UTILISATION OF SLAG FOR THE DEVELOPMENT OF FIRE RESISTANT GEOPOLYMERS

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Introduction

A number of serious fires in buildings have been reported worldwide causing injuries and life loss(es), as well as heavy damage to the concrete lining. In addition, during July of 2018 in Greece a large fire was ignited in the eastern Attica causing almost 100 life losses and more than 1000 houses were destroyed. Fires in buildings can seriously damage the concrete thus threatening the stability of the house and rendering it to collapse. The damage is caused particularly by the spontaneous great amount of heat release and aggressive fire gases, resulting in spalling of the concrete. Spalling is described as the breaking of layers or pieces of concrete from the surface of a structural element when it is exposed to the high and rapidly rising temperatures experienced in fire. Also, in most of the houses there is a lot of material which can be easily ignited such as wooden ceiling, insulation material, carpets *etc.* and as a result the fire and the high temperature is spread in all the house in a small period of time. Additionally, very serious problems may be encountered by the firefighting service personnel rendering their work substantially more difficult and dangerous. In addition, spalling phenomena in concrete are expected at several temperatures depending on the strength and the densification of the concrete. According to Hertz,[1] in dense concrete, explosive spalling has been observed at temperatures between 300°C and 450°C. However, it is generally accepted that concrete loses its carrying capacity when exposed at temperatures higher than 380°C. This temperature is near to the calcium hydroxide dehydration temperature (400°C) which causes significant reduction of the mechanical strength of the concrete.[3] This is considered to be significantly reduced at temperatures higher than 300°C.[2] Therefore, it is crucial to avoid the fire to be spread in the building as well as protect the concrete structure. Thus, it is required to apply fire protection in order for the building to be able to withstand the anticipated temperatures of a fire incident, for an appropriate period of time without losing its stability. The efficiency of the fire protection materials is commonly assessed by passive fire protection testing. According to the EFNARC (European Federation of National Associations Representing producers and applicators of specialist building products for Concrete) guidelines,[5] a concrete slab specimen, coated with 3 cm geopolymer layer, is subjected to the ISO – 834 fire curve.

This curve is based on the burning rate of materials found in residential and commercial buildings (fire of cellulosic nature) and defines a test method for determining the fire resistance of the different components which can be found in a building.

Geopolymers

Geopolymer is the common name of the family of synthetic aluminosilicate materials formed by alkali activation of solid aluminosilicate raw materials.[4] The term "alkali activation" refers to a heterogeneous chemical reaction between an aluminosilicate raw material and an activating phase composed primarily from an aqueous solution of an alkali metal (sodium or potassium) silicate and hydroxide. The geopolymerisation reaction is exothermic and takes place at atmospheric pressure and temperatures below 100°C.[4]

Raw Material

The Cu slag used in the present study was provided by Boliden industry which produces copper. For the synthesis of the geopolymer, an adequate quantity of granulated slag was ground to < 180 µm. The Cu slag is a siliceous material (SiO_2 – 39.95 wt%) rich in iron oxide (44.41 wt%) with a low amount of alumina (Al_2O_3 – 3.3 wt%). It also contains substantial amounts of calcium oxide (4.08 wt%). It is a totally amorphous material, as is indicated from the broad hump in the region between 2θ = 20 - 40°. rendering a satisfactory raw material for geopolymerisation.

Material Synthesis

The specimens for material characterisation and testing were prepared with the following procedure. A homogeneous viscous paste was initially prepared by mechanical mixing of the slag with 8 M potassium hydroxide solution. The solid to liquid ratio was selected equal to 6 g/ml. Then the foaming agent is added in order to reduce the density. Then, the paste was moulded in appropriate open plastic (Ertacetal) moulds in order to prepare the required specimens for testing. Cubic moulds of 5 cm internal edge were used for preparing cubic specimens. After moulding, the specimens with the moulds were placed in an oven and thus the material was cured at 70°C for 48 hours. After curing, the specimens were de-moulded and stored at temperature 20 ± 2°C and 50 ± 10% RH, until testing.

Analysis and tests

The performance of the material under thermal loading was assessed by subjecting the material to passive fire protection testing. To facilitate the experiments, a test

furnace was designed and constructed according to the EFNARC guidelines.[5] A temperature variation with time can be prescribed and controlled and thus the furnace has the ability to simulate all the temperature–time curves including the ISO-834 fire load curve. For this test a 15 x 15 x 15 cm composite specimen was prepared, consisting of 2 cm thick Cu-geopolymer material and 10 cm thick concrete slab. The concrete mix design also followed the EFNARC guidelines. The test was performed 28 days after the specimen production. In order to enhance the adhesion of the Cu-geopolymer with concrete the special Fischer FNA / 32 anchors were applied after the material development. During the test, the surface of the geopolymer material was exposed to a heat flux simulating the ISO-834 fire load curve. The temperature at the geopolymer/concrete interface was measured by using a "K"-type thermocouple, while the temperature of the unexposed concrete surface was measured at regular intervals with a high-performance infrared thermometer.

Results

In Figure 1 the temperature development on the concrete/geopolymer interface and on the unexposed concrete surface is shown for the 2 hours exposure of the coated concrete specimen to the ISO-834 fire load curve. As it is observed, the temperature at the geopolymer/concrete interface was lower than 180°C during the whole test duration. Thus, the 30 mm thick geopolymer coating maintained the interface temperature at least 60°C lower than the EFNARC performance requirements for an efficient fire-resistant material in a passive fire protection test with the ISO-834 fire load curve.

During the first 10 minutes, when the furnace temperature was increased from the ambient temperature to 600°C, the interface temperature was remained at 30°C establishing a temperature gradient equal to 25°C/mm across the fire-resistant material. Then, the interface temperature started increasing reaching a plateau of 100°C at about 45 minutes of test duration. At this time the furnace temperature was 950°C and the established temperature gradient across the geopolymer was 28.3°C/mm. The interface temperature remained near 100°C for the next 20 minutes. At 120 minutes of the test (end of the test), the furnace temperature and the unexposed side reached their highest values of 1049°C and 120°C respectively establishing the highest temperature gradient (31°C/mm) during the entire test duration. The temperature plateau of 100°C is attributed to the removal of endothermic water through an evaporation process consuming a large amount of the incoming heat due to the large latent heat of water vaporisation. The temperature at the unexposed surface of the concrete slab did not exceed 50°C during the whole test duration, as is seen in Figure 1, which means that the temperature across the

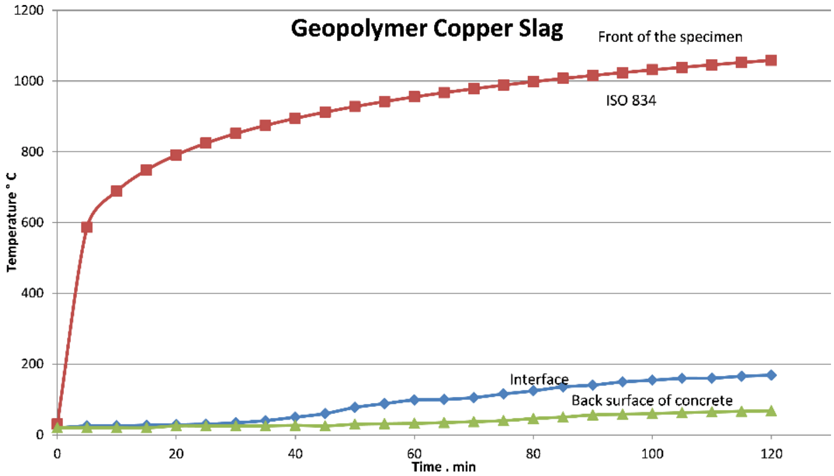

Figure 1: Performance of material under ISO-834 fire load curve

concrete slab was varied in-between 50°C and 120°C, which is substantially lower than the temperature at which the concrete undergoes spalling phenomena. As it is seen in Figure 2a and b, the material coating did not show any macroscopically visible mechanical damage after the end of the test. It remained on top of the concrete slab without any change of its geometry as well as without the appearance of deep cracks and wide openings. The exposed surface of the material remained almost intact, with shallow surface cracks and no other mechanical damages.

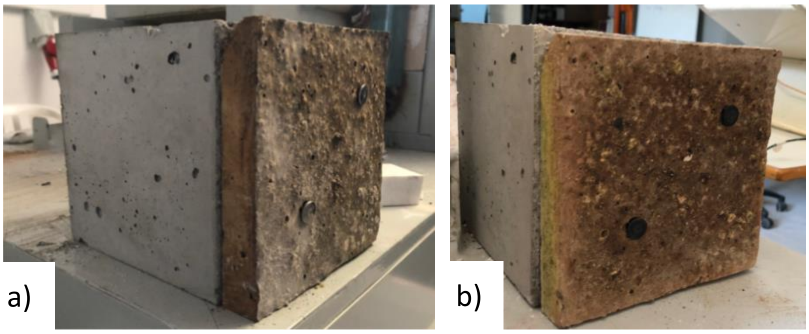

Figure 2: Specimen before (a) and after (b) the fire test

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