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THE IMPACT OF METAL REINFORCEMENT UPON THE PROPERTIES OF A COMPOSITE

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ABSTRACT

The aim of this paper is to present the effect of a metal reinforcement placement upon the properties of a sandwich composite. The authors conducted an investigation of the composite with a metal reinforcement, which is an equivalent of an ablative material used in aviation technology, among others for covers of avionics instruments. The need to ensure ablative properties of the examined material as well as the homogeneous temperature field in the material lead to experimental studies over various modifications of ablative materials. The authors have attempted to determine impact changes in the metal reinforcement setting in the examined structure upon the change in ablative properties. The most important parameters determined from the experimental testing were the temperature increase on the rear surface of the test sample and the ablative mass loss.

Keywords: composite, ablation, metal, thermal protective, ablative shields.

INTRODUCTION

The present paper deals with the problem of an ablative phenomenon which refers to materials of spacecraft surfaces entering the earth's atmosphere (Bianchi, 2016; Laub, 2003) as well as hypersonic vehicles moving at speeds much exceeding the speed of sound (Glass 2008; Ho, 2009). Ablation is a self-regulating heat and mass transfer process, which, due to physical and chemical reactions, leads to irreversible structural and chemical changes of a material combined with heat absorption at the same time. The process is initiated and sustained by external sources of thermal energy (Kucharczyk, 2010; Torre, 1998). Therefore, ablative materials during their exploitation undergo thermal decomposition at the time of heating the surface to a temperature of 250 to 600 °C. This brings about the necessity of conducting continuous research into the properties of ablative materials which are to meet their exploitational function by applying a different type of matrix with fibres and additives in order to create a material of optimal thermo protective properties (Butler, 2016).

Fibre-metal laminates combine the properties of both a metal and a composite material reinforced with fibres. Their application, as ablative materials, is constantly growing, mainly in the aviation and space industries, due to a demand for modern materials with high thermal properties. The reason for this is the possibility of further exploitation of a spacecraft which is exposed to heat, causing the rise in temperature of the vehicle surface to even above 1,000°C (Kucharczyk, 2010).

Currently, studies are being conducted over the manner of modifying structures of ablative materials made with fibre-reinforced epoxy composites (Zang, 2010) as well as the modification of composite structures through the addition of nanofillers (Czigany, 2005) or aerogels structure (Natali,2012). 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.

EXPERIMENTAL

In the ablative materials during the course of ablation, it is possible to observe several characteristic layers (Figure 1) at the border of the gas phase and the solid phase, an ablation surface is created. The surface of decomposition, separating the ablative layer from the original material is called the ablation front.

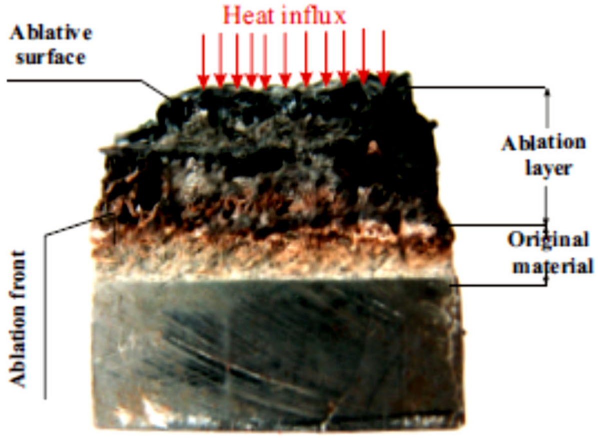
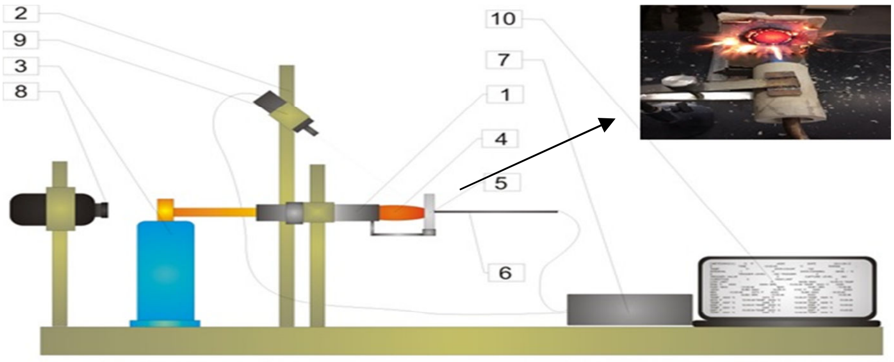


Fig. 1 - Diagram of the physical model of ablation [Kucharczyk, 2010]

The thermo protective ablative research was realized on the author’s own construction stand (Figure 2), in accordance with the assumptions and methodology.



Research stand: 1 - "ablative gun",2 - stand, 3 - the gas cylinder with burner nozzle,4 -flame, 5 - speciment, 6 - thermoelement, 7 - measure, 8 - thermal imaging camera, 9 - pyrometer, 10 - computer.

Fig. 2 - Laboratory research stand [Szczepaniak, 2017]

The authors attempted to determine the ablative properties of polymer composites combined with Inconel/Alloy 600 and the effect of its placement upon a temperature rise on the rear surface. The composites were made with Inconel/Alloy 600 with aramid and carbon reinforcement, whereas the matrix base was made with resin Epidian 52 and TFF hardener.

The tests were carried out with regard to a temperature rise also in the tested material in order to accurately determine the propagation of heat inside the material. The thermal stimulation on the surface equaled approximately 1,100°C over a period of up to 180 seconds.

The structure of the test samples and the places of measuring the temperatures are shown in Figure 3 while the variability of placing the metal reinforcement is depicted in Figure 4.

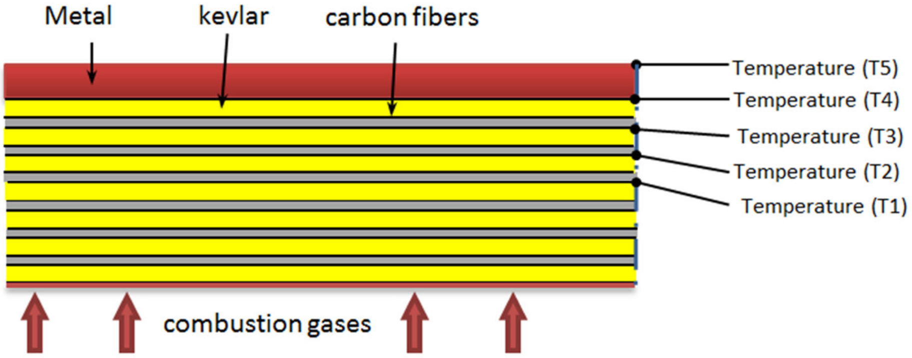


Fig. 3 - Sample structure and places of temperature measurement

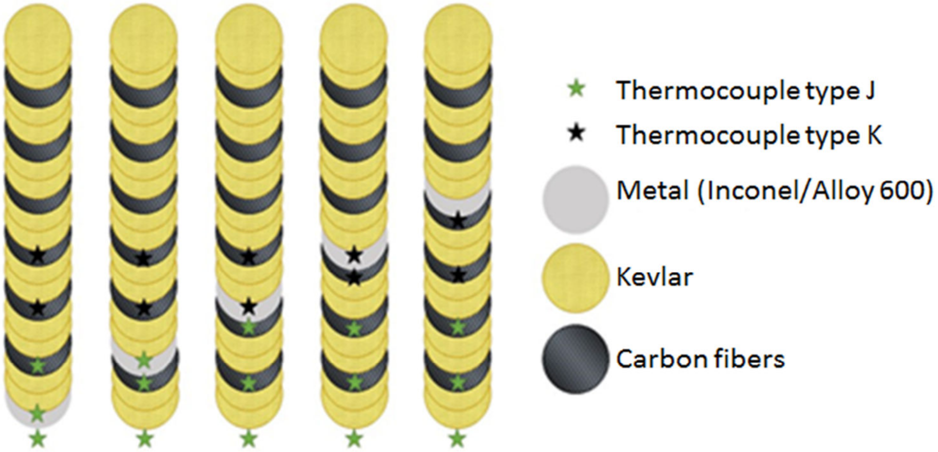


Fig. 4 - Movement of metallic reinforcement in the sample

The mass and thickness of particular samples before experimental studies have been presented in Table 1. The number of layers behind the metal plate in the composite was given.

Table 1 - Placement of thermocouples and Inconel/Alloys 600 in composite, including its mass and thickness

Sample number	Number of layers behind the metal plate	Mass [g]	Sample thickness
1	0	23.06	8.54
2	3	26.53	9.79
3	6	22.89	7.38
4	9	25.45	8.73
5	12	22.50	7.87

RESULTS AND CONCLUSIONS

During the testing the samples were exposed to temperatures of approximately 1,100 °C (1,000-1,200 °C measured by means of a pyrometer), generated by a heat flux during the combustion of propane-butane (Figure 5 - temperature of ablative surface). During the examination, neither the angle nor the strength of the heat flux was changed.

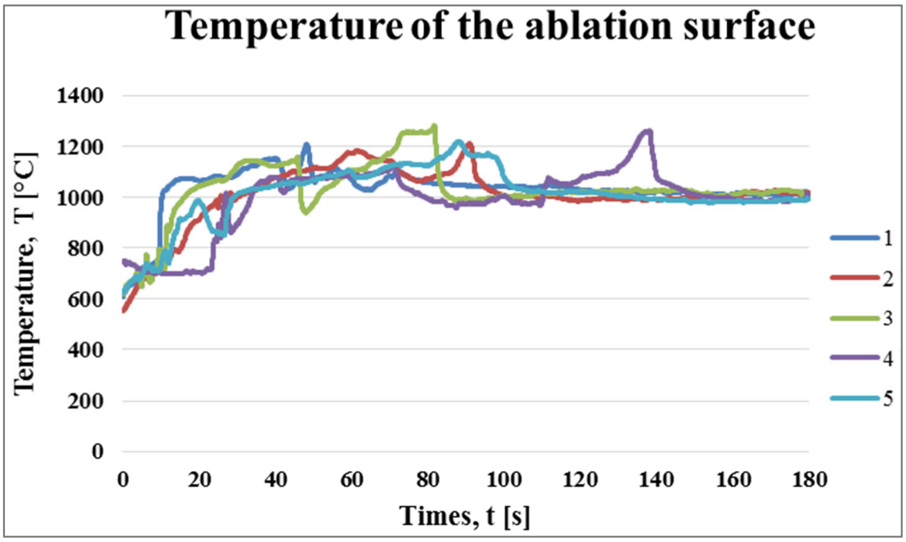


Fig. 5 - Temperatures of ablative surface

At the time of the examination, 5 measurements of temperature values using thermocouples were distributed in the sample. The sample temperature changes resulting from the impact of the heat flux are presented in Figure 6.

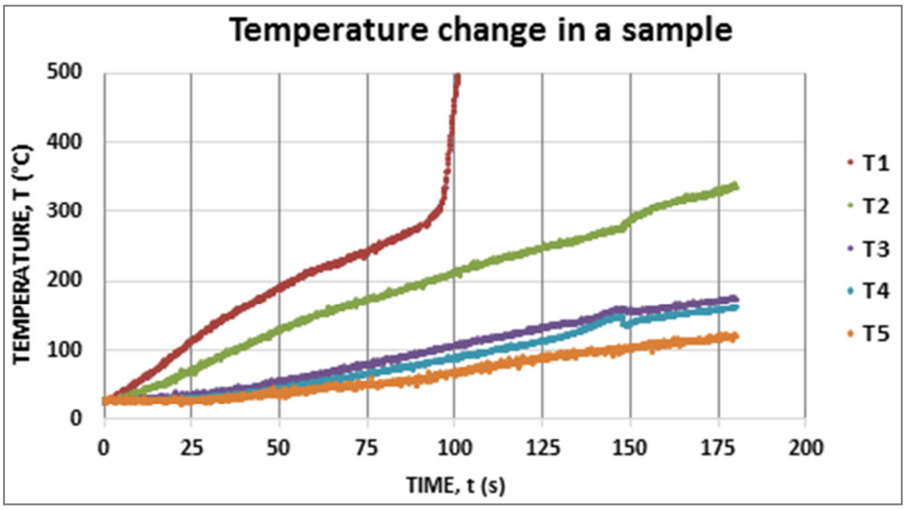


Fig. 6 - Temperature change in sample

On the basis of the photos taken by a thermal imaging camera, an assessment of the correctness of fixing the samples in the protective plate was made (Figure 7). Which is more an even distribution of the temperature field of the rear surface was checked.

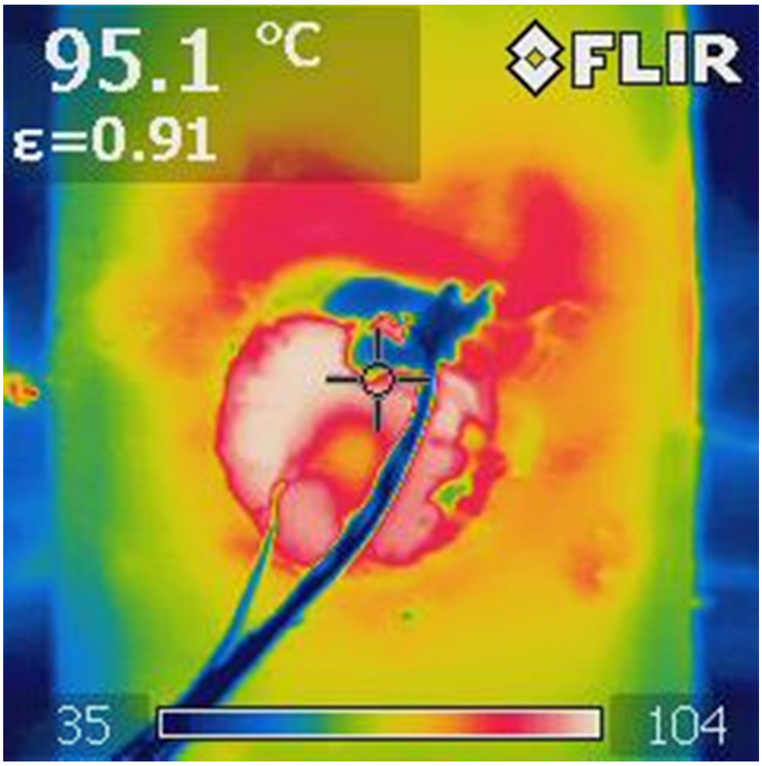


Fig. 7 - Sample structure and places of temperature measurement

An important phenomenon occurring during ablative combustion is aerodynamic erosion, as a result of which the layers of material on the border of the gas phase and a solid phase float, which can be seen in the photos of the sample after ablative testing (Figure 8)

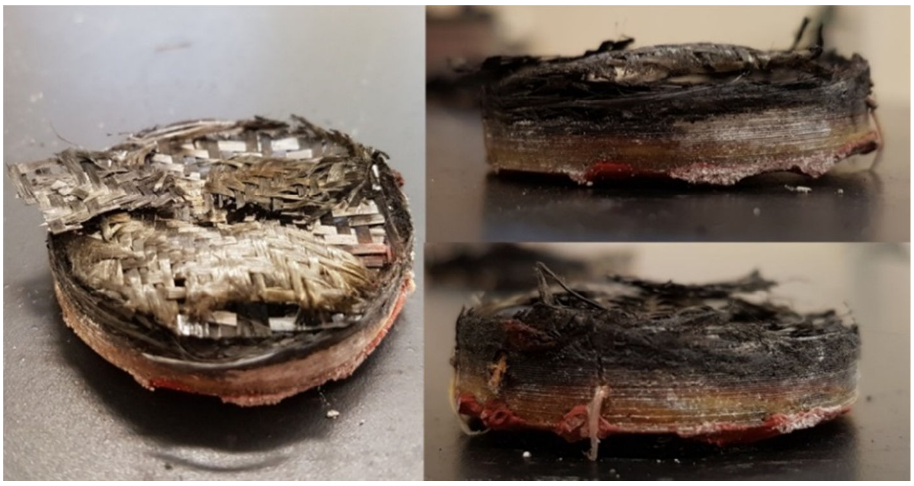


Fig. 8 - View of the sample after ablative testing

If there is ablation with the erosive effect, it is necessary to take into account the loss of mass of the ablation surface (Table 2) since it exerts a significant impact on the occurring thermochemical reactions. During the erosion, the position of the ablative surface changes its position while the process is taking place. This fact, changes the speed of the front of ablation and the speed of increasing the thickness of the ablation layer. The constant mass loss also changes the thermal conditions in a heated material, which may lead to the halt of initiating certain thermochemical processes in the ablative layer. This is one of the characteristic parameters during the testing of ablative thermo-protective properties, being referred to as the relative mass loss (Figure 9). It describes a percentage rate of erosion of a material at a given time and under specific conditions of the ablation process.

Table 2 - Mass of samples, ablative mass loss and thickness after the tests

Sample number	Sample mass after examination [g]	Ablative mass loss [g]	Ablative mass loss [%]	Thickness after the test [mm]
1	19.56	3.5	15.17	7.4
2	20.92	5.61	21.15	8.24
3	18.94	3.95	17.27	6.74
4	21.83	3.62	14.22	7.87
5	20.14	2.36	10.49	7.31

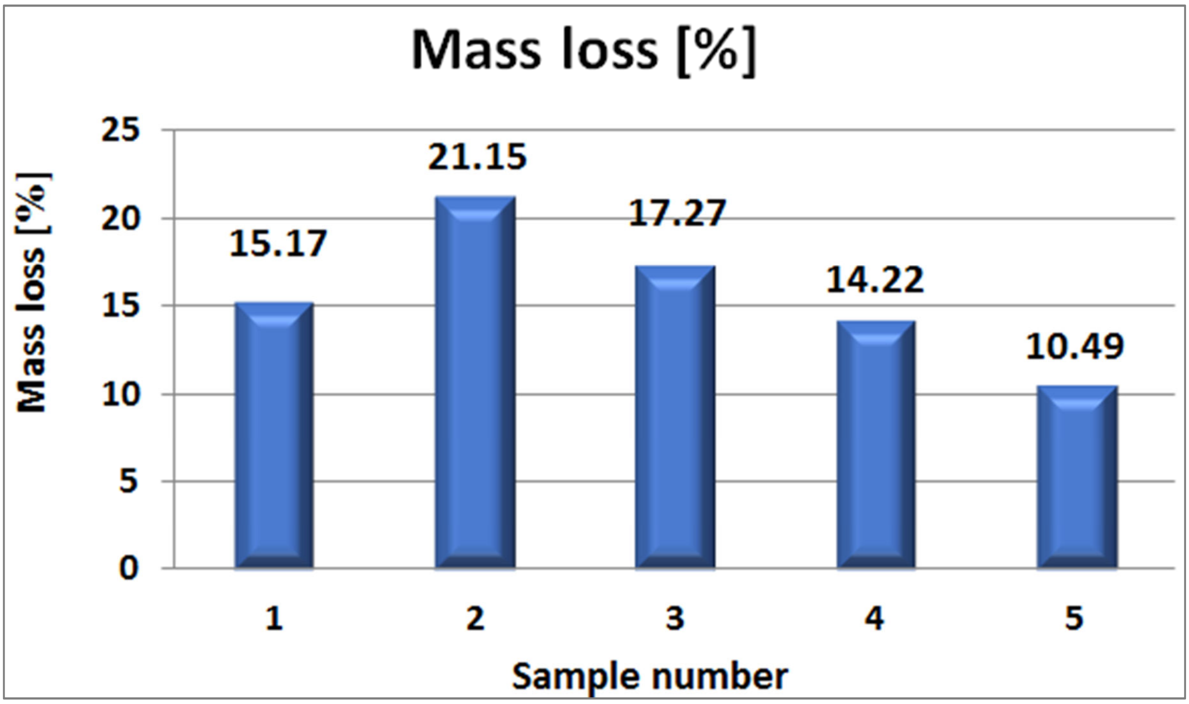


Fig. 9 - Ablation mass loss

Another important parameter measured after the test is the loss of the thickness of the sample resulting from thermo protective processes during the investigation (Figure 10). On the graph the blue colour was selected to mark the sample thickness after the experimental tests, while the orange colour indicated the loss of sample thickness.

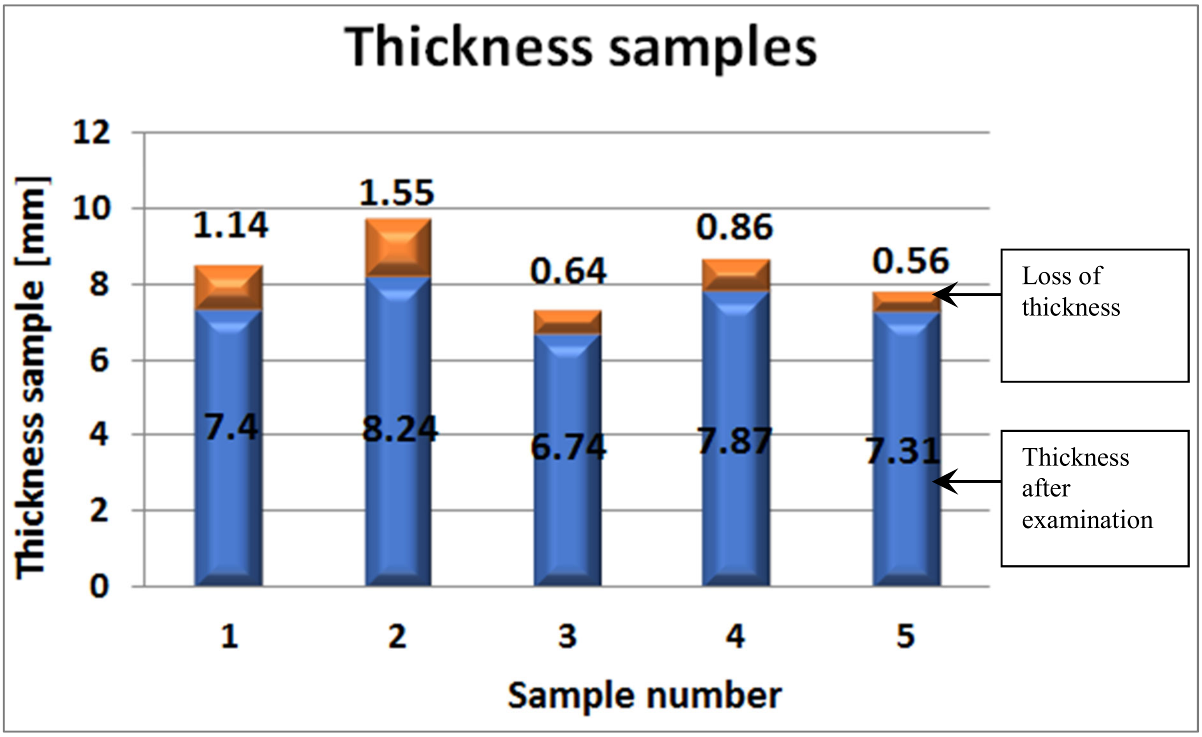


Fig. 10 - Change in sample thickness

The most relevant ablative parameter, however, is the temperature on the rear surface of the insulating wall (Figure 11). It is used to determine the reduction of the temperature in the insulating wall, which is a decisive parameter when choosing thermo protective materials.

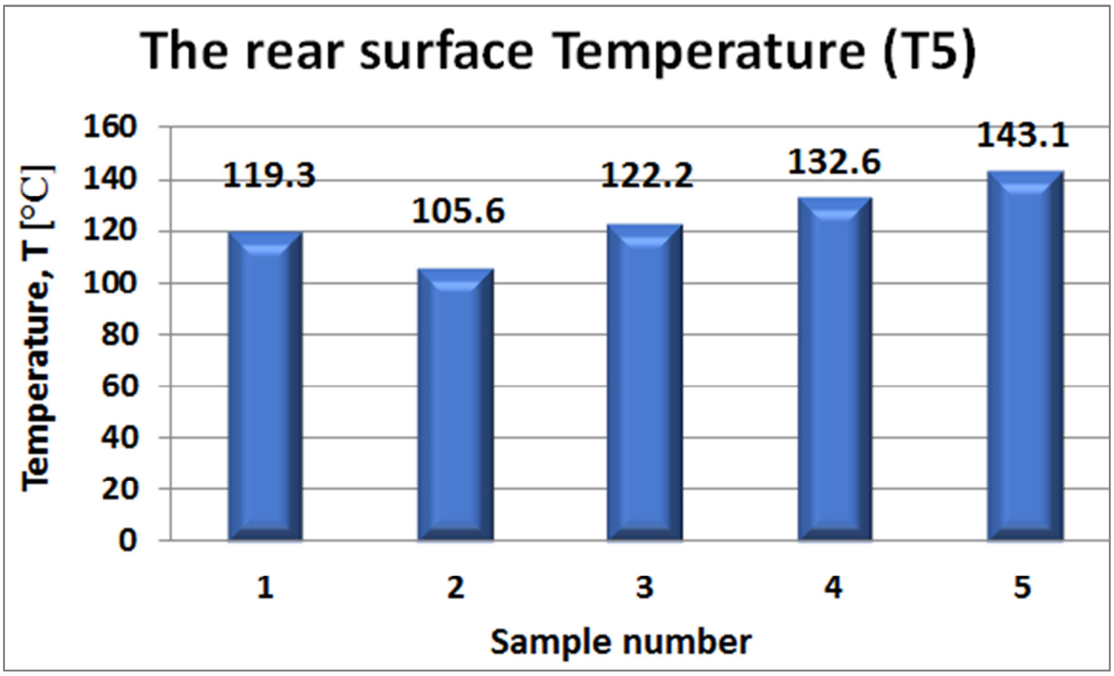


Fig. 11 - Rear surface temperature (T5)

In order to evaluate the impact of a high temperature thermal stream upon the structure of the examined materials, photos of the surface of sample no 1 were taken on an electron microscope. The damaged layers were removed; the remainder of aramid fibres and carbon fibres as well as all types of impurities were cleared. The authors took pictures in magnifications (Figure 12) 4 layers of the sample (photos on the left) and 7 layers of the sample (photos on the right) from the ablation surface.

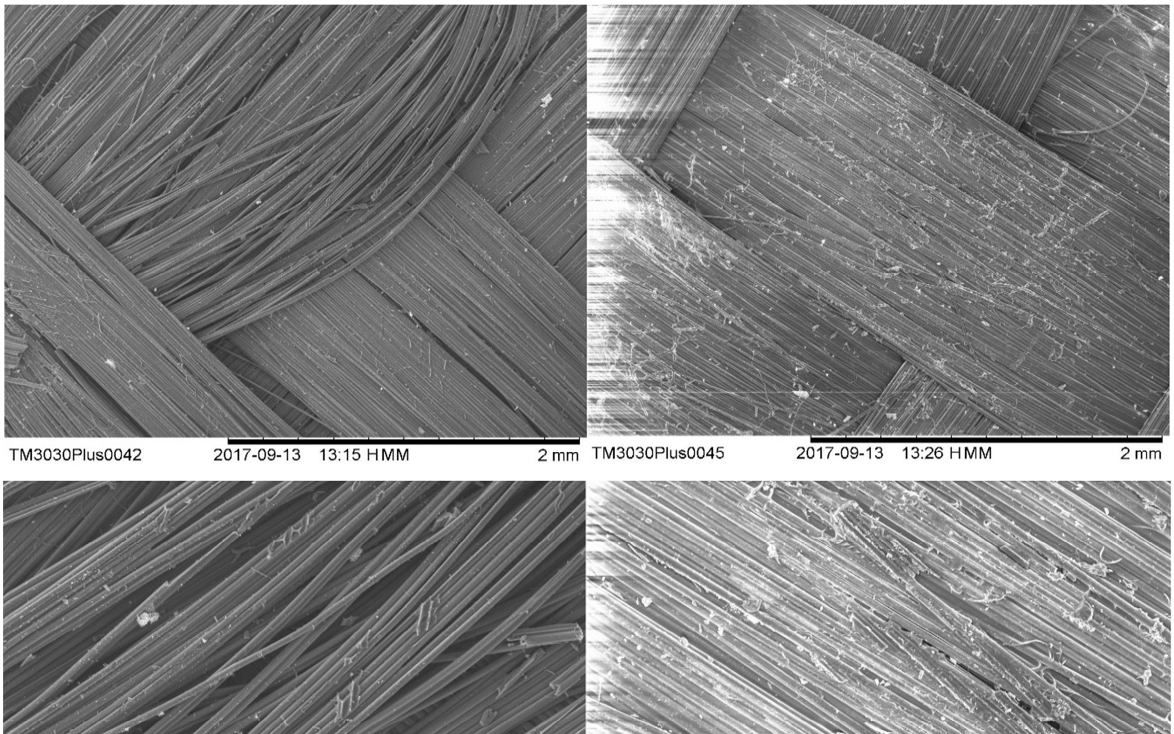


Fig. 12 - Structure of composite components after testing thermal resistance (layer 4 and 7 of the sample)

CONCLUSIONS

Having analysed all the research findings and observation of the course of the investigation as well as microscopic photographs of the structure, the following conclusions may be drawn:

- Owing to the use of polymer ablative composites in connection with the superalloy Inconel/Alloy 600, the temperature was reduced several times in relation to the ablation surface temperatures obtained during experimental studies;
- During the test with the burner, the first layers underwent aerodynamic erosion and were partially or completely separated from the sample, which indicates ablative properties of the investigated materials;
- The distribution of temperature on the rear surface of the sample was roughly homogenous; the occurring disturbances could have resulted from an uneven thickness of the sample, which did not considerably influence the final measurements;
- Changing the position of the metal plate 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, as well as reducing thickness loss.
- The location of the metal plate in the composite also affected the ablation mass loss U_a. Along with the change in the placement of the metal and its moving away from the ablation surface, the relative ablation loss of mass was decreased (from approximately 21% in sample 2 to approximately 10.5% in sample 5).
- The structure of the samples differs depending on the layers which were examined microscopically. In the samples it was possible to observe destroyed structures of fibres which were affected by ablation. However, after the separation of successive layers, smaller wearoff and larger matrix remains were visible.

Thus, it can be clearly stated that the use of the spacer in the form of metal in the composites with fibre reinforcement may considerably change the ablation mass loss; it will also affect the temperature reduction on the rear surface of the sample.

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