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IMPROVED FIRE RESISTANCE BY USING DIFFERENT DOSAGES OF METAKAOLIN

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SUMMARY

Concrete is a composite material that consists mainly of mineral aggregates bound by a matrix of hardened cement paste. Strength reduction of high strength concrete during and after fire may be different from that of normal strength concrete. The use of metakaolin as a recent material in the construction industry proves to be very useful to modify the properties of concrete. An extensive experimental study was carried out to analyses the post-heating characteristics of hardened cement paste subjected to temperatures up to 800 °C. Major parameters of our study were the content (0, 3, 6, 9 or 12 m%) of one type supplementary material (metakaolin) as a replacement of cement, as well as the value of maximum temperature of exposure (50, 150, 300, 400, 500, 800 and 900°C). In the experiments specimens were exposed to the given maximal temperatures and then cooled down to room temperature. Present studies included analysis of compressive strength.

1. INTRODUCTION

Concrete can be exposed to elevated temperatures during fire or when it is applied by furnaces and reactors. The behaviour of a concrete structural members exposed to fire is dependent on physical, thermal, and mechanical deformation properties of concrete of which the member is composed. The deterioration processes influence the durability of concrete structures and may result in undesirable structural failures. Therefore, preventative measures such as choosing the right materials should be taken to minimize the harmful effects of high temperature on concrete. The high temperature behaviour of concrete is greatly affected by material properties, such as the properties of the aggregate, the cement paste, and the bond between the aggregate and cement paste, as well as the thermal compatibility of the aggregate and cement paste.

2. BEHAVIOUR OF CONCRETE IN FIRE

2.1 Physical behaviour

It is generally agreed (Short, Purkiss and Guise, 2001; Colombo and Felicetti, 2007) that concrete containing siliceous aggregates when heated between 300 °C and 600 °C it will turn red; between 600 °C and 900 °C, whitish-grey; and between 900 °C and 1000 °C, a buff colour is present. The colour change of heated concrete results from the gradual water removal, dehydration of the cement paste, and transformations occurring within the aggregate, respectively. The most intense colour change, the appearance of red colouration, is observed for siliceous riverbed aggregates containing iron. This colouration is caused by the oxidation of mineral components. While siliceous aggregates turn red when heated, the aggregates containing calcium carbonate get whitish. Due to calcination process $CaCO_3$ turns to lime and give pale shades of white and grey (Hager, 2013a).

2.2 Thermal behaviour

Thermal properties that govern temperature dependent properties in concrete structures are thermal conductivity, specific heat (or heat capacity) and mass loss (Kodur, 2014). The density of concrete shows only slight temperature dependence, which is mostly due to moisture losses during heating. However limestone concretes show a significant decrease of density at about 800 °C due to the decomposition of the calcareous aggregate. The thermal conductivity of concrete depends on the conductivities of its constituents. The major factors are the moisture content, the type of aggregate and the mix proportions. The conductivity of any given concrete varies approximately linearly with the moisture content (Schneider, 1988).

2.3 Mechanical behaviour

The mechanical properties that are of primary interest in fire resistance design are compressive strength, tensile strength, elastic modulus and stress-strain response in compression (Kodur, 2014). The mechanical response of concrete is usually expressed in the form of stress-strain relations, which are often used as input data in mathematical models for evaluating the fire resistance of concrete structural members (Hager, 2013b).

Generally, because of a decrease in compressive strength and increase in ductility of concrete, the slope of stress-strain curve decreases with increasing temperature. The strength of concrete has a significant influence on stress-strain response both at room and elevated temperatures.

3. METAKAOLIN

Metakaolin (MK) is a recent addition in the list of pozzolanic materials. It is a thermally activated alumino- silicate produced from kaolinite clay through a calcining process. Unlike other pozzolans, MK is a primary product, not a secondary product or by-product. This allows the manufacturing process to be structured to produce the optimum characteristics for the MK, ensuring the production of a consistent product and a consistent supply. The white color of MK results in a concrete with lighter color, another advantage making it popular (Mlinárik and Kopecskó, 2013; Kopecskó and Mlinárik, 2014).

MK enhances the strength and durability of concrete through three primary actions which are the filler effect, the acceleration of ordinary Portland cement (OPC) hydration and the pozzolanic reaction with calcium hydroxide (CH). Wild, Khatib and Jones (1996) found that the filler effect is immediate, the acceleration of OPC hydration has its major impact within the first 24 h and the maximum effect of pozzolanic reaction occurs between 7 and 14 days. It was concluded that the optimum replacement level of OPC by MK to give maximum long term strength is about 20% by weight.

Kostuch, Walter and Jones (2000) discovered that a 10% replacement of cement with MK reduced the CH content in concrete by 70%, and a 20% replacement reduced it to almost zero after 28 days. However, the amount of MK required for complete elimination of CH depends on a number of factors such as purity of MK, Portland cement composition, water/binder ratio and curing conditions (Oriel and Pera, 1995). The reduction in CH content results in superior strength and durability performance, even at elevated temperatures (Lin, Lin and Powers-Couche, 1996). Poon, Kou and Lam (2000) prepared normal and high strength concrete (HSC) mixes incorporating 5%, 10% and 20% MK and compared their performance with the equivalent silica fume (SF) and fly ash (FA) mixes. They observed that the MK concrete possessed higher strength, lower permeability and less porosity as compared to the corresponding SF and FA concretes. In another study in the case of the mortar samples prepared with 10 or 17 m% MK, the smaller substitution (10 m%) was found more effective, than the higher substitution of the cement (17 m%). The compressive strength of the samples with 17 m% substitution is very similar to that of the reference samples (specimens made without metakaolin addition). The higher dosage of MK is expectedly resulted in the aggregation of the particles, which could not completely disperse during mixing. The results of the samples made with SF were the opposite; the higher substitution ratio (10 m%) was found to be more effective than the smaller substitution ratio (5 m%) (Mlinárik, Kopecskó and Borosnyói, 2016).

It was observed that the fire resistance of concrete is highly dependent on its constituent materials, particularly the pozzolans. A number of research studies (Phan, 1996) indicated that the addition of pozzolanic SCM highly densifies the pore structure of concrete, which can result in explosive spalling due to the build-up of pore pressure by steam. Since the evaporation of physically absorbed water starts at 80 °C which induces thermal cracks, such concretes may show inferior performance as compared to pure OPC concretes at elevated temperatures.

4. EXPERIMENTAL DETAILS

An experimental program was designed to analyse the post-heating characteristics of hardened cement paste subjected to temperatures up to 800 °C. Major parameters of our study were the different dosages (0, 3, 6, 9, 12 or 15 m%) of supplementary material (metakaolin) of the binder (as replacement of cement) and the value of maximum temperature (50, 150, 300, 400, 500, 800 °C). In the experiments specimens were exposed to the given maximal temperatures and then cooled down to room temperature. Tests were carried out at room temperature. Present studies included analysis of compressive strength.

4.1. Materials

Preparing the specimens OPC (CEM I 42,5 N) and metakaolin supplementary material was used. The water cement-ratio was 0.35. 2 g/kg liquid superplasticizer was applied. Cubic form cement paste specimens were cast with the size of 30 mm.

4.2. Curing and heating regimes

The specimens were demolded 24 h after the casting and placed in a water tank at 20 °C. After 7days of water curing, they were transferred to an environmental chamber maintained at 20 °C and normal humidity. At an age of 90 days, the specimens were heated in a furnace (20, 50, 150, 300, 400, 500, 800 and 900 °C). Our experimentally applied heating curve was similar to the standard fire curve up to 800 °C. Specimens were kept for two hours at the actual maximum temperature levels. Specimens were then slowly cooled down in laboratory conditions for further observations. During the heat load a program controlled electric furnace was used. The compressive strength was measured on the heat loaded and, than cooled down specimens and the average values of the measurements were analysed. The specimens were allowed to cool naturally to room temperature, and tested.

5. RESULTS AND DISCUSSIONS

The development of compressive strength as a function of temperature is presented in Fig. 1.

Residual compressive strength of cement stone specimens is shown in Fig. 2 relating to the concrete composition and the maximum temperature of thermal load, from which the following conclusions can be drawn: the relative residual compressive strength decreases up to 150 °C heat loading, then increases up to 300 °C. In the case of higher temperatures than 300 °C the residual relative compressive strength decreases again. Specimens loaded up to 300 °C show higher residual strength comparing with the average strengths measured on specimens loaded up to 150 °C because the intensive dehydration in the temperature interval between 60 and 180 °C probably causes the hydration of the unhydrated cement grains in the microstructure. To sum up these results, the temperature load at 900 °C caused increasing residual relative compressive strength with the increase of content of supplementary materials.

In case of cement stone prepared with metakaolin containing binder (to 12 m% related to the mass of cement) the strength increased due to the temperature load of 800 °C. Addition of metakaolin was found to be unfavourable for fire resistance of concrete at the age of test (thermal load was applied at the age of 90 days).

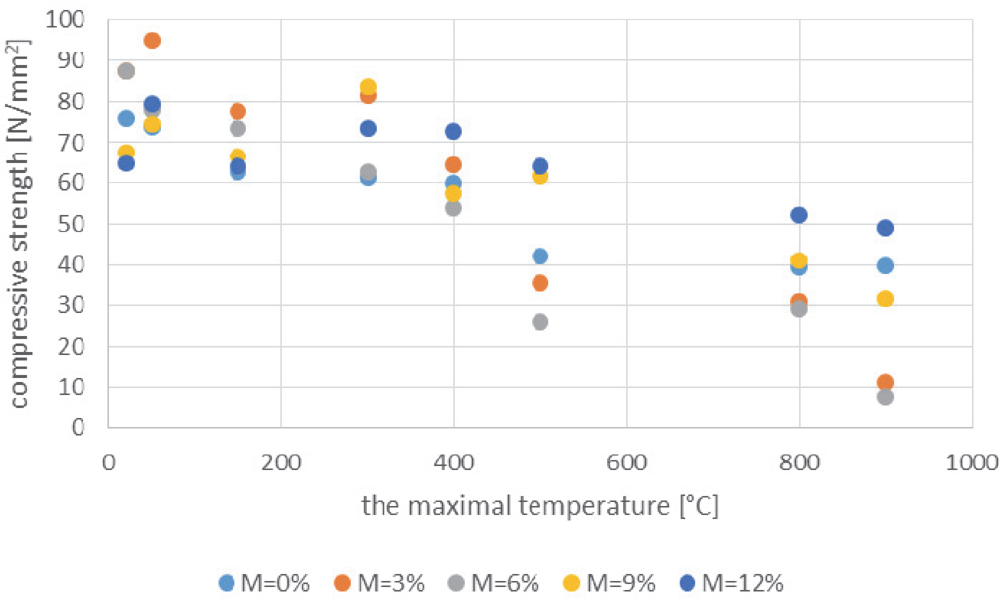

Fig. 1: The compressive strength for the different mixes as a function of maximum temperature (averages of 5 measurements)

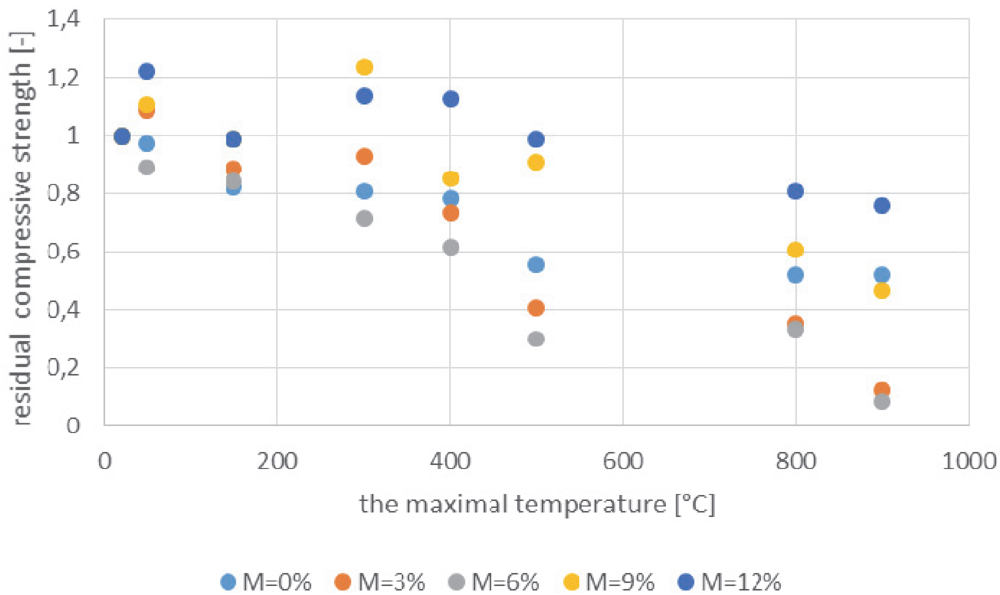

Fig. 2: Relative residual compressive strength for the different mixes as a function of maximum temperature (averages of 5 measurements)

6. CONCLUSIONS

Concrete is a composite material that consists mainly of mineral aggregates bound by a matrix of hardened cement paste. Strength reduction of high strength concrete during and after fire may be different from that of normal strength concrete. The use of metakaolin as a recent material in the construction industry proves to be very useful to modify the properties of concrete. An extensive experimental study was carried out to analyses the post-heating characteristics of hardened cement paste subjected to temperatures up to 800 °C. Major parameters of our study were the content (0, 3, 6, 9 or 12 m%) of supplementary material (metakaolin) of cement and the value of maximum temperature (50, 150, 300, 400, 500, 800 and 900°C). In the experiments specimens were exposed to the given maximal temperatures and then cooled down to room temperature.

The relative residual compressive strength decreases up to 150 °C heat loading, then increases up to 300 °C. In the case of higher temperatures than 300 °C the residual relative compressive strength decreases again. Specimens loaded up to 300 °C show higher residual strength comparing with the average strengths measured on specimens loaded up to 150 °C because the intensive dehydration in the temperature interval between 60 and 180 °C probably causes the hydration of the unhydrated cement grains in the microstructure. To sum up these results, the temperature load at 900 °C caused increasing residual relative compressive strength with the increase of content of supplementary materials.

In case of cement stone prepared with metakaolin containing binder (to 12 m% related to the mass of cement) the strength increased due to the temperature load of 800 °C. Addition of metakaolin was found to be unfavourable for fire resistance of concrete at early ages (thermal load was applied at the age of 28 days). This could be explained by the different rate of pozzolanic reaction of the SCMs.

7. ACKNOWLEDGEMENTS

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