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Determination of the Fire-Retardant Efficiency of Magnesite Thermal Insulating Materials to Protect Metal Structures from Fire

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Abstract. This paper presents the results of fire test of an I-beam protected by a combined magnesite plate-magnesite mixture heat-insulating material. It was shown that a composite with an average thickness of 37 mm maintained an average temperature of 380 °C on the metal surface after 150 minutes of fire exposure, not exceeding the critical value of 500 °C. From 60 to 100 minutes of fire testing (furnace temperature of 980-1025 °C), the temperature of the metal did not exceed 100 °C. This was achieved both due to the high thermal insulation properties of the magnesite mixture, and due to gas and vapor release from the hydration products of magnesia cement. The developed fire-retardant material provides the first group of fire-retardant efficiency (150 minutes) and, after the fire test, is characterized by density of 352.4 kg/m^3 and compressive strength of 0.85 MPa, which is three times lower than the original.

Introduction

Fire incidents are responsible for significant losses regarding human lives, infrastructure and natural environment [1]. Domestic or industrial activities, as well as natural phenomena, are among the risk factors that may cause ignition [2, 3]. Since most of the existing buildings and structures are constructed with extensive use of metal parts [4], the development of materials ensuring their protection against the effects of fire or maintenance of their functionality during fire events, is crucial [5, 6]. To this aim, intumescent coatings [7, 8], fire-protecting coatings and plate-type heat-insulating materials, are commonly used [9, 10]. It should be noted that some of them are suitable for the fire protection of several elements of metal structures, while other are only applicable to supporting metal structures.

General requirements for flame retardant materials, intended for steel load-bearing building structures, are defined in the Fire Safety Standards (NPB 236-97) "Fire-retardant compositions for steel structures. Method for determining fire-retardant efficiency." According to them, six fire-retardant efficiency groups were established for coating steel structures, determined by the time from the onset of high temperature exposure until the surface of the structure reaches a temperature of 500 °C. For the first group of effectiveness, this interval is 150, for the second – 120, for the third – 90, the fourth – 60, the fifth – 45, the sixth – 30 minutes.

Fire-retardant materials prepared on the basis of mineral binders filled with heat-insulating fillers, are of particular interest [11, 12]. Such compositions can be in the form of mixtures or thermal-insulating plates. The mixture is applied on the steel structure as a layer, whose thickness is determined by the required time of flame-retardant efficiency. The thicker the layer, the longer the steel is protected against heating up to 500 °C. Thermal-insulating plates of a given thickness are directly mounted on the supporting elements of metal structures. However, a fire-retardant material consisting of a plate base and a heat-insulating layer is of significant importance, in view of the synergetic function of both components.

This paper aims to determine the fire-retardant efficiency of a combined heat-insulating magnesite material for the fire protection of metal structures.

Experimental

Materials. The combined fire-retardant material was prepared using two components: (a) premium class magnesite plates (LLC NPP Ukrmagnesit, Sumy, Ukraine) 12 mm thick, characterized by fire resistance up to 1200 °C, water absorption of no more than 18%, bending strength of at least 8 MPa, density in the range of 950-1100 kg/m^3, thermal conductivity from 0.58 to 0.69 W/m·K; and (b) a heat-insulating magnesite mixture, whose main properties are given in [13, 14].

Fire test was performed on a hot-rolled steel I-beam No. 20 GOST 8239-89. The scheme showing the layout of the thermocouples used and of the heat-insulating composite material on the metal surfaces [15], is shown in Fig. 1.

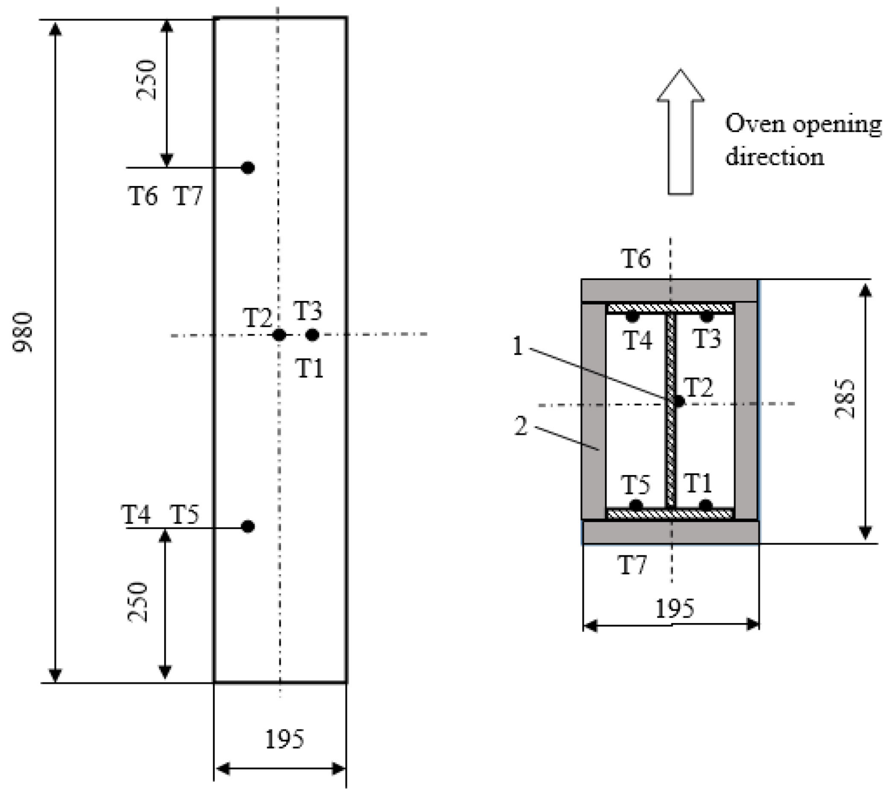

Fig. 1. Schematic representation of the insulated I-beam and of the layout of thermocouples set on it: 1 - I-beam; 2 fire-retardant cladding (magnesite plate); T1-T3 - the main thermocouples for the I-beam; T4-T7 - additional thermocouples for the I-beam

In Fig. 2, snapshots taken during the preparation of the I-beam for the fire test, are illustrated. The rusty surfaces of the I-beam were first treated with a rust converter Contrrust (PE "Ruslan and Lyudmila", Kyiv, Ukraine) [16]. Then magnesite plates of specified sizes were attached on the flanges of the I-beam, using an aluminosilicate glue manufactured by LLC Geofip (Kropyvnytskyi, Ukraine) [17]. Subsequently, a 25-mm thick heat-insulating magnesite mixture was applied, using wooden parts to achieve the required thickness. Special plastic elements were attached on the cross-sections of the I-beam with gypsum. Finally, the surfaces were plastered with gypsum and painted with the FB2 geopolymer paint manufactured by LLC Geofip (Kropyvnytskyi, Ukraine).

Fig. 2. Snapshots of the work stages during the preparation of an I-beam for fire test

Tests. Fig. 3, depicts the insulated I-beam placed free in the furnace before the fire test, was were carried out according to the requirements of DSTU B V.1.1-4-98. The average temperature in the furnace T_f (°C) is determined as the numerical average of the temperature of the thermocouple mounted on the furnace. During testing, T_f varies in accordance with the standard temperature regime T_s, determined as:

$$T_s = 345 \lg (8t + 1) + 20 \quad (1)$$

where t is the time (min) counting from the beginning of the fire test and T_s is the temperature (°C) at time t.

Permissible deviations d of the T_f were calculated by the formula

$$d = (T_f - T_s / T_s) \cdot 100\% \quad (2)$$

The deviation of T_f from T_s should not exceed the following values:

a) ± 15 % for $0 < t \leq 10$
b) ± 15 – 0.5(t-10) % for $10 < t \leq 30$
c) ± 5 - 0.083(t-30) % for $30 < t \leq 60$
d) ± 2.5 % for $t > 60$.

Fig. 3. Ready to test I-beam placed in the furnace

Results and Discussion

The temperature regime during the fire testing of an I-beam protected by a combined heat-insulating material, is shown in Fig. 4. It is demonstrated that the deviation of the temperature in the furnace (T_f) from the values of the standard temperature regime (T_s) is insignificant and corresponds to the above conditions. At 115 and 138 minutes after the ignition, insignificant deviations of T_f from T_{min} were recorded, which can be attributed to the release of CO_2 and H_2O as a result of thermal decomposition of the components of the magnesite heat-insulating mixture [18, 19].

Fig. 5 reports data on the temperature distribution on the metal surfaces of the I-beam, acquired using the thermocouples T1-T7. Further, the appearance of the lower part of the composite material during the fire test, is depicted as inset. During the first 60 min of the test, a small increase in temperature (from 20 to 100 °C) was observed. The surface temperature was maintained at 100 °C over the next 40 minutes, despite the temperature in the furnace reached 980-1025 °C during the test. Such stability is due to the heat-insulating properties of the magnesite mixture applied to the magnesite plates, and to the thermal decomposition of the mixture components and the products of dehydration of magnesian cement (magnesium oxychlorides of the type $xMgO \cdot MgCl_2 \cdot yH_2O$, $MgCO_3$ and $Mg(OH)_2$ [19]), with the release of water vapor and carbon dioxide. This behavior can be tailored to the needs of certain applications by altering the water content in the magnesite mixture or the annealing temperature to obtain MgO powder, both affecting the microstructure and the properties of the obtained heat-insulating material, similarly to magnesium potassium phosphate ceramics [20, 21].

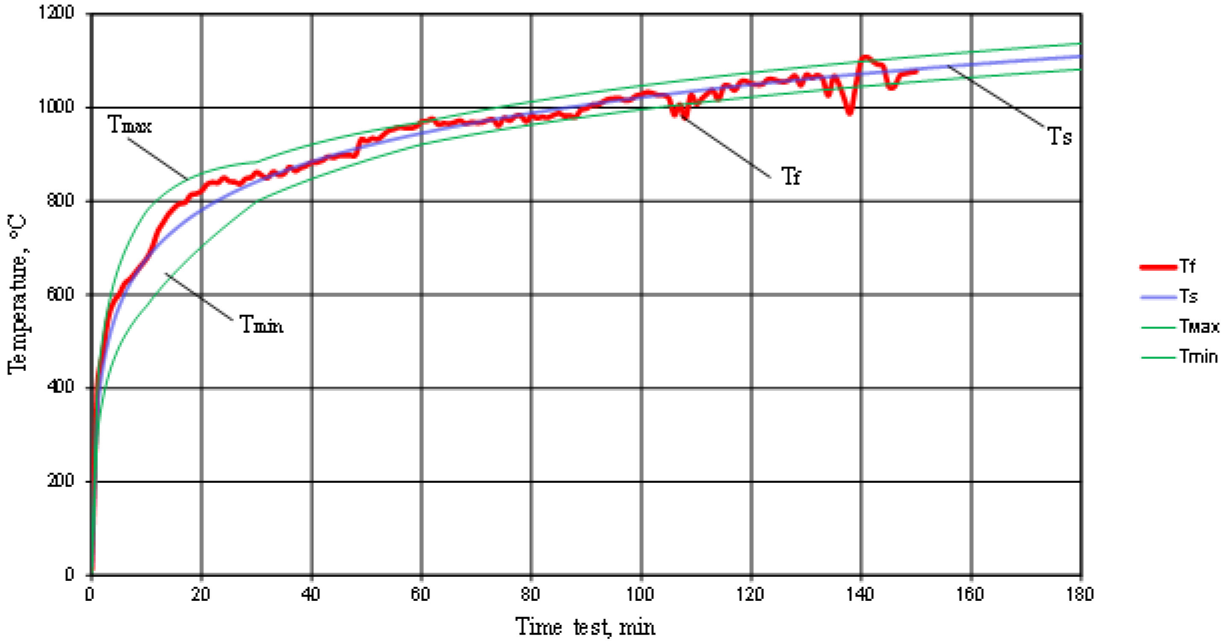

Fig. 4. Variation of the average furnace temperature (T_f) with time. Standard temperature regime (T_s), maximum temperature (T_{max}) and minimum temperature (T_{min}), are indicated.

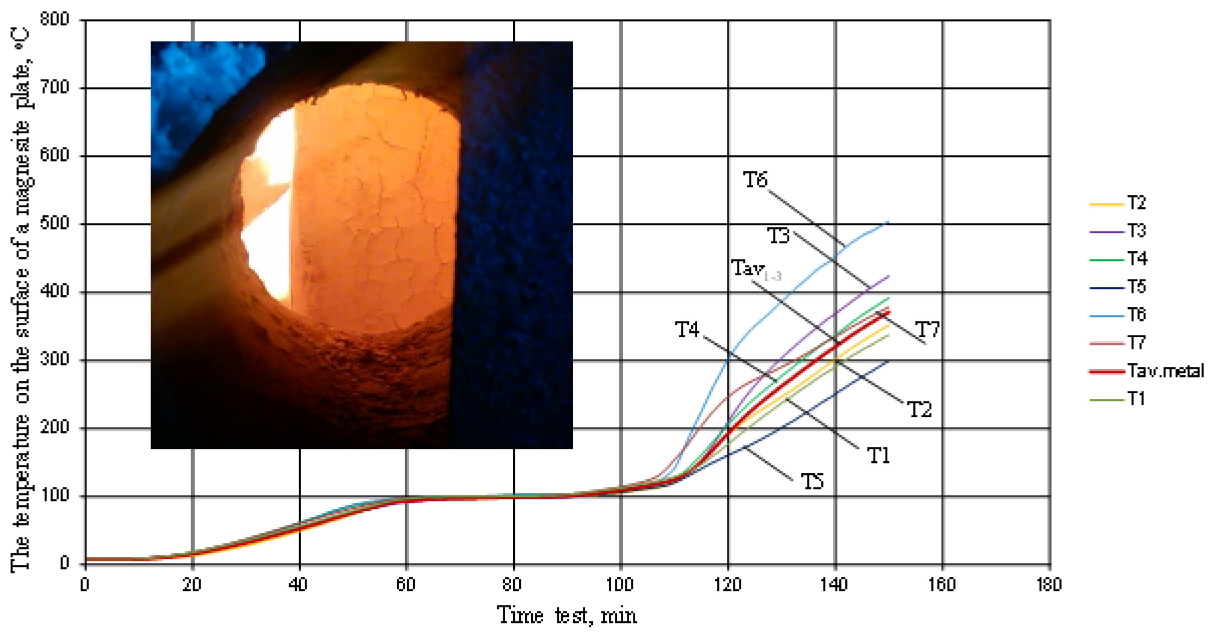

Fig. 5. Evolution of temperature on the metal surfaces of the I-beam: T1-T3 – the main thermocouples adapted on the I-beam; T_{av1-3} – average values of thermocouples T1-T3; T4-T7 – additional thermocouples. The appearance of the magnesite composite during testing is provided as inset.

Between 100 and 150 min of the fire test, the temperature of each metal surface begun to gradually increase from 100 to approx. 380 °C. According to the values recorded at 150 min (the temperature in the furnace was 1050 °C at that time), the average temperature of the metal surfaces of the I-beam did not reach the critical value of 500 °C (Fig. 5). The only exception was the temperature measured with the T6 thermocouple, located on the side flange of the I-beam (Fig. 1), slightly exceeding 500 °C and, thus, marking the end of the test. This phenomenon can be attributed to a partial destruction of the continuity of the heat-insulating magnesite mixture, allowing for the penetration of heat flux through its raptured surface that subsequently heated the metal surface up to 500 °C.

After the completion of the fire test, the density of the heat-insulating magnesite mixture was 352.4 kg/m^3, and the compressive strength was 0.85 MPa, which is three times lower than the original.

Summary

Fire test results indicated that a combined magnesite heat-insulating material with an average thickness of 37 mm provides the first group of fire-retarding efficiency for protecting steel metal structures (150 minutes). Due to the heat-insulating properties of magnesite mixture, the temperature of the metal surfaces of the I-beam tested, did not exceed 100 °C after 40 min of heat exposure. Their average temperature after 150 min of firing did not exceed 380 °C. After the fire test, the density of the heat-insulating magnesite mixture was 352.4 kg/m^3, and the compressive strength was 0.85 MPa, which is three times lower than the original.

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