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INFLUENCE OF PROPERTIES OF BUILDING MATERIALS IN WOODEN SANDWICH CONSTRUCTIONS ON OVERALL FIRE RESISTANCE

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Abstract: *By choosing suitable individual building materials for a sandwich structure, we can ensure an increase in the fire resistance of the entire structure. The influence of the properties of individual building materials on the overall fire resistance in sandwich constructions has not been well researched. It is for this reason that we focus our contribution on the influence of the properties of building materials in wooden sandwich structures on overall fire resistance. In the wooden sandwich constructions we created, we worked with reference constructions composed of thermal insulation with different surface treatments and with constructions that have the same thermal insulation, but we added 40 mm thick mineral wool to them. Subsequently, we tested the structures according to the EN 1365-1 standard [4]. After processing the obtained results, we came to conclusions about the effect of mineral wool and its combination with suitable thermal insulation on overall fire resistance.*

Key words: *fire resistance, bearing walls, sandwich structures.*

1. Introduction

The fire resistance of building materials can be characterised as a key feature, thanks to which we choose materials for the structure of a building. We consider this data to be well researched and easily accessible, but what is not so well researched is how the given materials behave in a joint construction. This paper analyses the influence of the properties of selected building materials in a construction on the resulting fire resistance. The selected building materials for the structure consist of fire-resistant plasterboard, insulating material, thermal insulation, and new fire-resistant boards. The load-bearing capacity of the structure is ensured by wooden columns. The load-bearing sandwich structure is subjected to an experimental study according to the EN 1365-1 standard [4]. The test structure is subjected to thermal stress for 125 minutes, while the development of temperatures behind the individual layers is monitored. The obtained data are then processed and evaluated.

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The aim of this contribution is to examine the influence of the properties of individual building materials in experimental wooden sandwich constructions. In experimental studies, we tested two reference wooden sandwich structures with different thermal insulations without the use of mineral wool, and two wooden sandwich structures with different thermal insulations using 40 mm thick mineral wool.

The issue of sandwich constructions was also examined by Haffke et al. [6], who pointed to the lack of knowledge about the fire resistance of prefabricated sandwich structures. The authors conducted an experiment which mainly investigated the thermal behavior of precast concrete sandwich panels using mineral wool as thermal insulation. Altogether, they tested three sandwich assemblies. All the tested structures retained their structural and fire-fighting functionality as a result of their increased bending stiffness and high thermal insulation ability [6]. Perera et al. [12] researched constructions composed of different types of plasterboard linings and thermal insulation from a numerical point of view. They discussed the fire resistance of modular wall panels with thermal insulation composed of three different materials, i.e. rockwool, glass fibres, and mineral wool. In the conclusion, the authors stated that the analysis pointed to an insignificant influence of the choice of thermal insulation material between rockwool, glass fibre, and mineral wool for structural fire resistance [12]. In their paper, Kontogeorgos et al. [8] examined the construction of structures from interesting building materials, conventional materials, but also from phase change materials and vacuum insulating materials. In an experimental study, the authors created four different sandwich structures, while exposing them to temperatures of 900°C from the exposed side. On the unexposed side, the structures were observed under ambient conditions. In the assembled structures, the authors alternated different types of plasterboard, thermal insulation, and thermal insulation plaster. In the conclusion, they unequivocally stated the positive influence of mineral wool as thermal insulation on fire resistance [8]. Freitas and Rodrigues [5] commented on the topic of the knowledge of construction materials that make up buildings from the point of view of the investigator of the causes of fires.

2. Materials and Methods

In experimental testing, we worked with several variants of wooden sandwich load-bearing wall constructions. At the same time, we worked with the variation of building materials in the internal composition of the investigated structures. A permanent element of each variant is an universal fire-resistant plasterboard. The fire-resistant plasterboard used in construction has a solid core reinforced with glass fibres. At the same time, it has increased strength and surface hardness. According to the EN 13501-1 standard, belongs to the reaction to fire class A2-s1, d0 [1]. The next layer of the structure behind the fire-resistant board consists of two types of thermal insulation, which abound in different surface treatments and properties. But what they have in common is their polyurethane core. As we have already mentioned, thermal insulations differ in surface treatment. In the test construction marked PUR C, it is an aluminum finish. Such material is resistant to petrol, mineral oil, microorganisms, and mold. Further, it does not decompose. In this case, the reaction to the fire class is C – s1, d0 [10]. The test construction marked PUR E has a surface treatment composed of mineral felt. Such material is resistant to petrol, mineral oil, microorganisms, and mold. It also does not decompose. In this case, the reaction to fire class is E [9]. Another insulating layer in the variants PUR C, MV 40, and PUR E, MV 40 is made of mineral wool. Mineral wool can be used as heat, sound, and fire insulation. The properties of the material are non-flammability, and in the event of a fire, there is no development and spread of flame on the surface, nor the formation of toxic fumes. The fire reaction class of mineral wool is A1 [7]. On the side not exposed to the flame, the test structures are closed by a fire-resistant board made of new materials. They are boards that have the ability to replace cement chipboards, plasterboard, OSB boards, fireproof boards, and other boards in construction. Their basic properties include strength and resistance to frost, mold, and pests. They are hydrophobic and belong to fire reaction class A1 [11]. In the constructions, we used wooden posts as a supporting element. They are made of glued wood and have significant load capacity, stability, and rigidity. The reaction to fire class is D – s1, d0 [2].

The size of the test structures used in the experimental test was as follows: height 1,000 mm, width 600 mm, and thickness 187 mm (PUR C, MV 0; PUR E, MV 0) or 227 mm (PUR C, MV 40; PUR E, MV 40).

The test specimens were placed in a frame that serves as the input structure for the test specimen. At the same time, the exact installation procedure was followed, which was specified during the real construction of the structure. Screws and low-expansion foam were used as connecting material between the individual layers of the sandwich structure. In the places where screws were used, it was necessary to pre-drill holes and then apply the screws. By its location in the furnace, the test frame provides conditions such as heating, pressure, and others. Four gas burners acted on the test samples, whose temperature increase in the furnace was calculated according to the standard temperature-time curve [3, 4]. The test structures were subjected to a thermal load from the side where the universal fire-resistant plasterboard was located. Monitoring of the test structures was carried out in accordance with the specifications determined in the standards. At the same time as smoking, the development and thermal behavior were monitored. The internal temperature of the individual layers of the test structures was observed using two thermocouples.

Figure 1 shows a drawing of the composition of the reference structure on the left and the real version of the structure with thermal insulation and mineral wool with a thickness of 40 mm, on the right.

Figure 2 shows a view of the test structures through a thermal camera. On the left of the picture, there is a test sample composed of thermal insulation with a surface treatment of mineral felt and an added insulating layer of mineral wool with a thickness of 40 mm.

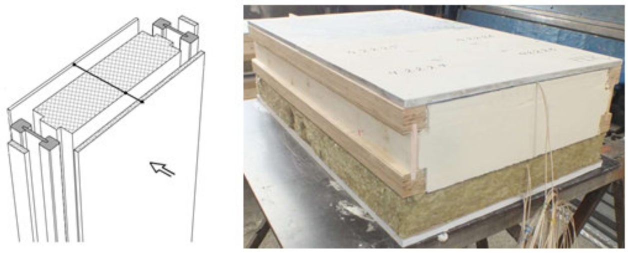

Fig. 1. *The left side of the image shows a drawing of the composition of the reference structure. The right side of the image shows the real version of the structure with thermal insulation and mineral wool*

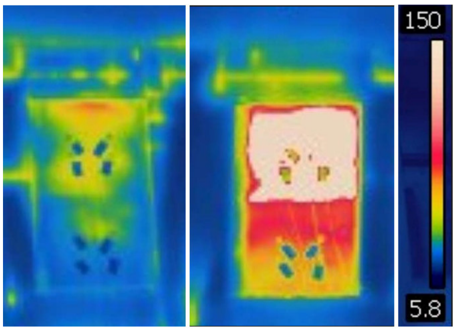

Fig. 2. *View through the thermal camera of the test structures during the experimental measurement with the attached temperature scale in °C. From the left side, the test sample marked PUR E, MV 40, in the center of the picture the test sample marked PUR E, MV 0. The right side of the picture is the scale in °C.*

In the middle of the picture, there is a reference construction also composed of thermal insulation with a surface treatment of mineral felt and without an added insulating layer of mineral wool. On the right side of the image, there is a temperature scale in °C. As can be seen in the figure, the temperatures in the test structures vary enormously. This phenomenon is caused by the addition of 40 mm thick mineral wool to the building structure.

3. Results

Figure 3 shows the results for the reference samples without the use of mineral wool in the wooden sandwich structures of the load-bearing wall. Figure 3 also shows the resulting values measured by thermocouples placed behind the heat-insulating material with an aluminum surface treatment marked PUR C, MV 0 and behind the heat-insulating material with a surface treatment made of mineral felt marked PUR E, MV 0. The temperature of the PUR C, MV 0 sample began to rise continuously after 5 to 10°C/min from 68 minutes. We recorded the first major temperature increase of almost 20°C in 95 minutes to a temperature of 120°C. Subsequently, the temperature increased by an average of 5 to 10°C/min. From 113 minutes to 120 minutes, the temperature increased by almost 400°C. In the remaining 5 minutes until the end of the test, the temperature rose by an average of 10°C per minute to a final value of 770.4°C. The temperature in the case of the PUR E, MV 0 sample after 5 to 10°C/min from 73 min, which represents a 5-minute delay in the onset of the temperature rose compared to PUR C, MV 0. We recorded the first major increase in temperature by almost 70 to 150°C in the 88th minute. Subsequently, the temperature rose by almost 330 to 478°C in 7 min.

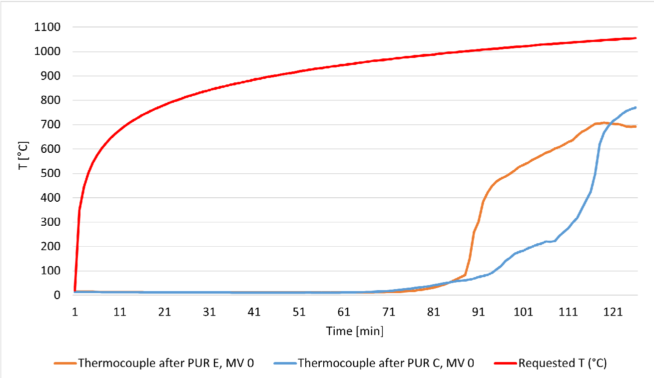

Fig. 3. *Development of temperatures behind reference samples without added mineral wool measurements behind a heat-insulating layer with different surface treatments*

In the previous case, the temperature at that minute was 150°C. From the 95th minute, the temperature rose continuously by 1 to 10°C/min to a final temperature of 692°C. We can therefore evaluate the not entirely logical conclusion when the PUR E, MV 0 construction with thermal insulation with lower fire resistance reached a lower final temperature in the end than the PUR C, MV 0 construction with thermal insulation with higher fire resistance. None of the construction variants exceeded the required temperature according to the standard.

Figure 4 shows the results of the investigated constructions PUR C, MV 40, and PUR E, MV 40 with the use of mineral wool with a thickness of 40 mm in the wooden sandwich constructions of the load-bearing wall. Figure 4 also shows the resulting values measured by thermocouples placed behind the heat-insulating material with an aluminum surface treatment marked PUR C, MV 40 and behind the heat-insulating material with a surface treatment made of mineral felt marked PUR E, MV 40, in front of which mineral wool is placed. The temperature in the case of the test sample PUR C, MV 40 started to rise continuously by 1 to 1.5°C/min from the 78th minute. Compared to the reference sample PUR C, MV 0, this is a 10-minute reduction in temperature rise. After 12 minutes, we observed that the temperature rose by 23 to 38°C. Subsequently, the temperature rose by 4 to 10°C/min. After 29 minutes, i.e., in the 118th minute of the measurement, the temperature rose by 116°C to a value of 154°C. At the end of the measurement, the temperature rise stabilised by 1 to 2°C/min to 165°C. In the last minute of the measurement, the temperature increased by 3 degrees to a final temperature of 168°C. Compared to the test sample PUR C, MV 0, this is a temperature reduction of 602°C. The temperature in the case of the PUR E, MV 40 test sample began to rise continuously at 0.5 to 1.5°C/min from 85 min, which represents a 7-minute delay in the onset of the temperature rise compared to PUR C, MV 40.

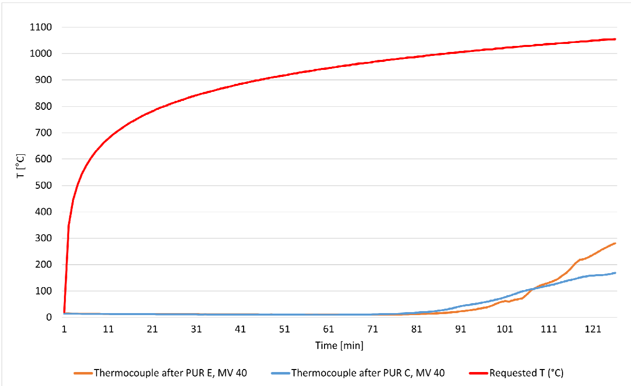

Fig. 4. *Development of temperatures behind samples with added mineral wool with a thickness of 40 mm measured behind a heat-insulating layer with different surface treatments*

Again, we observe a phenomenon where the structure with weaker thermal insulation experienced a later increase in temperature compared to the sample with better thermal insulation. The temperature continuously rose for 104 minutes by 1 to 4°C/min. The temperature value at 104 minutes was 73°C. At 106 minutes, the temperature was 103°C. In the next 18 minutes, the temperature rose by 200 to 273°C. In the last minute, it rose by 7°C to the resulting 281°C. Compared to the sample PUR C, MV 40 with more fire-resistant insulation, this is the expected achievement of a temperature increase of 90°C. Compared to the reference sample PUR E, MV 0, this is a temperature reduction of 410°C.

As can be seen from Figure 5, where the obtained results are compared, none of the created building structures of wooden sandwich load-bearing walls exceeded the required temperature. The reference samples marked PUR E, MV 0, and PUR C, MV 0 reached the highest temperatures during the measurement in 125 minutes. Specifically, a sample with PUR E thermal insulation without added mineral wool was 692°C and a sample with PUR C thermal insulation without added mineral wool was 770°C. From a logical point of view, we expected the opposite result, since thermal insulation with a surface treatment made of an aluminum layer should have provided a higher degree of protection than thermal insulation with a surface treatment made of mineral felt. Further in the figure, we can see that after adding mineral wool with a thickness of 40 mm to the structure of the load-bearing wall, the temperature decreased dramatically in both cases.

The difference in the resulting temperatures between the tested structures is 112°C. In the case of a structure with PUR E thermal insulation and added mineral wool with a thickness of 40 mm, the resulting temperature is 281°C. In the case of construction with PUR C thermal insulation and added mineral wool with a thickness of 40 mm, the resulting temperature is 168°C. Here, compared to the reference samples, we can observe the improvement of the results and therefore the reduction of the final temperature reached, as well as the achievement of better results in the case of more durable thermal insulation.

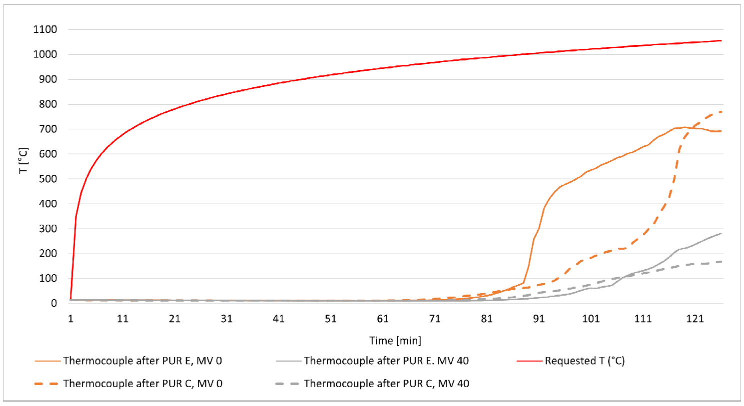

Fig. 5. *Development of temperatures behind samples without added mineral wool (reference samples) and with added mineral wool with a thickness of 40 mm measured behind a heat-insulating layer with different surface treatments*

4. Conclusions

By revealing the temperature changes during testing and their subsequent comparison, we reached the following conclusions. Testing lasted 125 minutes. The initial test temperature measured by thermocouples was 14.1°C. During testing, we monitored the development of the temperatures behind the thermal insulation layer and at the same time, we also performed a comparison with the required temperature according to the EN 1365-1 standard [4]. Subsequently, we compared the temperature changes between the reference samples composed of a fire-resistant board, thermal insulation with a polyurethane core, and a surface treatment of mineral felt and aluminum, new fire-resistant boards together with structures that had added thermal insulation from mineral wool with a thickness of 40 mm. We documented the effect of mineral wool on temperature development and the increase in fire the resistance of the structure itself in the images above. For the reference structure PUR C, MV 0 (without mineral wool), the temperature measured at the end of the experiment in 125 min behind the thermal insulation PUR C was 770°C; by adding mineral wool 40 mm thick to the structure marked PUR C, MV 40, the annotated temperature dropped to 168°C. This represents a four and a half times reduction in temperature behind the thermal insulation. For the reference structure PUR E, MV 0 (without mineral wool), the temperature measured at the end of the experiment in 125 min behind the thermal insulation PUR E was 698°C; by adding mineral wool of thickness 40 mm to the structure marked PUR E, MV 40, the annotated temperature dropped to 281°C, which represents a two-and-a-half-fold decrease in temperature behind the thermal insulation. As a result, this means that by adding mineral wool together with appropriately chosen thermal insulation, we can achieve a more fire-resistant building structure.

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