

PAPER REF: 7097

INVESTIGATION INTO THE THERMAL RESISTANCE OF A POLYMER COMPOSITE WITH AEROGEL

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ABSTRACT

The aim of this paper is to demonstrate the influence of a sandwich composite with aerogel upon the change in thermal properties of the examined structure. The authors conducted research into this kind of a composite due to its application in aviation technology, including covers of avionics instruments. The necessity of providing thermal insulation for sensitive components of these devices requires ensuring their airworthiness after the impact of a heat flux on their covers. The research aimed at determining the thermal resistance of the structure made with a sandwich composite with aerogel. The most important parameters determined from experimental testing were the temperature increase on the rear surface of the test sample and the structure of the sample after the examination.

Keywords: composite, ablation, aerogels, thermal protective, aviation.

INTRODUCTION

Fibre-metal sandwich laminates combine the properties of both an aerogel and a composite material reinforced with fibres. Their development was intensified mainly in the aviation and space industries due to a demand for modern materials with high thermal properties and low weight (Bianchi, 2006, Schmidt, 1969). Spacecraft are exposed to large amounts of heat due to friction in the atmosphere, as a result of which the protective surface is heated to even above 1,000°C. Therefore, it is necessary to use modern materials with increased thermal resistance and low mass, at the same time. In addition, high heat resistance is also required for the construction of protective shields in flight data recorders.

Polymer-based composites remarkably quickly lose their properties when the temperature, at which their elements are made, rises above the glass transition temperature which, in the case of duroplasts ranges from 60 to 160°C, and for thermoplasts it is between 80 - 300°C. The addition of a spacer element in the form of aerogel can improve composite resistance to temperature changes of the operational environment, since shaping ablative thermo protective properties is based on searching for materials with high specific heat $c_p(T)$, high-density (high heat capacity) as well as low thermal conductivity coefficient (t) (i.e. low thermal diffusivity (t)) (Kucharczyk, 2007).

Currently, studies are being conducted over the method of creating structures of ablative materials made with fibre-reinforced epoxy composites (Zang, 2010, Bogoeva-Gaceva G, 2009) as well as the modification of composite structures through the addition of nanofillers or aerogels structure (Natali, 2012; Cheng, 2010, Beaudet J, 2011). The effect of additives on the properties of ablative composites has been more and more widely studied due to

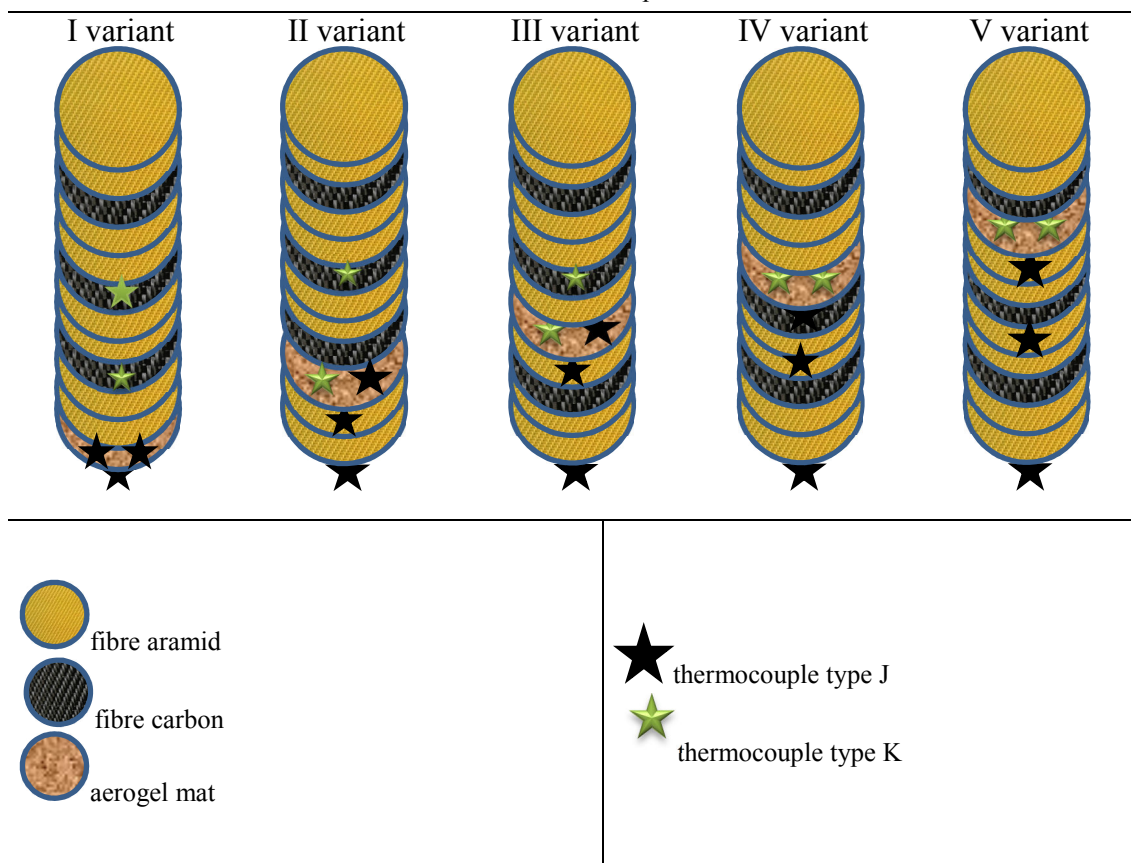
significant changes in their structures and thus the ablative properties of a composite, resulting from the impact of a heat flux.

In view of the high demand for this type of material (resistant to degradation during long periods of operation at increased temperatures (Jurkowska 2010, Butler, 2016), an attempt was made to determine the impact of placement of an aerogel sandwich layer for thermal resistance of a polymer composite with a fibre reinforcement.

METHODOLOGY OF RESEARCH

The authors prepared 10 composite samples, 35 mm in diameter. As the reinforcement material, 8 layers of aramid fabric were used, 220 g/m² in weight and 3 layers of carbon fabrics, 160 g/m² in weight. The matrix was made up of Epidian 52 resin, cured with TFF hardener, produced by the chemical plant Organika-Sarzyna in Nowa Sarzyna. The sandwich material was "Pyrogel XT-plus E", 5 mm thick. In order to determine the impact of the application of the spacer material on the ablative thermo protective properties of the polymer composite, the authors prepared samples in five variants of the distribution of aerogel and thermocouples in the composite (Table 1).

Table 1 - Distribution of sandwich material and measuring items in individual variants of the manufactured composite



For the needs of the research, the authors used a test stand equipped with an ablative gun designed and constructed for an investigation of this type of materials (Figure 1).

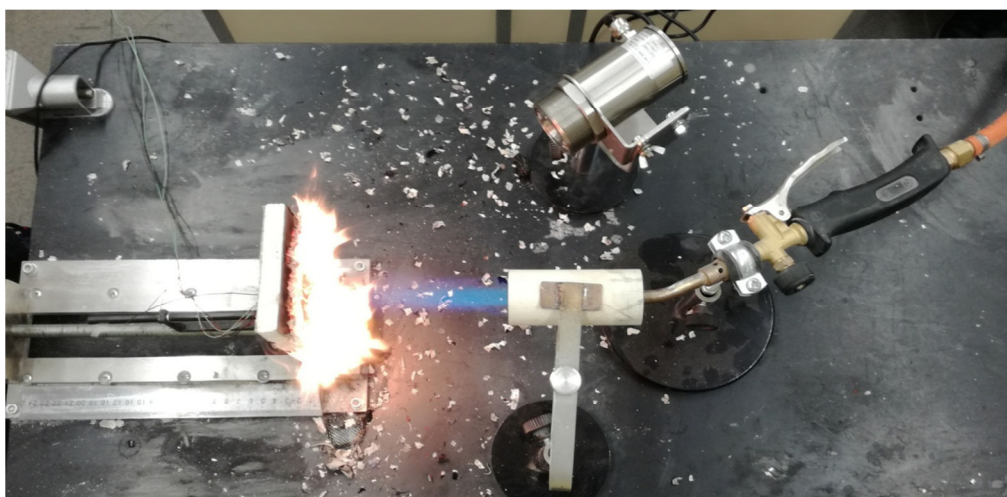


Fig. 1 - Research stand

The sample was subjected to a flame, whose temperature was equal to 1,100 °C. The duration of the test was limited to 120 seconds for each sample. Because of a wide range of temperatures occurring in different places of the composite, it was necessary to use two different types of thermocouples. For higher temperatures (the ablation front of the sample), the authors used a thermocouple type K, while for the lower temperatures (from the rear surface of the sample) - type J. There were 3 thermocouples - type J and 2 thermocouples - type K, placed in each of the tested samples, in accordance with the variants presented in Table 1. The temperature was recorded by means of a device made by National Instruments, model SCB as well as LABVIEW software. The temperature on the ablation surface (exposed to a flame) of the tested sample was measured using a pyrometer made by Optris, model CT, along with the head equipped with a laser pointer of the place of measurement. In addition, the image of the temperature distribution on the rear surface of the sample exposed to a heat flux was recorded by a thermal imaging camera Flir b50, image resolution of 19,600 pixels (140 x 140) and camera resolution of 2.4 MP (Figure 2). On completion of the examination, the authors evaluated the structure of the selected samples using a microscope Hitachi's, TM3030 Plus model.

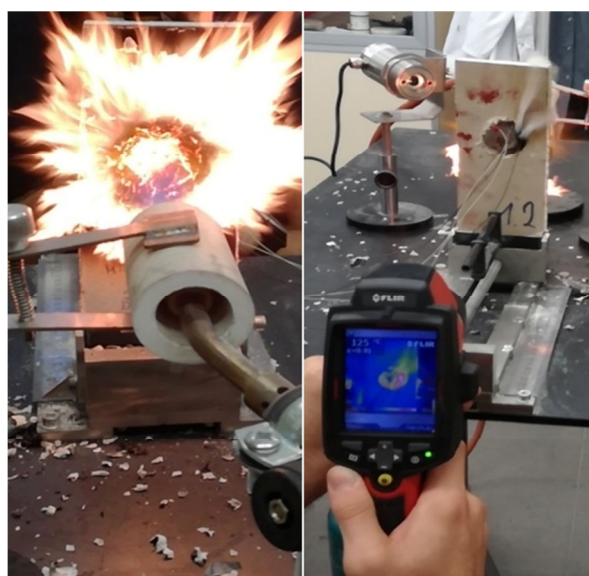


Fig. 2 - Course of thermal resistance examination

In order to analyse the impact of placing a sandwich layer in aerogel upon thermal resistance of a polymer composite with a fibre-reinforcement, the temperature was measured on the back surface of sample *T5*, inside composite *T1-T4*; also the relative ablation mass loss U_a was determined, as well as analysing the structure of composite components, especially the material of the aerogel sandwich layer.

RESULTS AND CONCLUSIONS

Prior to the test, the measuring system was calibrated. Also the optimum distance from the ablation gun to the ablation surface was determined in order to obtain the temperature of approximately 1,000-1,200 °C. The recorded temperatures were marked from "T1", specifying the temperature inside the composite layers which was most exposed to the heat flux, up to "T5", which specifies the temperature on the rear surface of the tested sample (Figure 3).

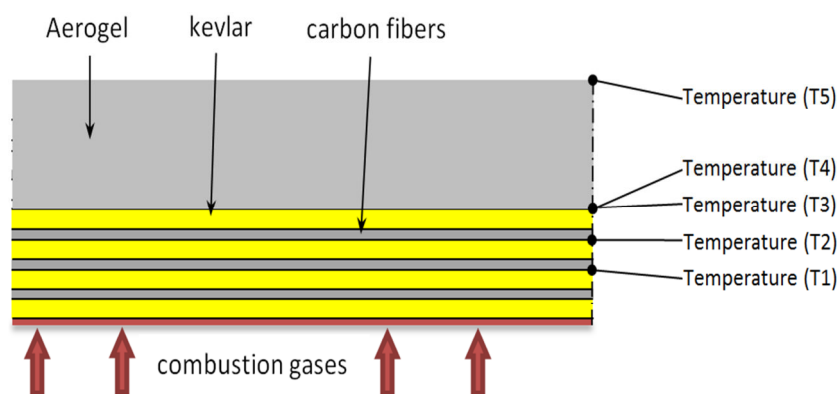


Fig. 3 -Manner of marking the recorded temperatures

On the basis of photos taken by the thermal imaging camera, an assessment of the correctness of fixing the samples in the protective plate was made (Figure 4).

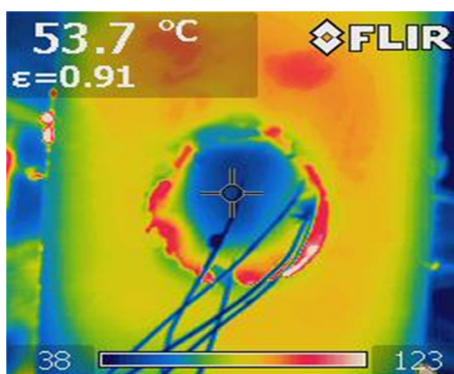


Fig. 4 - An example of a photo of the rear surfaces during the test

The centre of the tested samples is much cooler than the remaining part. The occurring high temperatures on the edges are caused by heat dissipation through places insulated with thermo protective silicone, whose properties may be not as good as of the tested material, preventing a total separation of the sample from the protective plate.

The main parameter for the analysis of the impact of the sandwich aerogel layer upon the thermal resistance of the polymer composite with a fibre-reinforcement was assumed to be the

temperature on the rear surface of the tested material ("T5"). Furthermore, in order to compare the impact of the location of the aerogel sandwich layer in particular variants of the manufactured composites, the authors used the temperature read out in the last second of the examination, thus after 120 seconds of the impact of the heat flux upon the tested material. The findings have been shown in Figure 5.

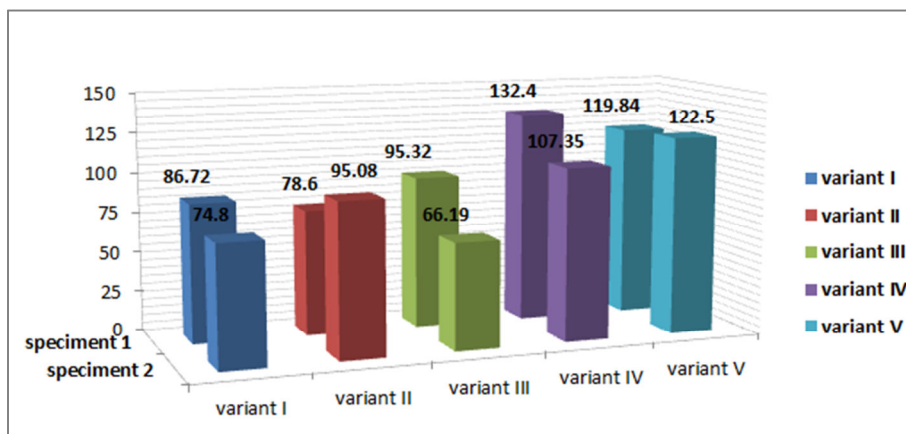


Fig. 5 - Final temperature of the rear wall surface of sample T5 in individual variants of the distribution of an aerogel sandwich layer

Along with moving the aerogel towards the front of the composite, the temperature on the rear walls is rising. However, this increase is not proportional. Despite this, one can easily observe that the average temperatures in variants I-III are much lower than in the last two. In addition, a detailed analysis of the distribution of the temperatures both inside the composite and also on the rear surface of the sample was performed (Figure 6).

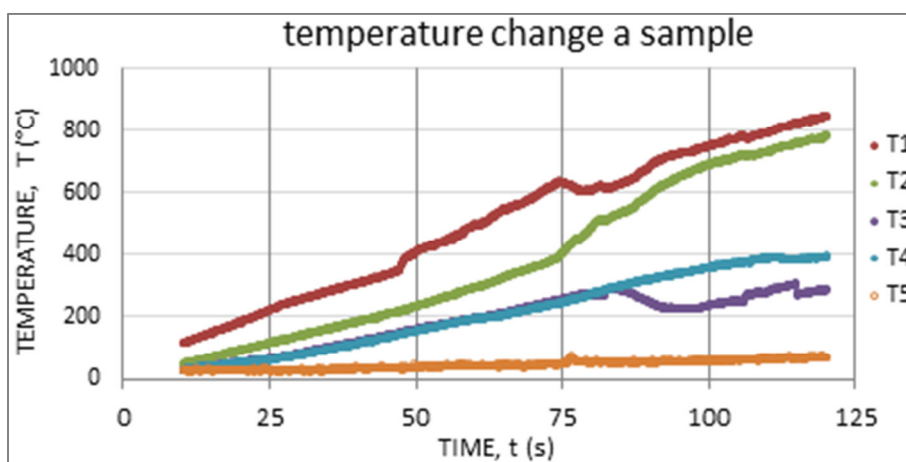


Fig. 6 - Temperature distribution during the examination for sample I-1

In the case of a composite with an aerogel spacer layer, placed behind the last layer of the aramid fabric, the maximum temperature value "T5" equals 86 °C, thus the composite reduces the temperature by approximately 790 °C. In addition, the difference between the average temperature before the last layer of fabric and the temperature on the rear surface is approximately 300 °C, which constitutes a 45.6% reduction in the temperature of the ablation layer.

Ablative loss of mass was determined on the basis of an analysis of the changes in thickness and weight of the examined samples, before and after the heat resistance tests (Figure 7).

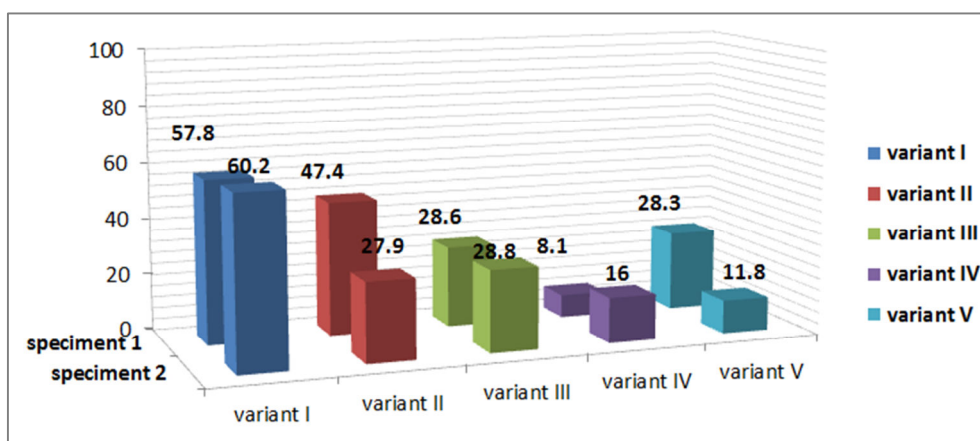


Fig. 7 - Relative ablative loss of mass U_a [%]

The greatest weight losses were recorded for samples of variant no. 1 (Figure 7). This was caused by an ablative distribution of layers which were the closest to the flame. Variants, in which the distribution of layers ended on aerogels are characterized by a much smaller loss of weight, in the sample of IV-1, merely 8.1%, while in variant I they reached the value of approximately 60%. The loss of thickness (thus also of volume) of samples is comparable for each distribution of aerogel in the composite (Figure 8).

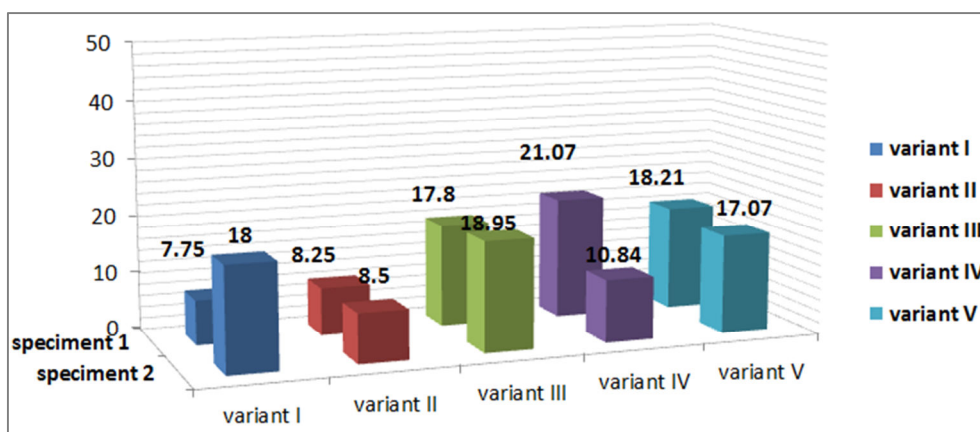
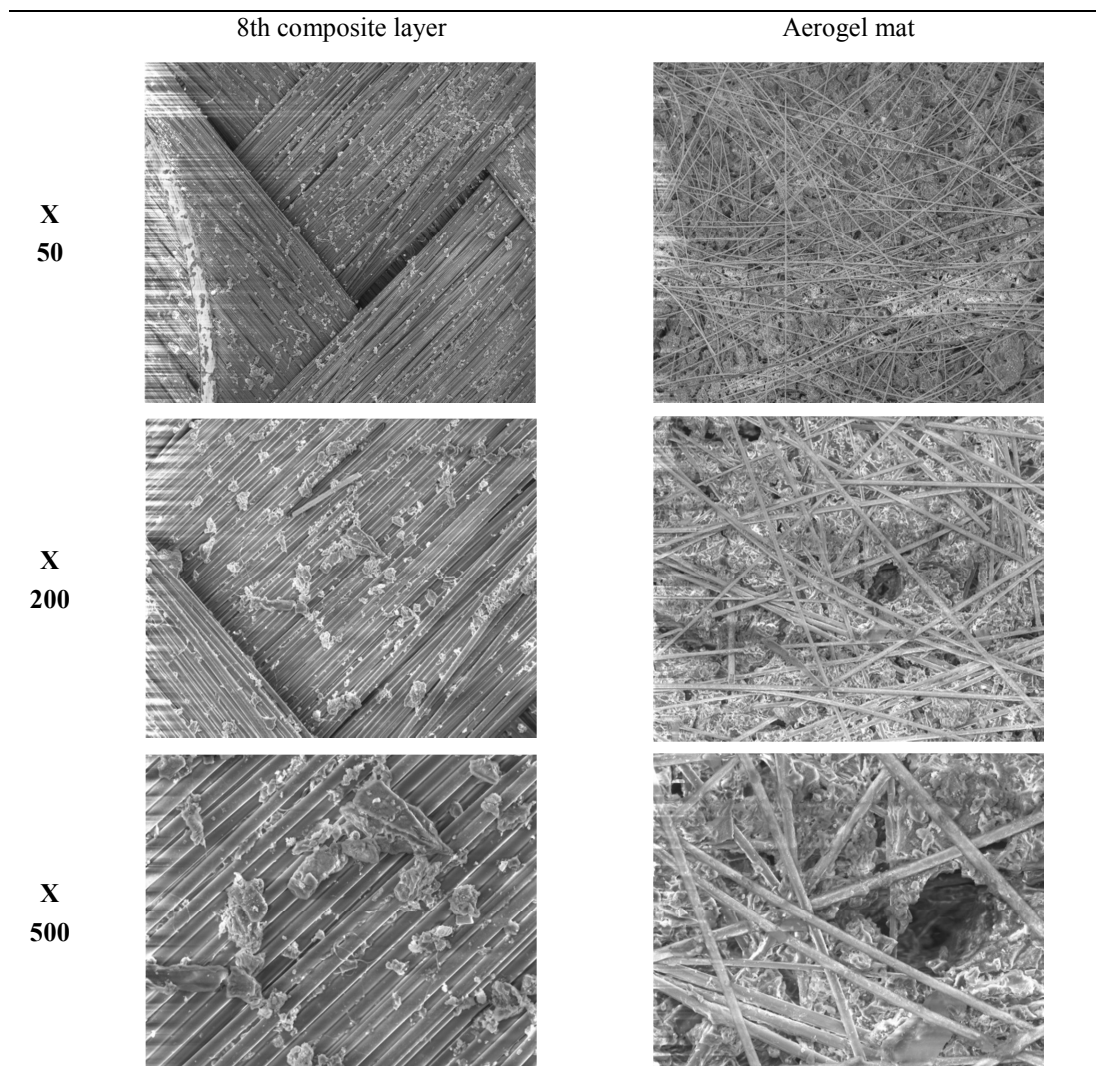


Fig. 8 - Relative ablative loss of mass [%]

In order to assess the impact of a high temperature flux on the structure of the aerogel, the authors selected samples no I-1 and III-2. The damaged layers were removed; the remainder of aramid fibres and carbon fibres as well as all types of impurities were cleared. Pictures at magnification 50x, 200x, and 500x (Table 2) were taken.

In the pictures shown in Table 2, it is possible to observe, on the left, the aramid fibres which were placed as layer 8 from the front of the sample. On the right side, there are photos of aerogel placed as the last layer of the composite. The photos of aramid show an undamaged structure of the fibers, regardless of the size of the applied magnification. Furthermore, the residues of resin which bonded particular layers are easily observed. The aerogel was not damaged in any way; the fibres are not fractured. In between it is possible to see the remains of the resin. In the photos one can also notice the differences in the structures of aramid and aerogel mats.

Table 2 - Structure of composite components after the examination of thermal resistance



CONCLUSIONS

On the basis of the analysis of the obtained findings of experimental studies and the observation of the course of the examination as well as the observation of microscopic structures of composite components, the testing led to the formulation of the following conclusions:

- during the tests, successive layers of the material were separated, which points to the ablative properties of the materials used for the front composite layers;
- burning up of the layers of thermal silicone, responsible for the thermal insulation of the rear wall of the sample, did not significantly affect the results of the examination;
- the use of aerogel as an additional "spacer" composite element with a fibre-reinforcement significantly improved thermal resistance. The material was capable of reducing the temperature even by approximately 91% in relation to the initial temperature. In variants IV and V, the reduction on the mat reached the value of 75%. The maximum temperature of the back wall surface of sample T5 equalled 134 °C, while the minimum one was equal to 66 °C.

- Changing the position of aerogel in the composite and its placement closer to the ablation surface resulted in a smaller reduction in the temperature on the rear wall surface of the sample in the final phase of the examination. The positive aspect of this treatment was a smaller weight loss of the composite, and most importantly in the context of examining thermo protective properties - better insulation to approximately 100 seconds of the experiment.
- The location of the aerogel in the composite also accounts for the ablation mass loss U_a . Along with the change in the placement of the aerogel mat and its moving away from the ablation surface, the relative ablation loss of mass was decreased (from approximately 60% in variant I to approximately 15% in variant V).

Therefore, it can definitely be stated that the use of a sandwich layer in the form of an aerogel mat in composites with a fibre-reinforcement, can considerably increase their thermal resistance.

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