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Investigation and simulation of temperature changes and thermal deformations of multilayered structure with gypsum plate

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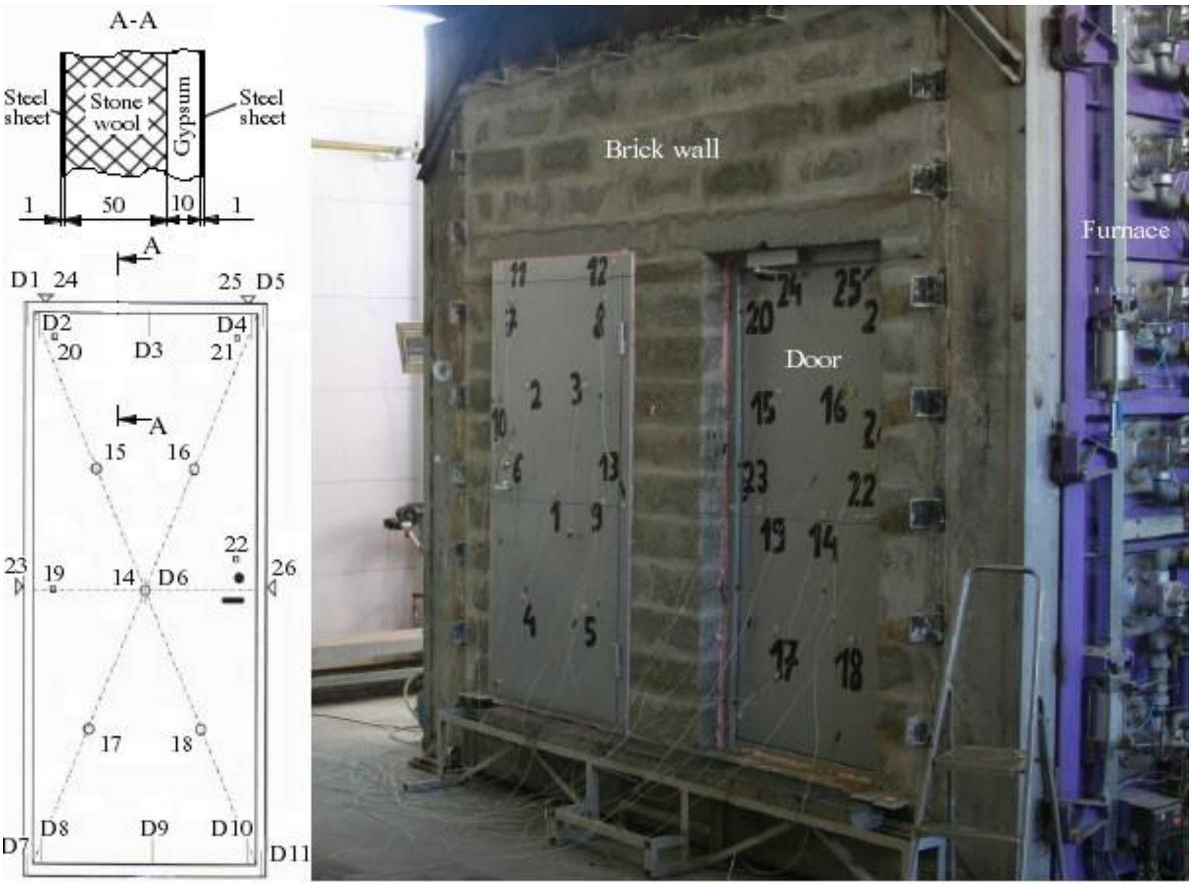
1. Introduction

Modern fire resistant multilayered structures must be able to withstand temperatures up to 360ºC in order to protect the escaping routes and escaping people against fire [1]. Wooden structures exhibit good thermal insulation properties, but their protection time interval is limited due to the high combustion rate of the wood (about 2 mm/min [2, 3]. Therefore such structures must be made of less combustible materials. In some cases gas and polymer fillers [4] are used in the structures, but these structures are expensive and complicated. Gypsum is one of the cheapest materials that has very good thermal insulation properties and can resist the spread of fire.

This work investigates the thermal behaviour of fire resistant multilayered structure containing gypsum plate.

2. Object of investigation

Fire resistant multilayered structure (Fig. 1, a, dimensions *H*×*W*: 2100×980 mm) consisting of outer 1 mm thick steel sheet, 10 mm thick gypsum plate, 50 mm thick stone wool (density 140 kg/m^3) layer and 1 mm inner thick steel sheet was chosen as an object of investigation. A door was installed into the brick wall fastened to the furnace as shown in Fig. 1, b. Because the investigated structure is asymmetrical with respect to the vertical centre plane, it was investigated under different fire conditions. In the first case (shown on the right side (from the viewer‘s perspective) of Fig. 1, b) gypsum layer was located closer to the flame than stone wool layer. In the second case (shown on the left side (from the viewer‘s perspective) of Fig. 1, b), stone wool layer was closer to the heat source.



a b

Fig. 1 Scheme of investigated multilayered structure (a) and photography of the wall with specimens fastened to the furnace (b): 1-26 - temperature measuring points; D1-D11 - thermal deformation measuring points

3. Experimental procedure and results

High-temperature tests were conducted in special gas-fired fire test furnace under real fire conditions [1]. The furnace temperature was controlled using six thermocouples distributed evenly inside the furnace. Thermocouple signals are transmitted to the computer, which compares measured and programmed temperature values and controls the fuel valve of the furnace.

Initial temperature inside the furnace at the beginning of the test was equal to 13ºC. Then it was increased according the recommendations [5]. Pressure inside the furnace was kept constant (20 Pa) throughout the whole experiment.

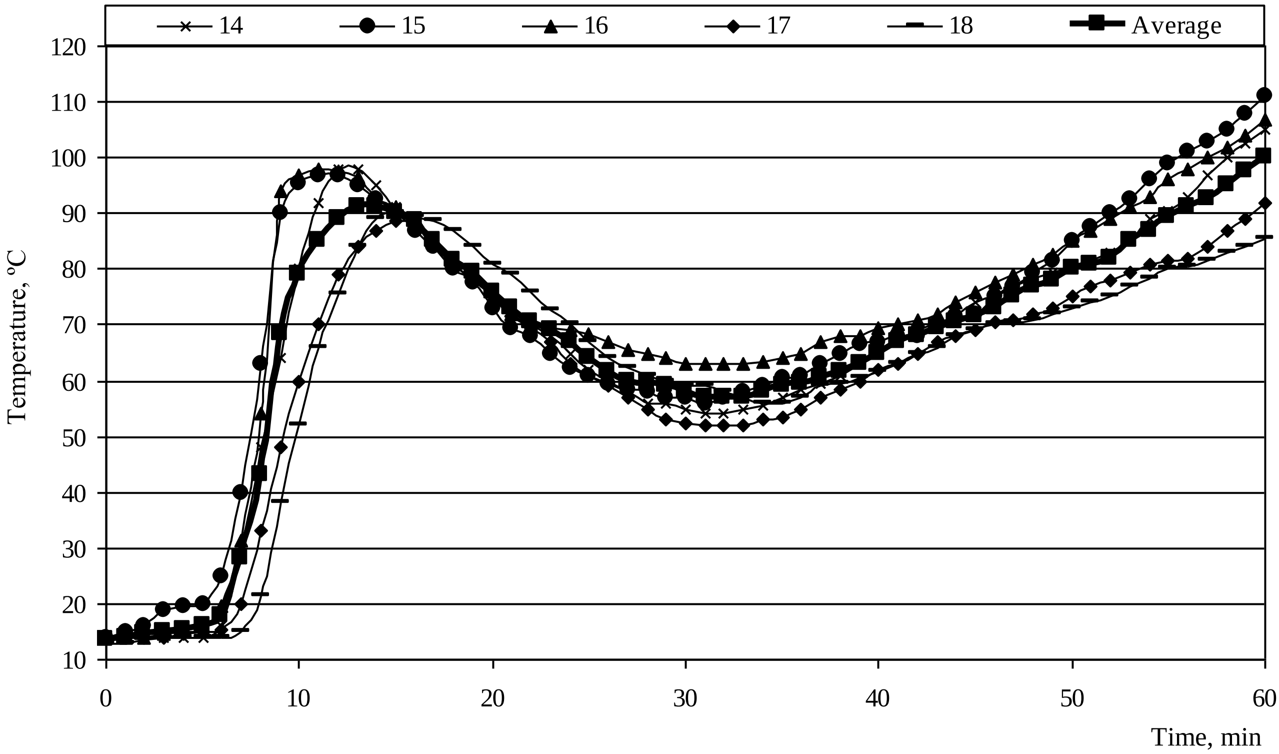


Fig. 2 Temperatures measured at the points 14-18 (Fig. 1) as the function of time

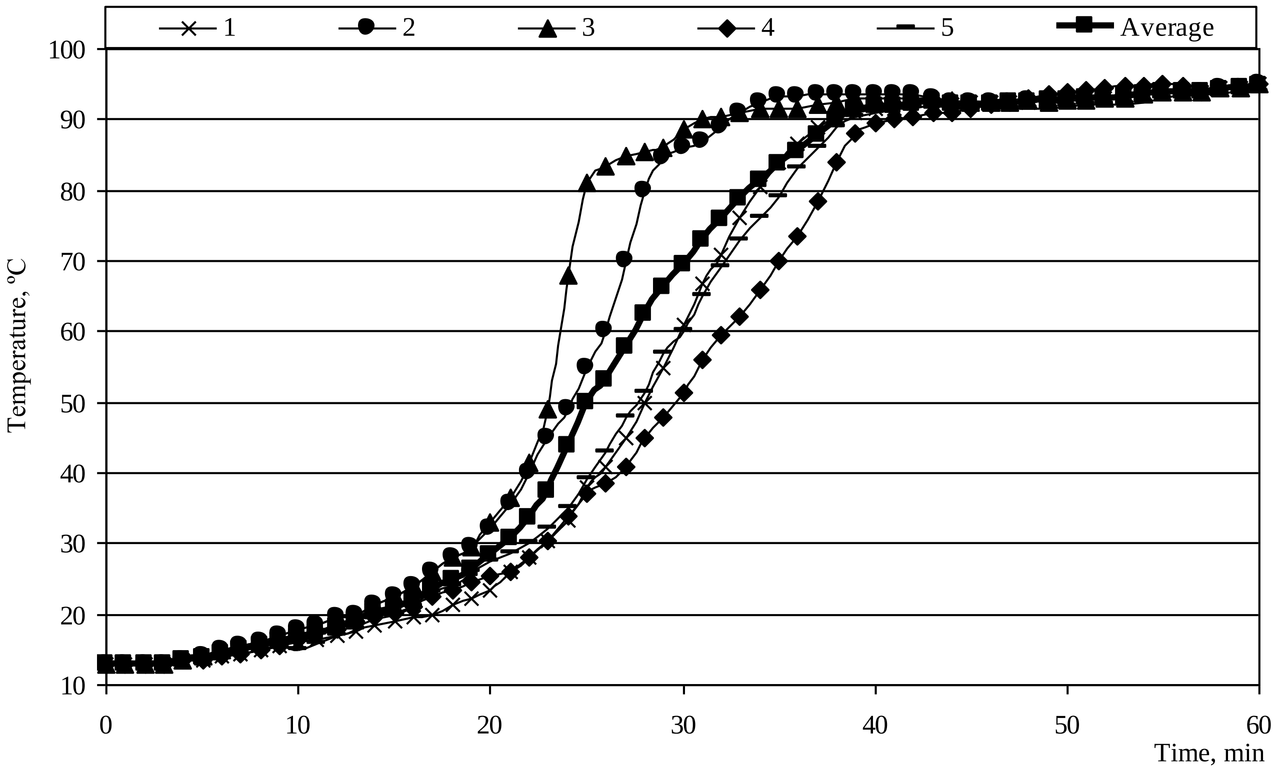


Fig. 3 Temperatures measured at the points 1-5 (Fig. 1, b) as the function of time

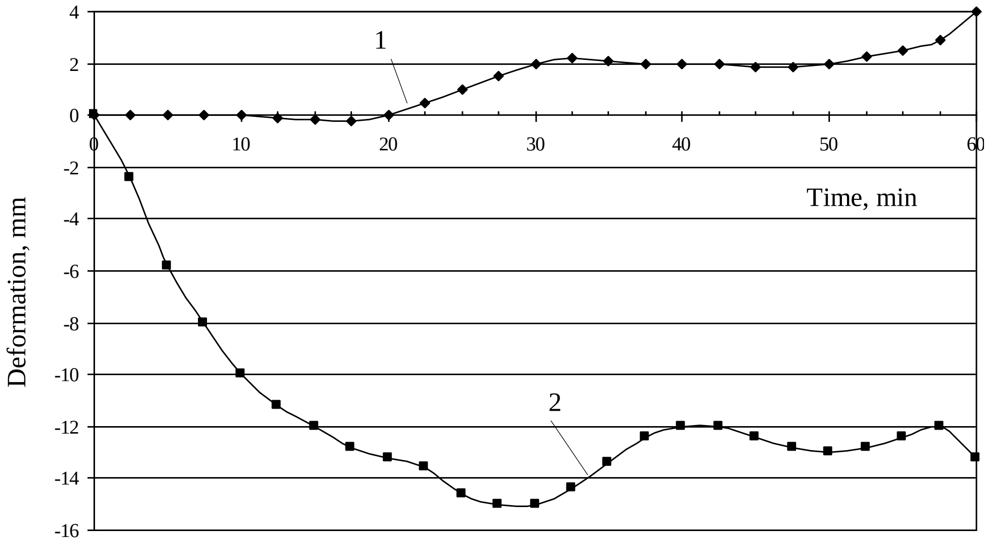


Fig. 4 Deformations measured at the centre point of the structure (D6) as the function of time (the negative sign means that the deformation occurs in direction to the heat source, otherwise it is positive): *1* - case shown on the right side of Fig. 1, b; *2* - case shown on the left side of Fig. 1, b

Temperature of the door was measured by thermoelements attached to the door at measuring points 1-26 (Fig. 1) according to the recommendations [6]. Temperature at the points 1-5 and 14-18 during the testing should not exceed 180ºC, temperature of the remaining points should not exceed 360ºC otherwise the experiment is considered as failed, because fire penetration through the structure can occur. The structure is considered as unable to ensure protection of premises and escaping from building people against thermal effects.

Thermal deformations of the door were measured with respect to the wall at the points D1-D11 shown in Fig. 1, a. For that purpose three horizontal steel strings were attached to the wall before the investigated structure, these strings are seen in Fig. 1, b. Thermal deformations of the structure were measured with respect to these strings by means of the calliper. Thermal deformations analysis is very important for such segmental structures, consisting of separate stone wool panels, a gap between segments can be created due to large deformations of the structure. These gaps sufficiently increase the risk of fire penetration and spread.

Temperatures versus time curves are presented in Figs. 2 and 3. The test was terminated after 60 min.

Thermal deformation values measured at the points D1-D11 at the end of the test are presented in Table.

Thermal deformation measured at the centre point of the structure versus time curves are presented in Fig. 4.

Temperature at the door points 14-18 increased to 92ºC during the period of 14 min then fell to 57ºC (Fig. 2). The structure "cooled itself" due to the layer combination during the period of 20 min. The cooling rate was about 2ºC/min. Then temperature raised evenly approximately at 1.5ºC/min rate. The effect of self-cooling was observed for the whole structure, not only for points 14-18. Temperature at the points 19-22 decreased slightly (about 15ºC only), less as compared to the points 14-18. In case shown on the right side of Fig. 1, b no self-cooling effect was observed (Fig. 3).

Thermal deformations at the centre point of the structure shown on the right side of Fig. 1, b were insufficient for practical applications. Maximum value of 4 mm was reached at the end of the test (Fig. 4, curve *1*). In case shown on the left side of Fig. 1, b the deformation reached 12-13 mm at the end of the test (Fig. 4, curve *2*).

Table

Thermal deformations of the structure at the end of the test (case shown on the right side of Fig. 1, b)

Measuring point (Fig. 1, a)	Deformation value, mm	
	Measured	Calculated
D1	10	10
D2	8	9
D3	13	12
D4	2	2
D5	0	0
D6	4	4.5
D7	5	6
D8	3	2.5
D9	3	2.5
D10	–8	–8
D11	–1	0

Note: The negative sign means that the deformation occurs in direction to the heat source, otherwise it is positive

4. Numerical analysis

Simulations of thermal behaviour of the structure were performed using SolidWorks® Simulation software. The case shown on the right side of Fig. 1, b was chosen for further numerical analysis only. In this case the structure demonstrated useful self-cooling properties and exhibited less thermal deformations compared with the case shown on the left side of Fig. 1, b.

Peculiarities of the structure and contact properties between layers [7, 8] of the structure were evaluated through simulations. Results of the simulation are presented in Figs. 5 and 6. It is evident from Fig. 5 that temperature graph obtained from the simulation tends to coincide with experimental one (Fig. 2). Calculated thermal deformation values (Fig. 6, Table) are in good concordance with experimental data presented in Table.

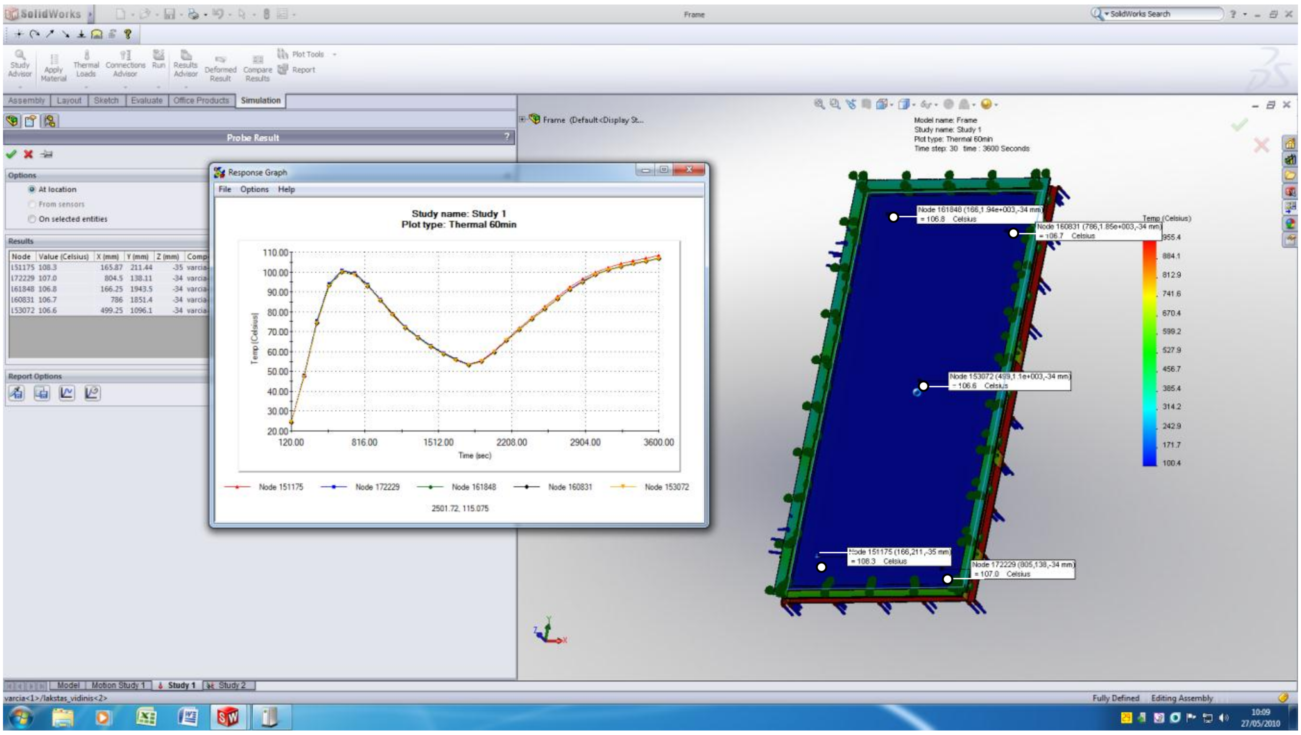


Fig. 5 Distribution of temperature in the investigated structure (temperature at measuring points 14-18 (Fig. 1) versus time graph is presented in separate window) at the end of the fire test; results obtained from SolidWorks® Simulation software

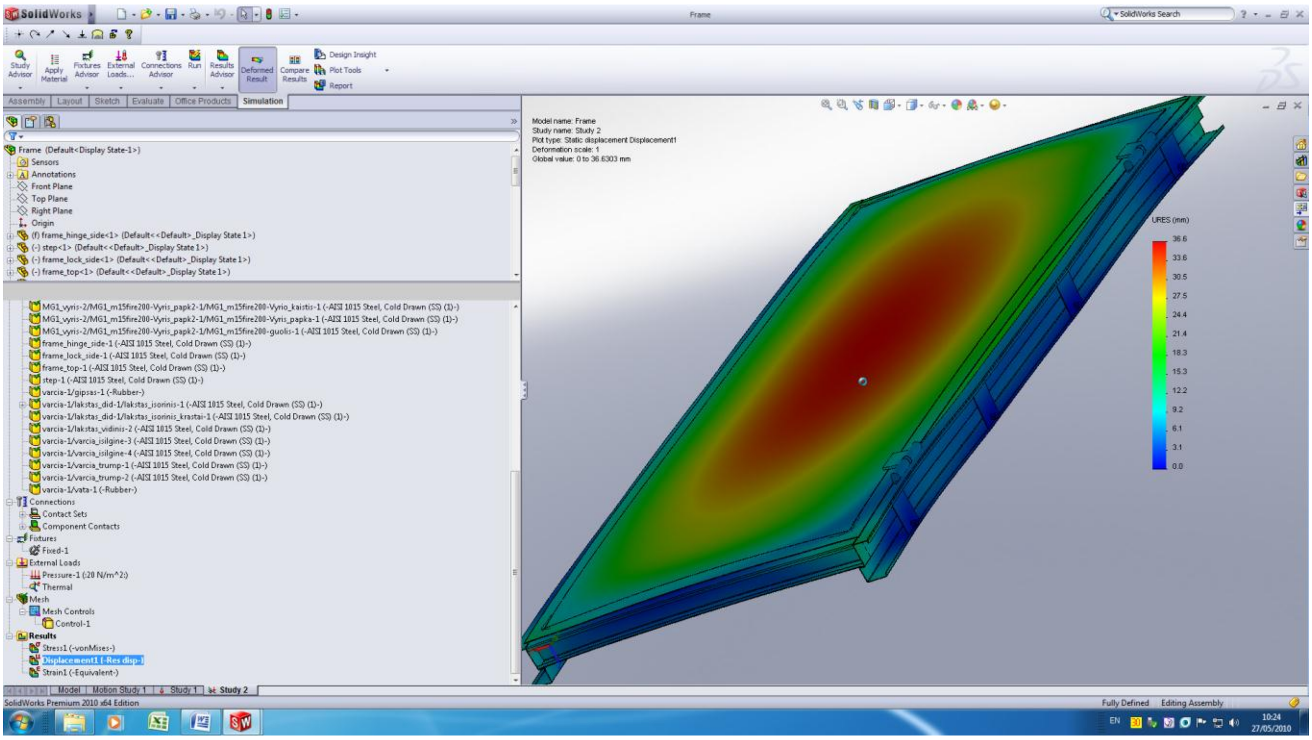


Fig. 6 Distribution of thermal deformations in the investigated structure at the end of the fire test; results obtained from SolidWorks® Simulation software

5. Conclusion

Results of numerical finite element analysis of multilayered structure with gypsum plate are found to be in good agreement with experimental results. This shows the suitability of numerical methods for the analysis of thermal behaviour of such type structures.

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DAUGIASLUOKSNĖS KONSTRUKCIJOS SU GIPSO PLOKŠTE TEMPERATŪROS POKYČIŲ IR TEMPERATŪRINIŲ DEFORMACIJŲ TYRIMAS IR MODELIAVIMAS

R e z i u m ė

Straipsnyje pateikti ugniai atsparios daugiasluoksnės konstrukcijos sudarytos iš dviejų plieno lakštų, gipso plokštės ir akmens vatos sluoksnio, temperatūrų ir temperatūrinių deformacijų modeliavimo resultatai. Modeliavimui buvo naudojama programinė įranga „SolidWorks® Simulation“. Skaitmeninio modeliavimo rezultatai buvo lyginami su eksperimentinių matavimų rezultatais, gautais kaitinant konstrukciją specialioje krosnyje. Skaičiavimo ir matavimo rezultatai gerai sutapo. Parodyta, kad tokio tipo konstrukcijų analizei galima sėkmingai taikyti skaitmeninius metodus, apsieinant be brangiai kainuojančių ir ilgai trunkančių eksperimentinių bandymų.

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INVESTIGATION AND SIMULATION OF TEMPERATURE CHANGES AND THERMAL DEFORMATIONS OF MULTILAYERED STRUCTURE WITH GYPSUM PLATE

S u m m a r y

This work presents numerical investigations of the thermal behaviour of fire resistant multilayered structure consisting of two steel sheets, gypsum plate and stone wool layer. Simulation was performed using SolidWorks® Simulation software. The numerical simulation results were compared with experimental data obtained from the fire resistance test. The simulation results were found to be in good agreement with experimental results. It is shown that thermal behaviour of such multilayered structures can be investigated numerically, thus avoiding costly and time-consuming laboratory experiments.

Keywords: fire resistant multilayered structure, fire test, steel, stone wool, gypsum plate, temperature, thermal deformations, numerical model.

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