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Research of Integrity of Fire Insulation Cladding with Mineral Wool of Steel Beam under Fire Impact

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Abstract. In the article, the processes of integrity loss of fire-retardant cladding from mineral wool of a steel I-beam are considered. The relation between fire-retardant cladding integrity and its thermal insulating ability was studied. Computer model of a steel beam with fire-retardant cladding of mineral wool, which takes into account its own weight, current mechanical load and temperature mode of heating under the heat-insulating effect of the cladding, using the computer system LS-DINA, is developed in this article. It is shown that the fire-retardant cladding loses its integrity under the thermal influence of fire long before the onset of the limit state of loss of fire resistance in terms of bearing capacity. The conditions under which fire-retardant cladding loses its integrity and fire-retardant ability are investigated. Having considered the time of fire-retardant cladding integrity loss the fire resistance limit can be significantly clarified and allows to avoid early collapse of building structures cause by fire.

1. Introduction

Due to the high thermal conductivity of the metal and small cross-sectional dimensions, steel structures heat up quickly in a fire. Using fire-retardant cladding remains an effective means of ensuring the design fire resistance of steel structures. Promising material for fire-retardant cladding are mineral wool boards, as their using provides advantages when performing installation work, their cost, as well as the ability to increase fire resistance without dismantling the main structures.

When fire-retardant cladding with mineral wool is used, an important question arises of preserving its integrity to ensure appropriate fire-retardant functions during the entire time of fire exposure until the onset of the limiting state of loss of fire resistance in terms of bearing capacity. Taking this into account, it is important to study the behavior of a steel beam with a fire-retardant mineral wool cladding and to establish the conditions under which the destruction of the cladding is possible with a possible loss of fire-retardant ability. Considering such conditions allows us to more accurately take into account the thermal effect of a fire and obtain updated data on the fire resistance of steel structures with a similar fire-retardant cladding, in particular, I-beams, as one of the most common elements of such structures. This can be achieved by switching at the appropriate time from the calculation of the temperature in condition of the fire-retardant cladding existing to the calculation when it is absent. Obviously, the limit of fire resistance will be less value. Taking this feature into account, the risk of erroneous assessment of compliance with the required fire resistance class can be



reduced and in this way fire safety level of such type building structures can be significantly improved. The above material is distinguishing actual of studies in this area.

2. Analysis of recent achievements and publications

Both experiments and calculations are devoted to the study of the thermal conductivity coefficient of building materials [1–8].

In [1], four options for assessing the fire protection of steel structures are described. Alternatives to the use of unprotected steel by the method of geometric average methodological and analytical hierarchy are also shown. However, using of mineral wool as a fire protection is not considered.

The work [2] is devoted to the study of realistic behavior of steel structures under the influence of fire. However, the behavior of fire-retardant structures has not been studied.

In [3–4] the results of application of the finite element method to obtain the necessary database for assessing the fire resistance of building structures are shown.

The paper [7] presents the essence of the published Brazilian standards for the design of fire-retardant steel structures. One of the options for fire protection is the use of mineral wool cladding. However, the requirements for the thickness and quality of the cladding are not given.

In the study [8], according to international recommendations, the results of the experimental study and the numerical calculation of the temperature inside the thermally protected steel structures under the action of fire were compared. However, the models were not verified.

3. Purpose

The purpose of this work is to identify the conditions under which the fire-retardant coating of mineral wool for a steel beam loses its fire-retardant ability due to loss of integrity under the thermal influence of the standard temperature of the fire. To do this, a numerical experiment was performed using a computer model created using the computer system LS-DYNA.

4. Method

To simulate the stress-strain state in a steel beam with fire-retardant cladding of mineral wool, we used a generalized engineering approach, which is based on the following provisions.

To calculate the stress-strain state of a deformed body, a general theoretical approach is used, which is based on the initiation of displacements of point of the system of deformed bodies using a system of generalized dynamics equations and stress-strain equations as a response to the displacement data, which is approximated by the finite element method, implemented in the computer system LS-DYNA.

To model a steel beam, two-dimensional shell finite elements (FE) of a rectangular shape of the Belichko-Tsay type [9–10] with four nodal points and five points of integration over thickness are used.

Three-dimensional massive hexahedral FE with eight nodal points are used for modeling mineral wool plates of fire-retardant facing.

As a model of steel beam material, a thermoelastic material with the possibility of plastic deformations is used, the deformation diagrams of which correspond to the recommendations of the second part of Eurocode 3, the shape of which includes only the growth section and the horizontal section. The descending branch is not taken into account, since its presence does not significantly affect the nature of the deformation of the steel beam, due to the prevalence of transverse displacements under conditions of section stability loss.

The Blatz-Co model is used to describe the nonlinear behavior of the material of mineral wool plates of fire-retardant facing [9–10].

It is assumed that the disturbance of the connection tightness between the mineral wool fire-retardant plates and the surface of the beam occurs under the condition of mineral wool delamination, because according to the technical conditions of the manufacturer, the glue has good adhesion and is

resistant to high temperatures, while the tensile strength at separation and shear of the mineral wool itself is much lower [7].

To describe the performance of the connection between the mineral wool plates of fire retardant cladding and the surface, the model of contact interaction with its violation is used, provided that the shear strength and abruption strength between the contacting surfaces are equal to the corresponding strength of the mineral wool itself as the least durable material.

The application of the load has a dynamic history and occurs gradually with the initial application of its own weight, the actual load and the application of the temperature load as calculated in the last stage.

The structural scheme of a beam with a protective mineral wool cladding is shown in Figure 1.

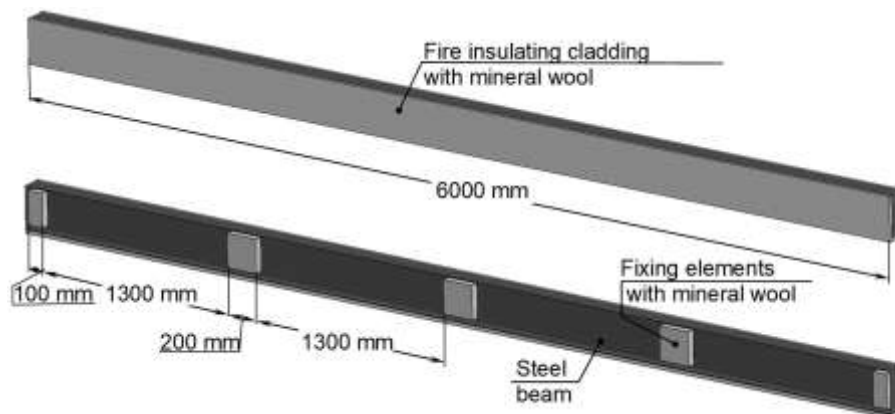


Figure 1. Structural scheme of a steel beam with fire-retardant facing on the basis of mineral wool.

For the calculation, it was assumed that the likely separation of the fire retardant cladding occurs not along the adhesive seam, but along the adjacent layers of mineral wool, that is, the destruction is cohesive. This assumption is made taking into account the fact that the strength of the adhesive seam is much higher than the tensile strength and shear strength of the mineral itself. This assumption is taken into account by means of the LS-DYNA software environment when describing the contact interaction between the elements of the model. The parameters of contact interaction are shown in Figure 2.

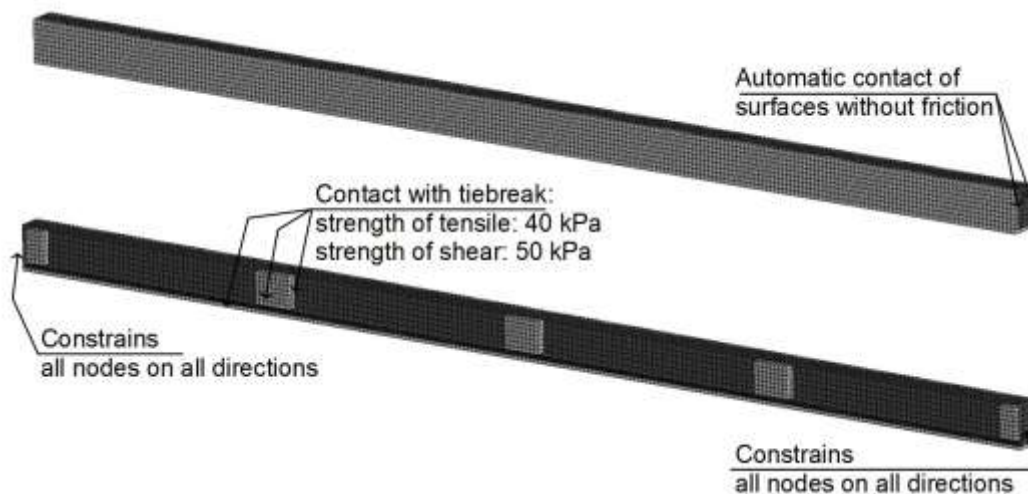


Figure 2. Finite element scheme of a steel beam with fire-retardant mineral wool cladding with boundary conditions and conditions of contact interaction

The scheme of load application of a steel beam with fire-retardant cladding from mineral wool, which is resulted as shown in Figure 3, shows type and a direction of the applied loading.

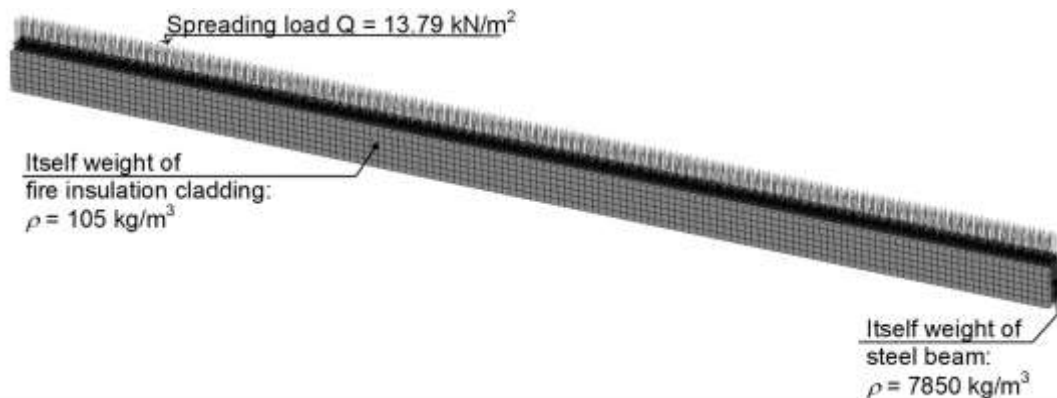


Figure 3. Scheme of load application to a steel beam with fire-retardant cladding on the basis of mineral wool with boundary conditions and conditions of contact interaction

5. Consideration on methods and results

After the calculation, the results were obtained on the behavior of a steel beam with fire-retardant cladding of mineral wool under the influence of the fire standard temperature.

Figure 4 shows graphs of changes in the maximum deflection of the beam and the rate of increase in the maximum deflection depending on the time of exposure to the standard temperature mode of the fire.

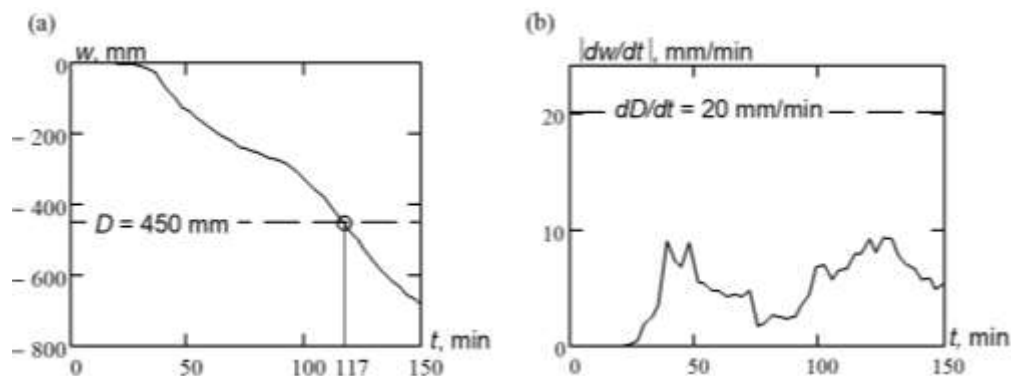


Figure 4. Graphs of changes in the maximum deflection of the beam (a) and the rate of increase of the maximum deflection (b) depending on the time of exposure to the standard temperature mode of the fire.

Figure 4 shows the critical values of the maximum deflection D of the beam and the rate of increase of the maximum deflection of the beam, above which the onset of the state of loss of bearing capacity is recorded. Critical values are determined by the formulas used in [11-12]:

$$D = \frac{l^2}{400H}, \quad \frac{dD}{dt} = \frac{l^2}{9000H}, \quad (1)$$

where l is beam span length (mm), H is height of beam cross-section (mm).

According to the graphs given in Figure 4 it can be concluded that the onset of the state of loss of fire resistance by bearing capacity occurs at 117 min under the influence of the standard temperature mode of the fire.

In order to study the integrity of the fire-retardant mineral wool cladding of the tested steel beam, the positions and geometric shape of the cladding at different points in time of exposure to the standard temperature mode of the fire, shown in Figure 5.

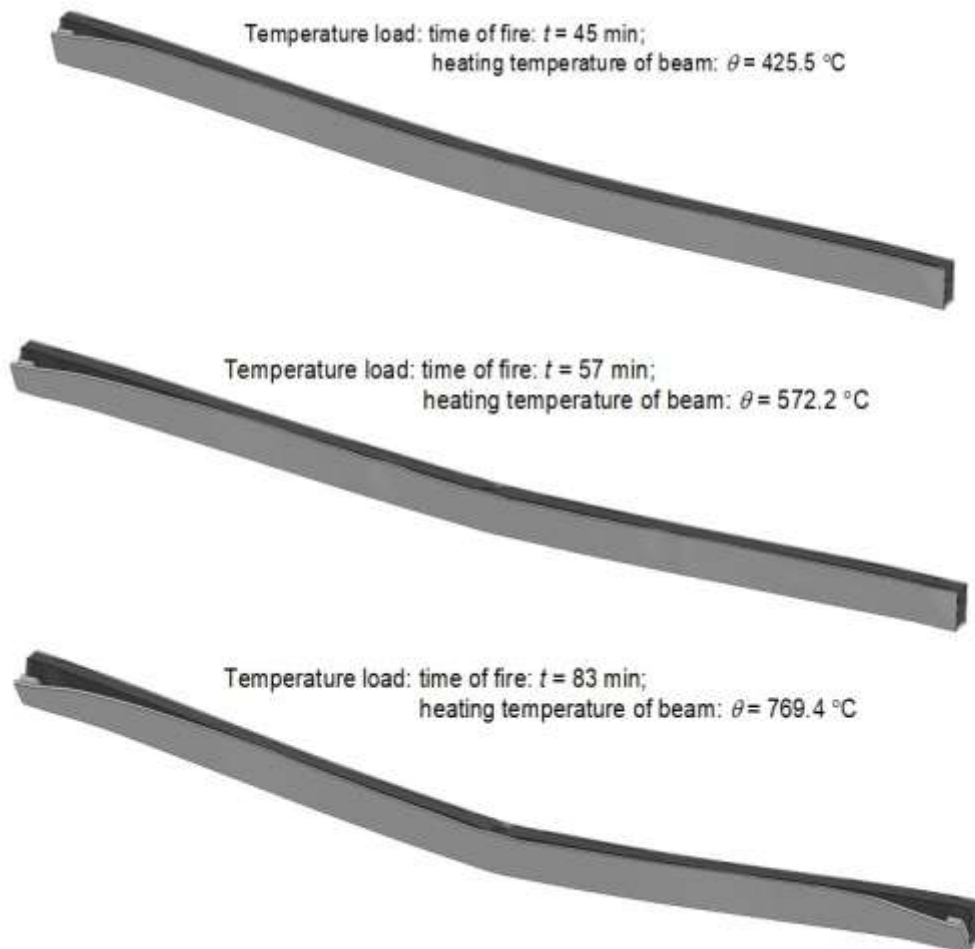


Figure 5. Position and geometric shape of the cladding at different points in the time of exposure to the standard temperature of the fire.

The graph of the gap depending on the time of exposure to the standard temperature mode of the fire is shown in Figure 5.

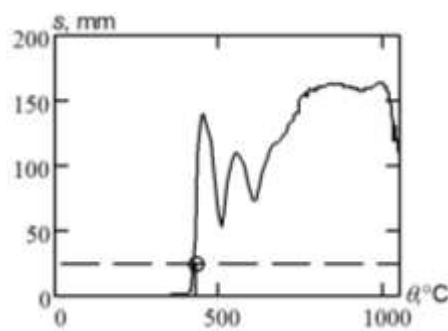


Figure 6. Graph of the gap between the cladding and the edge of the steel beam depending on the heating temperature.

These graphs indicate the moment of opening the gap with a delamination of 25 mm. It was found that the opening of the gap between the beam and the cladding of 25 mm in size is observed at a time of 44.5 min at a heating temperature of the steel beam 425°C.

6. Conclusions

Conducted research lets to make such conclusions.

1. The behavior of a steel beam with fire-retardant mineral wool cladding under the influence of the standard temperature mode of the fire in the period from 0 to 150 minutes was studied.

2. During fire exposure of 60 minutes at a temperature of 433°C, detachments of fastening mineral wool elements are observed, and at a temperature of 967°C, signs of local loss of stability are observed in the form of folds in the shelves and the wall of the I-beam in the middle and at its fixed ends it was found that the onset of the state of loss of fire resistance by the bearing capacity of the investigated steel beam with mineral wool fire-retardant cladding occurs at 117 minutes of exposure to the standard temperature mode of the fire.

3. It was found that the opening of the gap between the beam and the mineral wool fire-retardant cladding 25 mm in size is observed at a time of 44.5 min at a heating temperature of the steel beam 425°C.

4. It was found that the loss of fire-retardant capacity of mineral wool on the basis of opening the gap between the beam and cladding 25 mm in size occurs earlier by 73 min at the onset of the limit state of fire-resistance loss, which must be taken into account in the calculations.

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