INNOVATIVE MATERIALS FOR PASSIVE FIRE PROTECTION OF CONCRETE

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Introduction

A number of serious tunnel fire incidents have been reported worldwide that have led to injuries and life loss, heavy damage in the concrete lining, thus threating the stability of the tunnel structure, excess material damage, and significant time periods of tunnel restoration during which the tunnels were unavailable for traffic. Fires in tunnels can seriously damage their concrete lining rendering it to collapse. In addition to the damage caused by fire to concrete, special attention has to be paid to the damage caused to structural steel rebars that normally reinforce the concrete structures. Therefore, steel and concrete are both fire sensitive construction elements requiring passive protection against fire in order to be capable of withstanding the effects of fire for an appropriate time period of time without loss of stability[1]. Passive fire protection methods are generally divided in two categories: external (insulation) and internal (concrete design) ones. The former are more advantageous being applied in new as well as in existing tunnels and consists of the cladding of the concrete by a fire resistant material which creates a protective external insulation envelope[2]. This work aims at designing and evaluating the performance under thermal loading of a fire resistant geopolymer for external passive fire protection of concrete tunnel linings.

Geopolymerisation

The geopolymerisation technology has been found to be very attractive in developing effective fire resistant materials. Geopolymerisation is a fast-growing technology that involves a heterogeneous chemical reaction between several solid aluminosilicate materials (naturally°Ccurring minerals, industrial by-products or waste) and alkali metal silicate solutions at highly alkaline conditions and mild temperature[3-5]. In this research the solid aluminosilicate material was a Fe-Ni slag, which was provided by the metallurgical plant of the Greek company LARCO G.M.M.S.A. that treats laterites to produce ferronickel. According to the chemical analysis the slag is a siliceous material, very rich in iron oxides. A strongly alkaline solution was also used for the synthesis of inorganic polymers and pure metallurgical alumina.

Experimental Procedure

Following the EFNARC guidelines, the efficiency was assessed by subjecting a concrete slab specimen, coated with 5 cm geopolymer layer, to thermal loading employing fire standard curves. Two geopolymeric materials were designed as fire resistant materials which can resist in temperatures higher than 1000°C. In order to test their fire resistance a 15 x 15 x 15 cm (thickness) composite specimen was prepared, consisting of 5 cm thick geopolymer material and 10 cm thick concrete slab, based on the EFNARC guidelines. The adhesion of the two materials was enhanced by the use of steel anchors, placed during material preparation. The specimens were subject to thermal loading by exposing the geopolymer surface to prescribed temperatures according to the ISO-834 or the RWS time-temperature curves. The test was performed 28 days after the production of the specimen. The developed temperature at the interface between the concrete and the geopolymer material was measured by using a "K"-type thermocouple, while the temperature of the back surface of the concrete slab was measured with a high performance infrared thermometer (RAYTEK, Raynger MX4). The syntheses and curing conditions and times of the two materials are summarised in Table 1.

Table 1. Syntheses of the fire-resistant materials

	Material I	Material II
Slag (wt%)	75.758	42.24
Al_2O_3 (wt%)	-	25.03
KOH (wt%)	-	8.09
NaOH (wt%)	5.303	-
H_2O (wt%)	18.939	24.64
S/L (g/ml)	4	2.73
Curing(^oC/h)	(25/4)	(70/48)

Results

The first material was tested to the international standard ISO 834 time-temperature curve that is the most commonly adopted fire curve for simulating a cellulosic fire. In Figure 1 the temperature development at the concrete-geopolymer interface during time is shown, together with the measured temperature at the unexposed concrete surface and the furnace temperature prescribed by the ISO 834 curve. As it is observed, the interface temperature has very low values in the beginning of the experiment for the first 35 minutes (30^{o}C). After the temperature increases linearly in a period of 75 min and reaches the temperature of 100^{o}C until a time of 110 min. The temperature remains around this temperature until the end of the experiment. The temperature in the back surface of the concrete specimen increases with a very low rate until 50 ^{o}C.

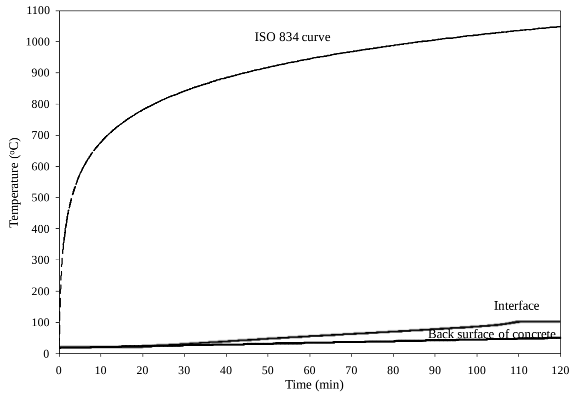

Figure 1: Results of the passive fire protection test under ISO 834 curve

Further, as it is clearly observed from the photographs of Figure 2, the geopolymer material did not appear any creeping or melting phenomena but only a change in colour, which is attributed to mineralogical transformations. The concrete slab protected by the sodium based geopolymer did not appear any form of spalling or other mechanical damage.

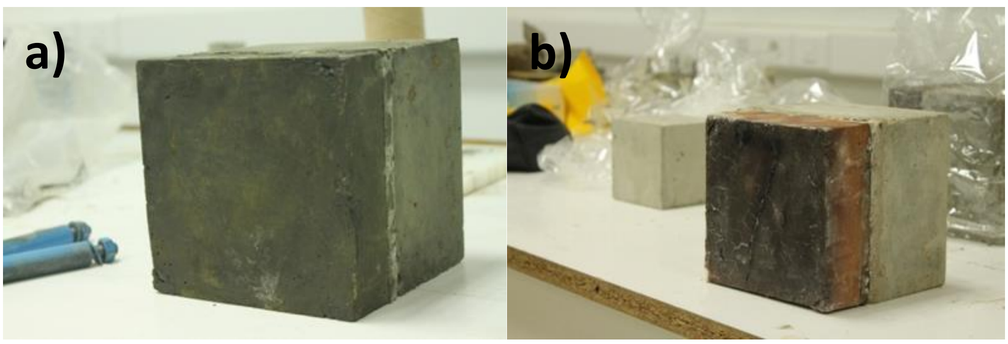

Figure 2: Specimen of material c: a) Before the passive fire protection test, b) After the passive fire protection test

The second fire resistant material was tested to the RWS (Rijkswaterstaat) curve. In Figure 3 the temperature development at the concrete – geopolymer interface during time is shown, together with the measured temperature at the unexposed concrete surface and the furnace temperature prescribed by the RWS curve.

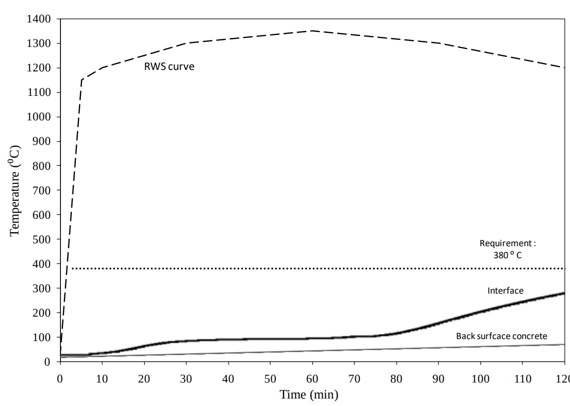

Figure 3: Results of the passive fire protection test under RWS curve

As it is observed the interface temperature in the first 8 minutes remains low at 30°C After the first 8 minutes the temperature increases linearly till 100°C, with the completion of 30 minutes of the test. The temperature remains almost stable for 50 minutes (up to the 80 minutes of the test). During this period the largest part of geopolymeric water in the material is removed. Because of this, the temperature at the geopolymer/concrete interface in this region remained lower and around 100°C. At that time a temperature difference of 1250°C was attained between the exposed and unexposed surface of the geopolymer material. With the completion of 80 minutes the temperature increases again until the end of the test. At the end of the test the temperature at the interface has a value of 280°C, which is 100°C lower than the RWS test requirements and the required temperature for maintaining the structural integrity of the concrete. The temperature in the back surface of the concrete slab did not exceed 70°C, which means that in the concrete slab the temperature had a range from 70°C – 280°C.

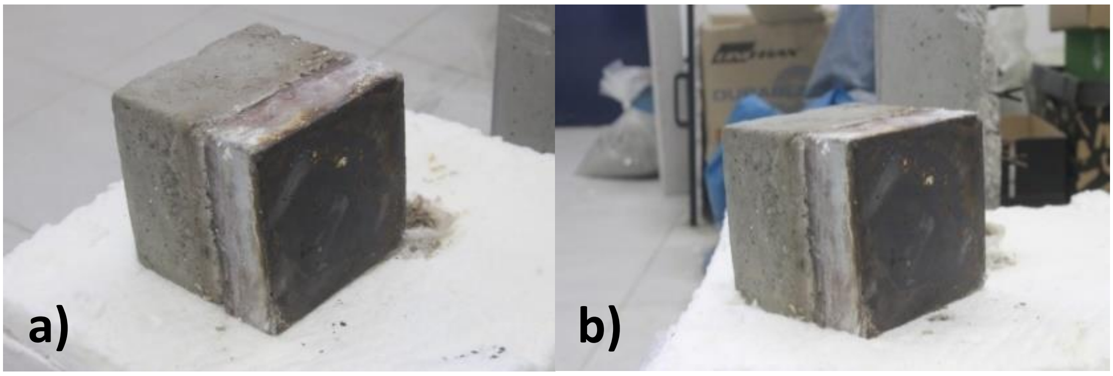

Figure 4: Images of the specimen after the test

Further as it is clearly observed from the photographs of Figure 4, the geopolymer material did not appear any creeping or mechanical damage except of changing in colour which is attributed to the mineralogical transformations. The concrete slab protected by the potassium based geopolymer did not appear any form of spalling and remained stable.

References

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