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Electroconsolidation of nanocomposite material for gas turbine blades

Edwin Gevorkyan[1], Miroslaw Rucki[2], Vasily Dutka[3], Zbigniew Siemiatkowski[2], Dmitrij Morozow[2]

[1]*Materials and Manufacturing Technology for Transport Applying Products Dept., Ukrainian State University of Railway Transport, Ukraine*
[2]*Kazimierz Pulaski University of Technology and Humanities in Radom, Poland*
[3]*Institute of Superhard Materials, Ukraine National Academy, Kiev, Ukraine*

Corresponding author: m.rucki@uthrad.pl

Abstract
The manufacturing process and properties engine gas turbine blades out of a novel composite material based on nanopowders alumina, zirconium dioxide and tungsten carbide are investigated. Attention was paid to the temperature field distribution during electroconsolidation under hot pressing technology. Dedicated software was prepared to analyze the temperature distribution in the graphite die of the Field Activated Sintering apparatus. Experimental measurement with contact thermocouples demonstrated good conformity of the theoretical predictions with real sintering conditions. During the heating process, the differences between temperature fields at the edges of the die and inside materials, is reduced with the increase of the temperature. This is very important because the consolidation time should be kept very short in order to obtain nanostructured grain pattern in the bulk material. The analysis of resulting mechanical properties shed the light on the influence of process features on some structure parameters and phase composition, as well as physical and mechanical properties of alumina composites. It was found that the formation of a composite structure due to the introduction of nanopowders of alumina and zirconium dioxide into the nanopowder of tungsten carbide makes it possible to increase some of the physico-mechanical properties of the obtained composite materials, which is very important in case of aircraft industry.

Keywords: electroconsolidation, alumina nanopowder, zirconium dioxide, tungsten carbide, sintering

1. Introduction

Numerous researches have shown that nanostructured ceramics have unique properties and performance characteristics in comparison with bulk material [1-4]. Developed nanostructured materials with high physical and mechanical properties have unique properties that allow them to be considered as perspective for use in various components of the gas turbine engine. Currently, many of the world's leading companies involved in aircraft engine manufacturing are considering the problem of replacing certain parts with ceramic ones. Ceramic materials have many advantages, but do not have high strength, in particular crack resistance. Despite numerous attempts, it was not possible to create a ceramic material capable of operating as gas turbine engine blades. Huge tensile loads and high temperatures negate all attempts to create the necessary material.

2. Electroconsolidation process

It is known that a multiple increase in wear resistance of ceramics, including those based on ZrO_2, can be realized on the way of creating a material with a thin homogeneous structure and ultimate density. Such conditions, as a rule, ensure high fracture toughness and microhardness of ceramics, and can be realized, for example, by hardening of the base material by a series of oxides [5]. In the current researches, apparatus described in [4] was used for sintering of gas turbine blade body out of a nanostructured composite based on Al_2O_3–ZrO_2 and WC. It was found experimentally, that for high-intensity processes with high heating rates, the rates of consolidation can grow by several orders of magnitude. This leads to a complete compaction of the powders in a very short time with the preservation of the nanoscale internal structure. Electrosintering makes it possible to obtain composite ceramic materials based on Al_2O_3, ZrO_2 with WC additives without impurities and with minimal grain growth over a time of the order of 10-15 minutes, whereas traditional sintering requires several hours and special additives that degrade the properties of the material. At the same time, electric sintering is used with an equally high result for both electrically conductive and non-conductive powders (by using electrically conductive graphite molds), and microwave sintering is successfully used for both sintering ceramics and metals.

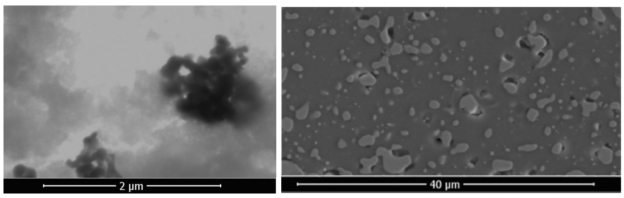

Figure 1. The initial mixture of nanopowders Al_2O_3–ZrO_2 nano–3 wt% Y_2O_3– 50 wt% nano WC before sintering (left) and sintered (right) at temperature T = 1450° C, pressure P = 30 MPa, sintering time 3 min

As can be seen from Fig. 1, nanograin tungsten monocarbide WC, distributed by separate small colonies in the form of fine black nanoparticles (left), is agglomerated after the hot pressing process into larger oval-shaped grains (right) resembling eutectic grains uniformly distributed in the solid solution matrix Al_2O_3 – ZrO_2.

3. Model and verification

The model of thermal processes during electric heating under a vacuum press unit was developed in order to analyze the spread of heat and temperature gradients in the sintered material. The electric voltage U=5.0 V is applied to the surfaces of brass electrodes. During 1000 s, heating was performed at the specified voltage, after this it was kept in the absence of an electric field for 500 seconds. The properties of the workpiece material (Al_2O_3 powder) and the properties of the materials of all other elements of the installation in this model are adopted to the actual temperature.

The problems of electrical conductivity and thermal conductivity are solved by the finite element method with a combined radiosity method. The spatial domain was partitioned into 1438 finite elements (8 nodal elements, quadratic approximation) and 4477 nodes. The calculation time with a relative error of 0.01 was 6 minutes. To check the model, temperature was measured with contact thermocouples.

Figure 2 and 3 present calculated temperature distribution and results of measurement in the specific points c1-c4.

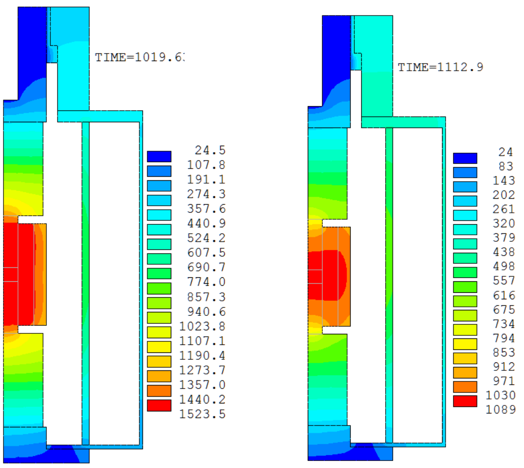

Figure 2. The modeled temperature distribution in the turbine blade bodies after 1019.6 seconds (left) and after 1112.9 seconds (right)

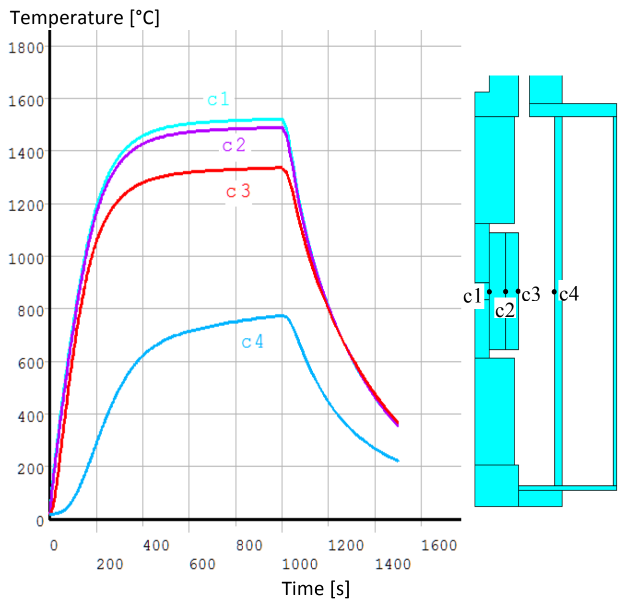

Figure 3. The results of contact temperature measurement in the points c1-c4 in the sintered turbine blade body during the process of electroconsolidation

4. Results and discussion

Table 1 shows the properties of a composite material obtained by electrosintering from the initial mixture specified in the section 2. The physical and mechanical properties of the material were determined using standard methods of mechanical testing.

Table 1 Main properties of the sintered material

Hardness, HRA	92..94
Hardness, GPa	20..22
Density, g/cm^3	4,2
Compressive strength, MPa	2600..2800
Bending strength (T = 20..900 C), MPa	600..800
Thermal conductivity, $W{\cdot}m^{-1}{\cdot}K^{-1}$ at 22˚C at 400˚C	25 40
Young's modulus	400
Coefficient of stress intensity, K_{1c}, $MPa{\cdot}m^{1/2}$	12..15
Temperature coefficient in the range 20–1000˚C	4..5

Considering the process of electrosintering, we can make the assumption that the main mechanism of mass transfer in the case of grain boundary diffusion is electrotransport. Thus, it can be stated that the composite material obtained by electrosintering out of Al_2O_3, ZrO_2 and WC nanopowders, performs increased mechanical characteristics. For instance, the typical ceramic material consisting of Al_2O_3 – 40 wt% TiC performs ca. 30% worse mechanical characteristics. Thus, the proposed nanocomposite can be successfully applied if the fabrication of gas turbine blades for the aircraft engine.

5. Conclusion

The analysis of resulting mechanical properties shed the light on the influence of process features on resulting physical and mechanical properties of the ceramic composite. It was found that the formation of a composite structure due to the introduction of nanopowders of alumina and zirconium dioxide into the nanopowder of tungsten carbide makes it possible to increase some of the physico-mechanical properties of the obtained composite materials, which is very important in case of aircraft industry. The model of thermal fields performed good conformity with experimental data enabling fair prediction of the expected bulk material properties. In further investigation, the effect of different sintering parameters on the resulting characteristics will be checked.

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