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THE INTERFACE CHARACTERIZATION FOR CERAMIC LAYERS COATED BY THERMAL SPRAYING

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The purpose of this paper is to determine the quality of the interface between the ceramic layers and the base material for the parts that are reconditioned through thermal spraying process. In the first phase, the flaws that may occur between the parent material and the material for coating will be highlighted by a nondestructive testing method using eddy currents, and in the second phase the behavior of the given specimens to thermal shock will be analyzed using finite element method. Two types of finite elements models which correspond to the two types of specimens tested on the experimental stand were created. The analyzed specimens were coated with a ceramic material of Yttria-Stabilized Zirconium. The obtained results allow the selection and evaluation of the technological reconditioning process.

Keywords: Reconditioning, Thermal spraying, Plasma spraying, Eddy Currents, Finite Element Analysis.

1. Introduction

The reconditioning is recognized as an industrial technology which aims to recover the worn parts, ensured through the restoration of their reliability, [1].

Thermal spraying is a method of coating for easily machinable materials, materials with outstanding features, superior base material (substrates) such as various metals, alloys, ceramics and carbides, which is advantageous from the economic point of view, [2]. Plasma spraying is defined as the process in which a no transferred arc is used as the source of heat that ionizes a gas which melts the coating material and propels it to the work piece (Figure 1). Plasma is an ionized gaseous cloud composed of free electrons, positive ions, neutral atoms and molecules. Because of its unique properties, some have referred to it as the "fourth state of matter". Plasma is generated whenever sufficient energy is transmitted to the gas, causing a part of it to ionize, [3].

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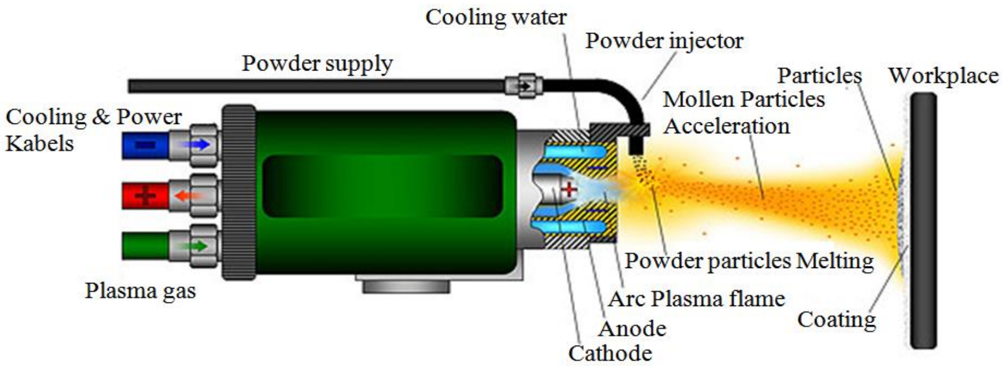


Fig. 1. Plasma Spray Process [3]

Nondestructive testing procedures allow the control of all reconditioned parts and provide assurance of product quality. Theoretical models may form a basis for the study of all environments, all the discontinuities (layer with porosities) and for other type of applications, [4]. The finite element method involves the construction of an approximate mathematical model for the analyzed structure by developing a meshed model. The meshed model is the result of dividing the geometrical continuous domain into a set of discrete sub-domains, usually called elements. Therefore, the thermal and mechanical behaviors for two given specimens, which have the top surfaces coated with a layer of Yttria-Stabilized Zirconium will be analyzed using the finite element method.

2. Experimental part

For the experimental research regarding the adhesion between the base material and the coating material, two types of given specimens presented in the Figure 2 were tested. The utilized specimens are manufactured from steel (OLC45) and they are coated with a thin layer of Yttria-Stabilized Zirconium (ZrO_2 +20%Y_2O_3). For coating, the thermal spraying plasma jet process was utilized.

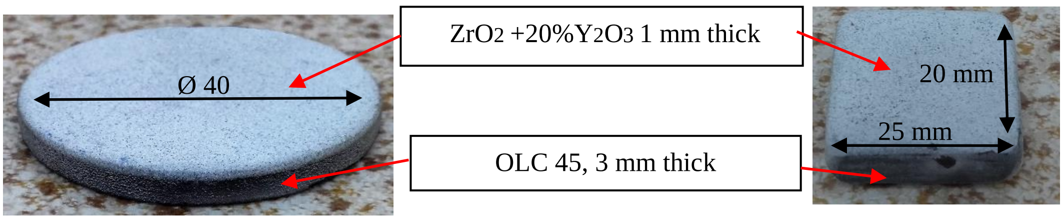
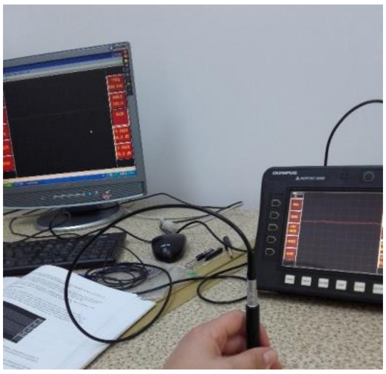
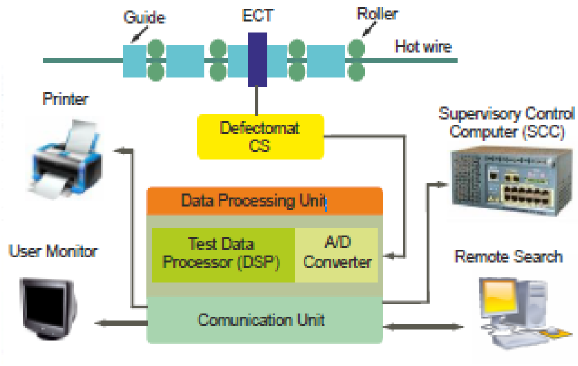


Fig. 2. Specimens coated with yttria- stabilized zirconium

The device able to determine the flaws between the base material and coated layer is Nortec® 500 Series Portable Eddy Current Flaw Detectors, as it can be seen in Figure 3.



a)



b)

Fig. 3. (a) Portable eddy current testing instrument. (b) Block diagram of the overall system for hot wire testing [5], [6]

2.1 Experimental research for controlling the thermal sprayed coated layers using eddy currents

The existence of a crack (Figure 4) creats an additional magnetic field of the flaw, which is composed of the magnetic field of eddy currents out of the rest of the body, providing thus a signal to the transducer, [4], [8], [9]

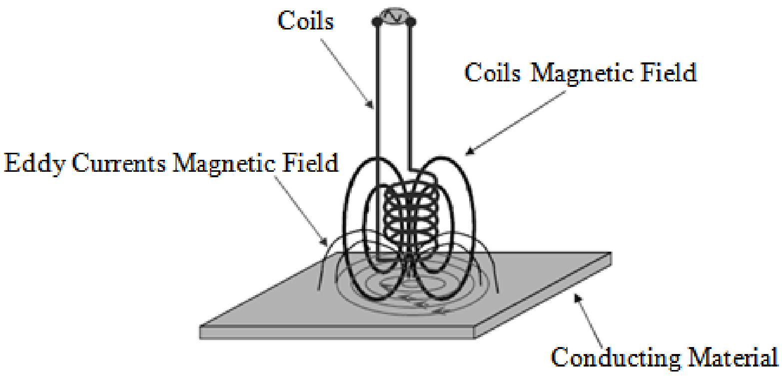


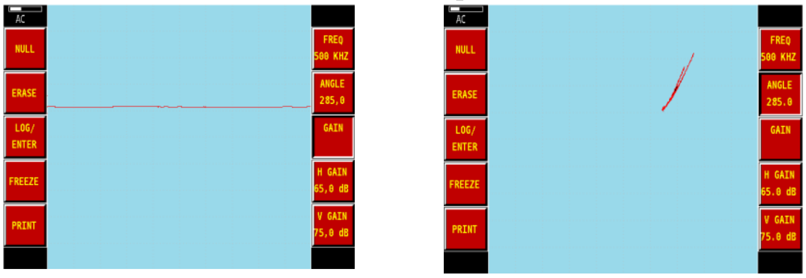
Fig. 4. Induction of eddy currents

The depth of penetration of eddy currents depends on the source of excitation, frequency electromagnetic oscillations, electrical conductivity, magnetic permeability. The adjustment of the device is made by using the probe type Nortec PL/500 kHz-1MHz/A presented in Figure 5 a and the calibration with the probe - P/N 9222162 A (Figure 5 b).

a) Sensor for flaw detection b) calibration with the probe

Fig. 5 The adjustment of the device

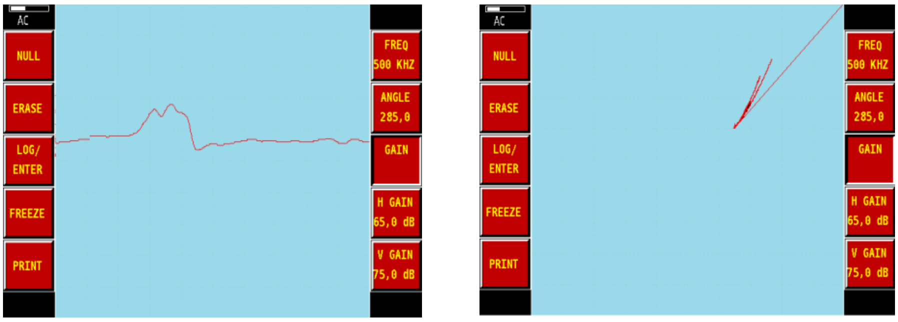
The result for calibrating the device is displayed as two graphic models, like in Figure 6. On the display, is represented the signal given by the eddy currents when the sensor detects a flaw on the surface or in the proximity of it for the examined part. Figure 6 shows the signal from the eddy currents which has been received from the surface of calibration probe.



a)Waterfall Display Functions b)Impedance Plane Display

Fig. 6 Calibration results

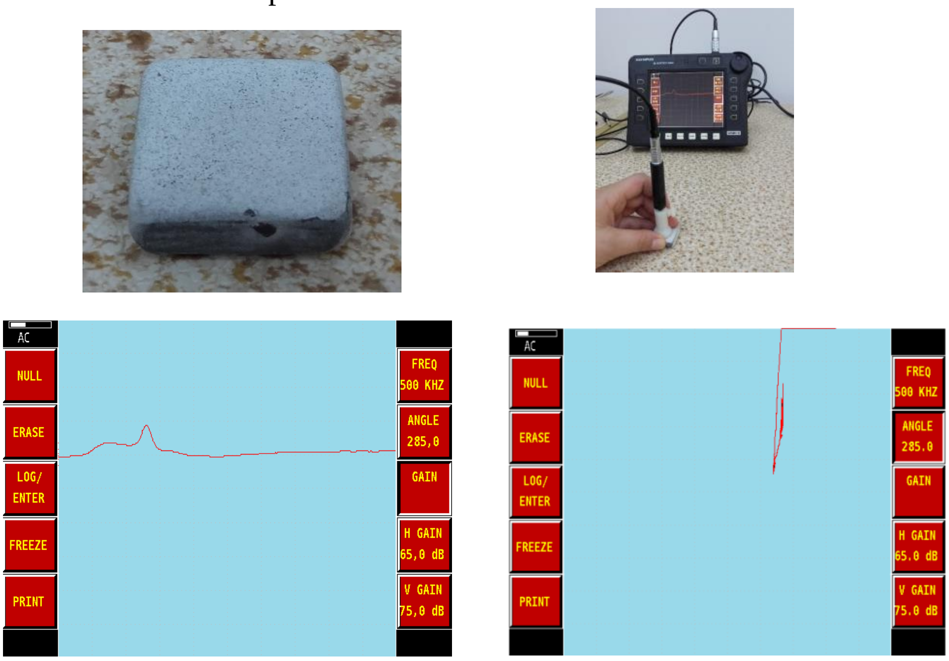
The probe is placed on the first specimen and it is pursued the position of the meter needle indicator (Figure 7). Then, the probe is moved as to pass through the crack and the indication of the pointer is tracked. The deviation represents the flaw indication [4]. Control by eddy currents have revealed a penetrating flaw in the first analyzed specimen and the results were displayed in two modes. In Figure 7, the eddy currents signal is detected in the surface depth for many areas of the examined sample.



a) external sweep display b) impedance display
Fig.7 Surface flaw detection

The probe is placed onto the coated surface of the second specimen and the position of the meter indicator needle is followed (Figure 8).

In Figure 8, the eddy currents signal is detected near the surface on many areas of the examined sample.



a) external sweep display b) impedance display
Fig.8 Surface flaw detection

Comparing the results obtained after the second specimen was tested with those associated with the first specimen, significant differences caused by the different dimensions of the parts can be observed. In conclusion, the possibility of obtaining flaws between the base material and the coated layer is larger if the sample used in the process is bigger. The layer adhesion is affected differently depending on the size of the specimen.

2.2 Analysis of the thermal shock behavior of the specimens using the finite element method

If the assembly is heated, by operating a thermal flow on the upper surface of the coated layer, it is necessary to perform a finite element simulation to determine the behavior of the specimens and the variation of temperature and heat flow in time. That is why a transient thermal analysis was undertaken for the case in which the time for the heating process is 20 seconds. The temperature applied onto the surface of the deposited material is 1400°C. The results obtained through the thermal analysis were linked to a static structural analysis to determine the strains and stresses that occur as a result of the thermal loads. The geometrical models of the specimens, were designed using the specialized software Ansys Workbench 16.0.

Ansys is a widely used software for analyses in industry and research, based on the finite element method, with the purpose of simulating the response of a system that is stimulated mechanically, thermally or electromagnetically. For solving the problems, in this method it is assumed that the continuous structure of the geometrical model is replaced by a discontinuous mathematical model (mesh).

Meshing means that the geometrical model of the part is divided and approximated through a network of elements that have a simple geometric configuration.

The intersection of the elements forms the nodes [7]. The geometric models for both specimens were built using the Design Modeler interface, provided by the Ansys software.

After the geometrical models were created, the constants for the used material were established. In Table 1 are presented the parameters for zirconia stabilized yttrium and for the steel used in the simulation.

Table 1

Material constants

Material	Density [kg mm^-3]	Young's Modulus [Mpa]	Poisson's Ratio	Bulk Modulus [MPa]	Shear Modulus [MPa]	Thermal Conductivity [W mm^-1 C^-1]	Specific Heat [mJ kg^-1 C^-1t]
Structural Steel	7.85e-006	2e+005	0.3	1.6667e+005	76923	6.05e-002	4.34e+005
ZrO2+20%Y2O3	6.6e006	160	0.32	148.15	60.606	2.2e-003	5.4e+005

After the parameters were introduced, the model was meshed. For both geometrical models of the specimens the automated mesh type was used. In Fig. 9 are presented the meshed models of the specimens.

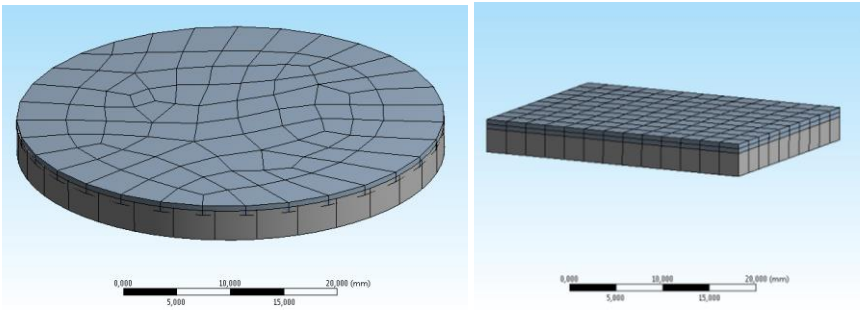


Fig. 9. Meshed models of the specimens

For transient thermal analysis, the time parameters were selected. In Figure 10 the graph of heat variation in time, in three phases is presented. The cycle begins with the increasing of temperature from 22°C to 1400°C in 5 seconds. After that, the temperature remains constant for 10 seconds. The cycle ends with the return of the temperature to 22°C.

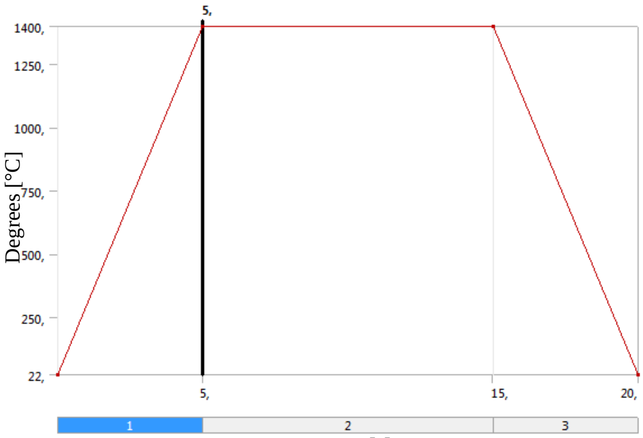


Fig. 10. The cycle time- temperature graph

The obtained result was the distribution of temperature in the specimens and the total heat flux. The variation of the temperature for the rectangular specimen is presented Figure 11 and the total heat flux in Figure 12. As it can be seen, the maximum value of the total heat flux is 2817W/mm², located near the heated surface, and the propagation direction is from the coated layer to the base material.

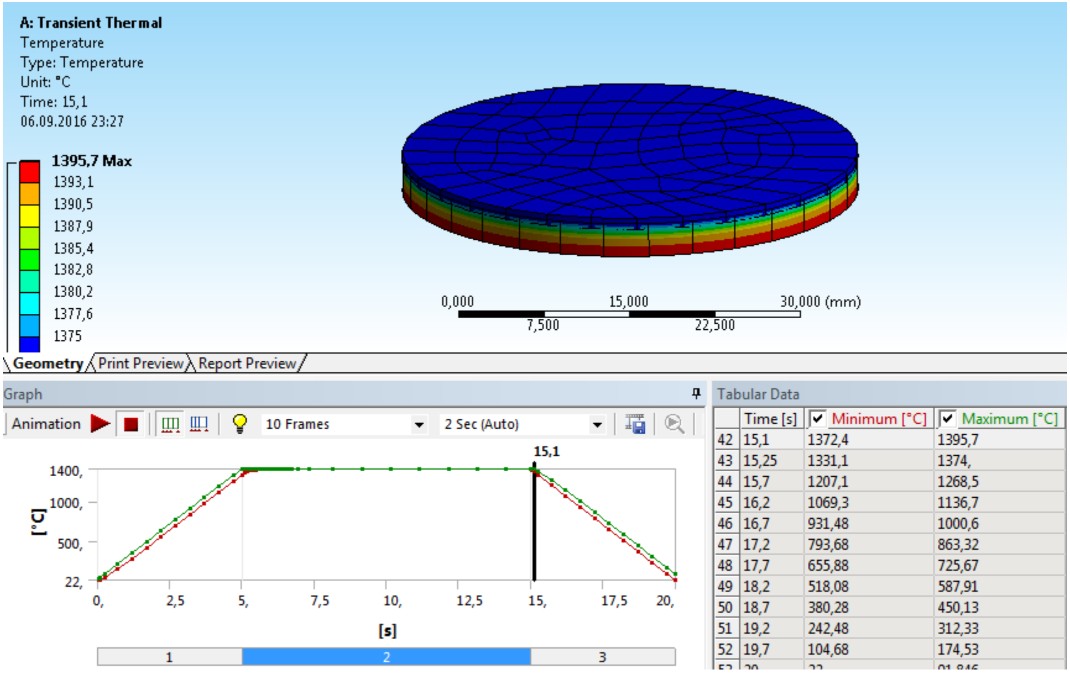


Fig.11. Temperature distribution for the first sample

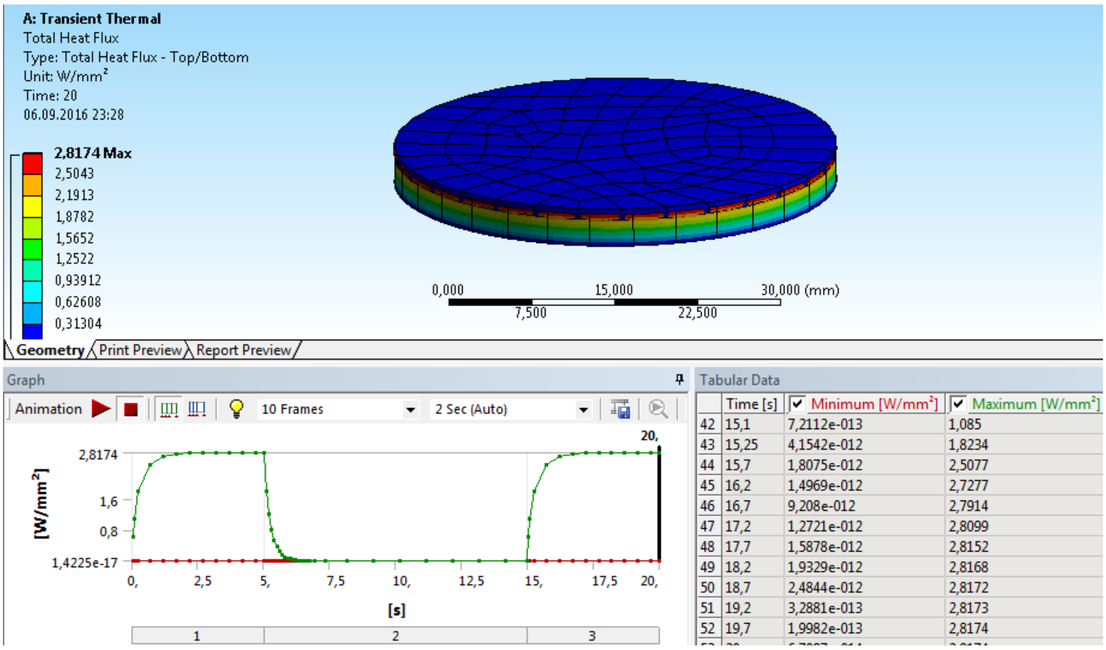


Fig.12. The total heat flux for the first sample

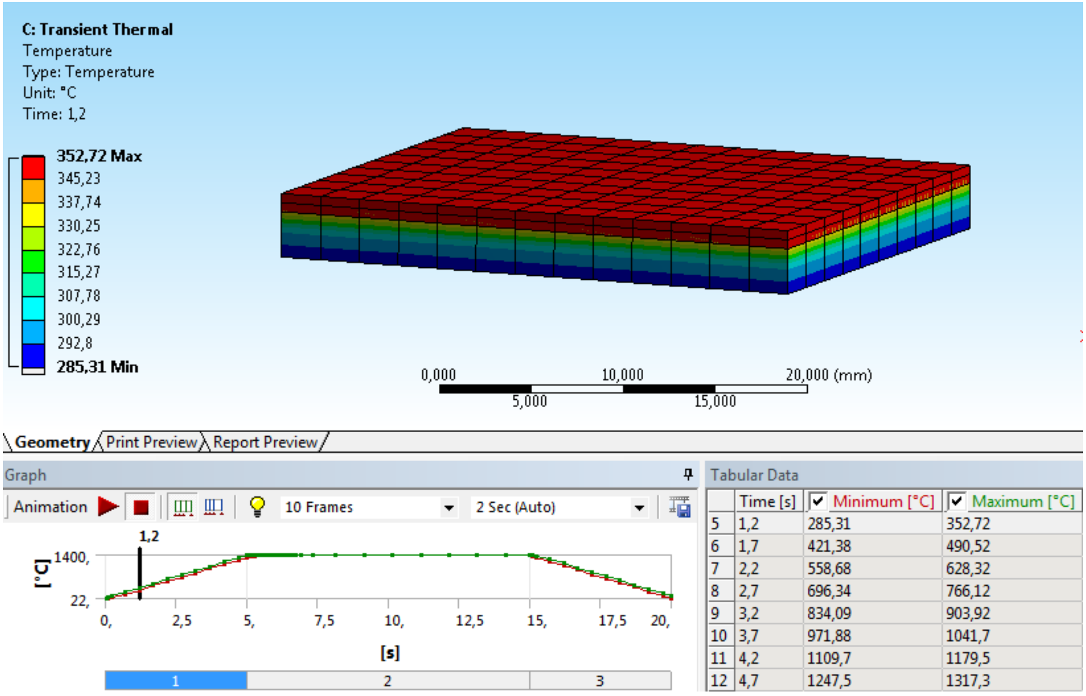


Fig. 13. Temperature distribution for the second sample

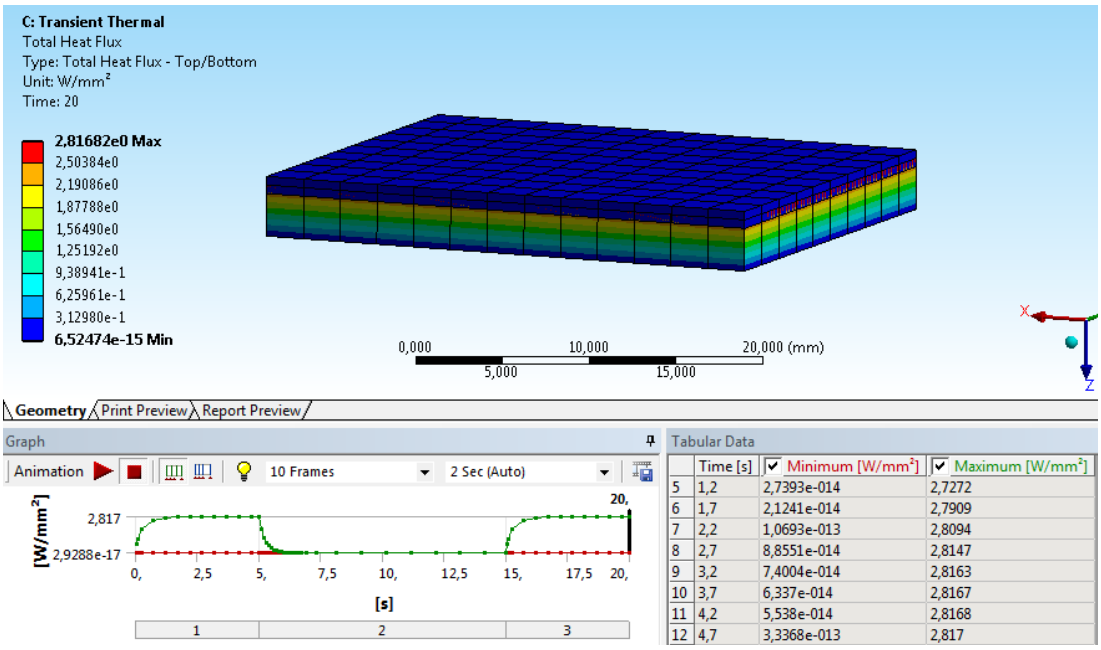
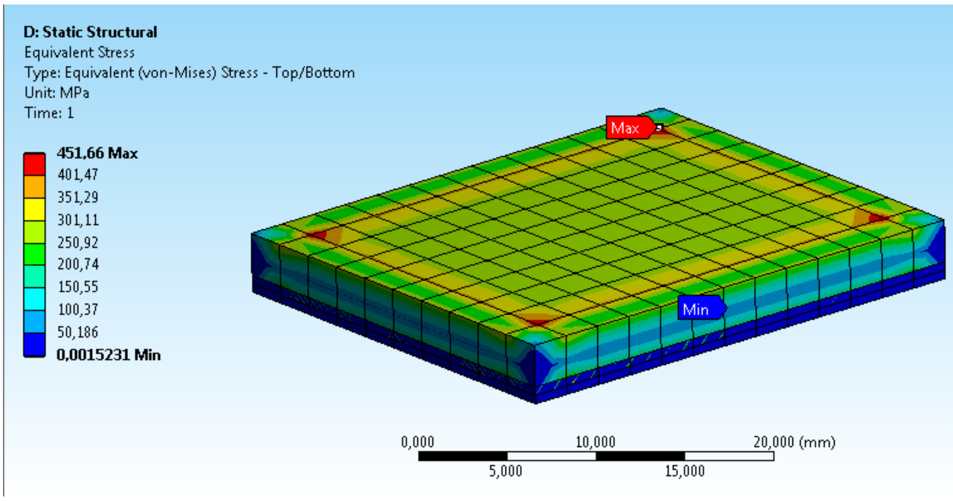
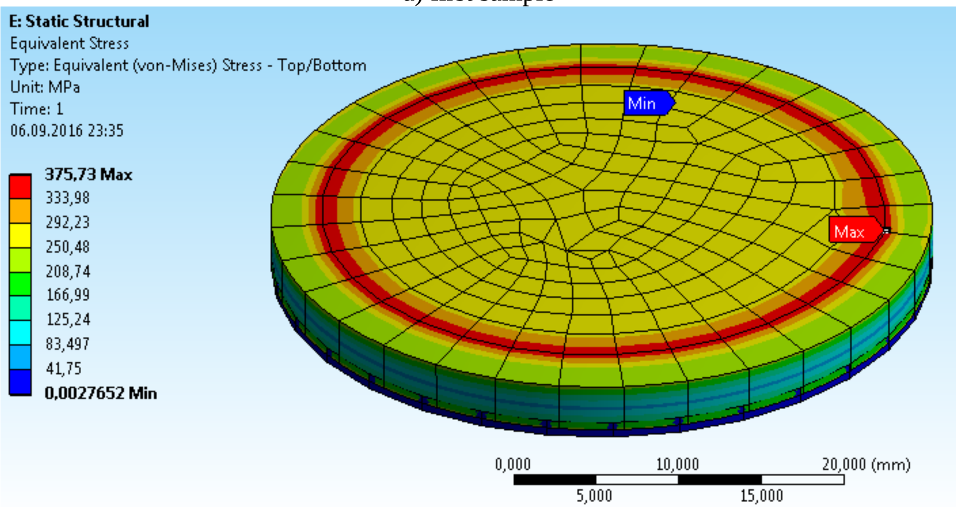


Fig.14. Total heat flux for the second sample

Under the action of temperature, the samples undergoes deformations. This information can be obtained by creating a coupled analysis (thermal - static) in Ansys. As a result of these analysis they the maximum stresses and total deformations for the specimens. In Figure 15 are presented the maximum stresses (Equivalent von Mises stress) that are obtained for the specimens (Figure 15 a) first sample, 15 b) second sample).

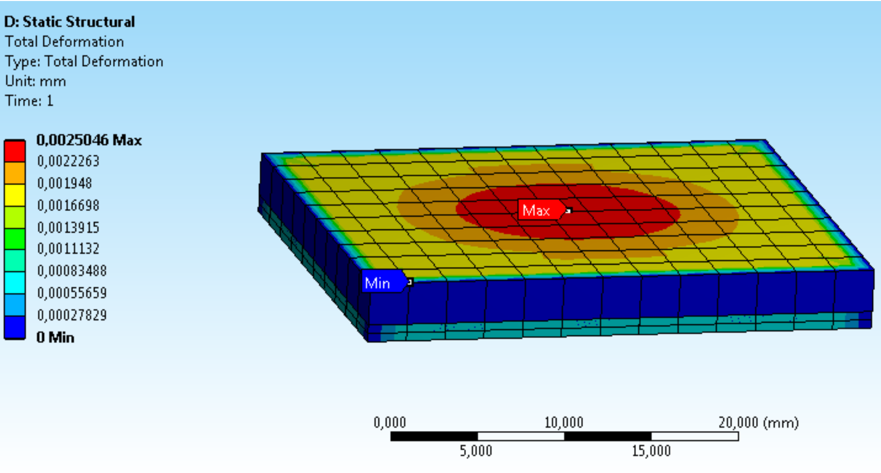


a) first sample

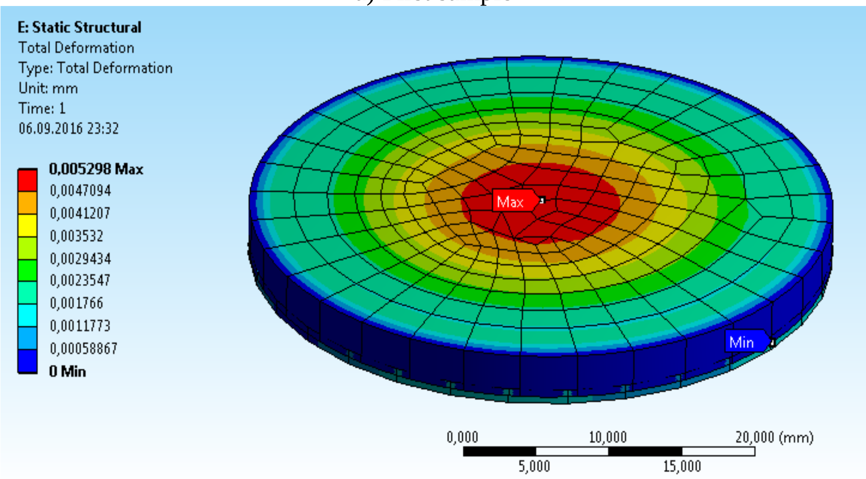


b) second sample

Fig.15. Equivalent stress



a) First sample



b) second sample

Fig. 16. Total deformation

It is clear that the different dimensions have impact also on the mechanical behavior of the parts when they are heated. Therefore, a greater value for the total deformations was obtained for the bigger sample, 0.005mm compared with 0.0025mm, although the value is lower for the von Mises stress - 376MPa for the bigger part compared with 451 MPa for the smaller sample.

3. Conclusions

The main flaws that occurs frequently from reconditioning processes are: the lack of adherence between the deposited layer and the base material, high porosity, the absence of the adherence between the deposited layers caused by an inappropriate thickness. The properties of the coated layers depend on the nature of the coating material, the spray technology used as well as of the spraying process parameters. The adhesion layer is affected differently depending on the size of the specimen. The results demonstrate that the available eddy currents technique allow detecting the flaws between the base material and the coated layer.

The finite element method can provide necessary information regarding the distribution of the temperature, total heat flow and also the mechanical behavior of the samples under the influence of heat.

By using the finite element method, the cooling-heating cycle, involved by the plasma spraying process was simulated. Applying this method led to determining a first possible causes for the occurrence of flaws in the reconditioned samples. The existence of flaws at the interface between layers leads to a drastic decrease of the adhesion as a result of the reconditioning process temperature.

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R E F E R E N C E S

[1]. *Gabriel Marius Dumitru*, *Constantin Radu*, *Bogdan Dumitru*, Recondiționarea și Repararea produselor (Reconditioning and repair products), Editura Printech, București, 2010 (in Romanian).

[2]. *Mariana Solomon*, Improving properties of metallic parts covered with thin layers by isostatic after working process, Brașov, 2011.

[3]. http://www.fwgts.com

[4]. *Mariana Goran, A.E Bușaru, M.E Militaru, G.M Dumitru, L. Hudea*, Modeling process control by Eddy Currents of thermal sprayed coatings, Conference Proceedings of the Academy of Romanian Scientists PRODUCTICA Scientific Session Vol. 7, Nr 1, Editura Academiei Oamenilor de Știință din România, București, 2015.

[5]. *Bae, J., Kim, S.*, Hot wire inspection using eddy current. In Proceeding of the 18th IEEE Instrumentation and Measurement Technology Conference, Budapest, Hungary, May, 2001.

[6]. *** www.mdpi.com/journal/sensors.

[7]. *Cristina Pupăză, Radu Constantin Parpală,* Modelarea și analiza structurala cu ANSYS Workbench (Modeling and structural analysis with ANSYS Workbench) Editura Politehnica, București, 2011 (in Romanian).

[8]. *D. J. Hagemaier*, Fundamentals of Eddy Current Testing, Columbus, Ohio, 1990.

[9]. *V.S Cecco, S. P. Sullivan, J. R. Carter, and L. S. Obrutsky*, Innovations in Eddy Current Testing, Enginrrring Technologies Division, Nondestructive Testing Development Branch, Chalk River Laboratories, Chalk River, Ontario, 1995.