positively created by less mortar shrinkage and higher resistance to crack formation due to postburn cooling (whether shock by rapid cooling or gradual cooling). At temperatures above 750 °C, the surface lightens, most likely by burning off residual black carbon, a feature that could be used for a quick colour indication of the temperature load history.

Heat-insulating H-cement mortar with experlite has created an effective fire suppression layer, preventing heat from entering the structure. The mortars have excellent adhesion to the steel element, dispensing with the need for any treatment of the steel by the underlying layers or coatings against corrosion.

Thermal conductivity of 0,093 W/m/K has been established for H-Cement with experlite mortar, with a specific heat capacity of 1150 J/kg/K at a dried weight of about 400 kg/m3 and 20 °C. The thermal conductivity increases slightly with temperature.

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