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APPLICATION OF FINITE ELEMENT METHOD (FEM) FOR DEFINITION OF THE RELATIONSHIP BETWEEN PROPERTIES OF LASER ALLOYED STEEL SURFACE LAYER

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Preliminary Note – Prethodno priopćenje

Investigations include FEM simulation model of alloying the PMHSS6-5-3 steel surface layer with the carbides and ceramic powders, especially WC, VC, TiC, SiC, Si_3N_4 and Al_2O_3 particles using the high power diode laser (HPDL). The FEM computations were performed using ANSYS software. The scope of FEM simulation was determination of temperature distribution during laser alloying process at various process configurations regarding laser beam power and method of powder deposition, as pre coated past or surface with machined grooves. The FEM simulation allows specifying the heat affected zone and the temperature distribution in the sample as a function of time and thus allows the estimation of the structural changes taking place during laser alloying process.

Key words: high-speed tool steel, temperature, computer simulation, FEM, laser remelting

INTRODUCTION

The laser modification of surface layers of tool materials encompassing surface remelting or alloying using powders with high hardness is a prospective direction of investigations into the improvement of material properties[1-3]. The Finite Element Method (FEM) is employed in many sectors of modern industry and in numerous computer aided technologies. This method is currently most popular and is witnessing fastest growth for numerical methods; it is used in aviation, rocket, automotive, shipyard, machine and electrotechnical sectors and comprises such fields of science as biomechanics, medicine, mechatronics and materials engineering [4-6]. Numerical models and computer simulations enable to precisely describe the structure and to identify the properties of the materials analysed within their entire volume. Laboratory research in the field of materials science allows in many cases only to measure the chosen values and parameters within limited areas due to complex shapes and variable properties of the investigated parts' cross section [7-10].

MATERIAL AND METHOD

It was found in preliminary investigations carried out with a high performance diode laser, HPDL Rofin DL 020, that the maximum travel rate at which the process is stable is v = 0,5 m / min. For this reason, all the experiments were performed at a constant rate of remelting by changing the laser beam power within the range of 0,7 do 2,1 kW. A numerical analysis of the thermophysical effects occurring in the laser surface treatment process was performed with Ansys 12.0 software.

The following was analysed: temperature distribution within the metal volume, the shape and size of liquid pool and of heat-affected zone, as well as heating and cooling time in the process of tool steel alloying with a high performance diode laser (HPDL).

All the relevant parameters of a technological process of surface laser treatment were considered when building a numerical model, including laser beam power and scanning rate, shape and distribution of power of the laser beam focussed on the specimen surface, the method of introducing powder in an alloying process through two grooves with the apex angle of 45° and depth of 0,5 mm. A lattice of the numerical model for the alloying variant is presented in Figure 1

It was assumed when building a numerical model that the initial specimen temperature and ambient temperature is 20 °C (293,15 K). The material simulated was heated with a heat flux corresponding to the laser beam power rates applied in the analysed processes of, respectively, 1,4; 1,7 and 2,1 kW.

The shape of the heat flux moving along the model surface was corresponding to the shape and dimensions of the HPDL laser beam focussed on the specimen surface and was 1,8 x 6,8 mm.

The heat flux was moving along the simulated specimen's surface with steady rectilinear motion according to the laser's movement at a rate of 0,5 m/min. Material cooling to ambient temperature occurs by convection and radiation in the analysed model.

Due to the fact that the process was carried out in a laboratory, convection of 800 J/kg in closed space was assumed in the mathematical model.

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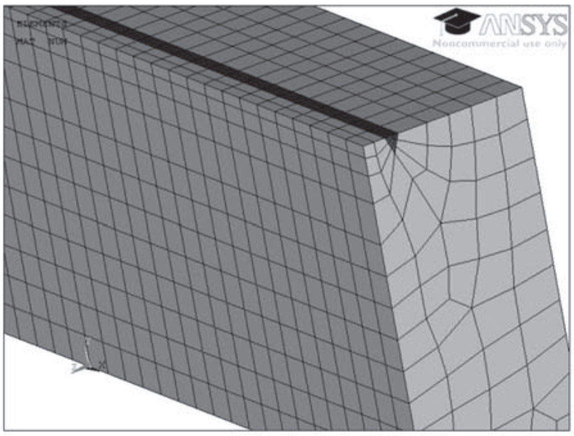

Figure 1 Analyzing numerical model after meshing

A condition of symmetry was the perfect isolation (no heat was exchanged by convection, radiation at the cross section), hence there was no need to set additional boundary conditions. It was assumed that the energy of laser radiation is supplied to the material evenly along the entire focal point surface of the HPDL laser.

PMHSS6-5-3 steel was obtained by powder metallurgy. Steel porosity of about 2 % was taken account of for correct calculations in the numerical model. An assumption was made that the space of closed pores is filled with atmospheric air (nitrogen of 78,08 %; oxygen of 20,95 %; carbon dioxide of 0,03 %; argon of 0,93; neon, helium, krypton, hydrogen, xenon, ozone 0,003%). A numerical model of the process was created with 20 second-order nodal elements for Solid 90 thermal analyses.

The hexadric form of elements exists in almost the entire model (degraded prism existed in few places). Non-linear variations in density and in thermophysical properties, such as heat conductivity and specific heat in the function of temperature, were considered when creating the model. The SI system of units was applied for setting boundary conditions and for describing material properties in the model considered.

RESULTS AND DISCUSSION

It was found according to metallographic investigations that the remelting zone (RZ) and heat-affected zone (HAZ) exist in the surface layer of the studied steels. Their thickness depends on the applied laser treatment parameters (laser treatment type, laser beam power, alloying coating type). Investigations show that a change in laser power at the constant scanning rate is impacting the size of the area where structural changes occur in the surface layer of steel. The power of the laser beam is also related to the formation of the weld penetration bottom and the convexity of the weld face, which are influenced by strong movements of the liquid metal. A mesh of finite elements was increased in the areas where the highest accuracy of calculations is needed, i.e. in the near-the-surface area, the groove area with alloying powder, heat affected zone and liquid pool volume.

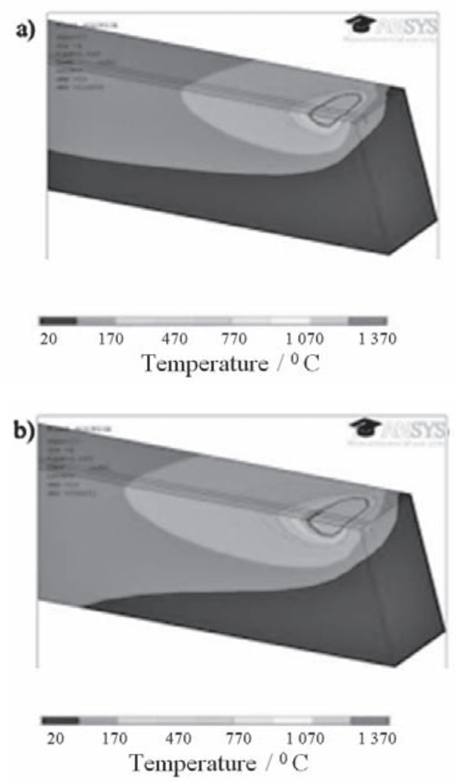

Figure 2 Temperature distribution at the cross section of the specimen in surface laser treatment process a) HS 6-5-3-8 steel alloyed with SiC particles with the power of 1,4 kW b) Hs 6-5-3 steel alloyed with WC particles with the power of 1,7 kW

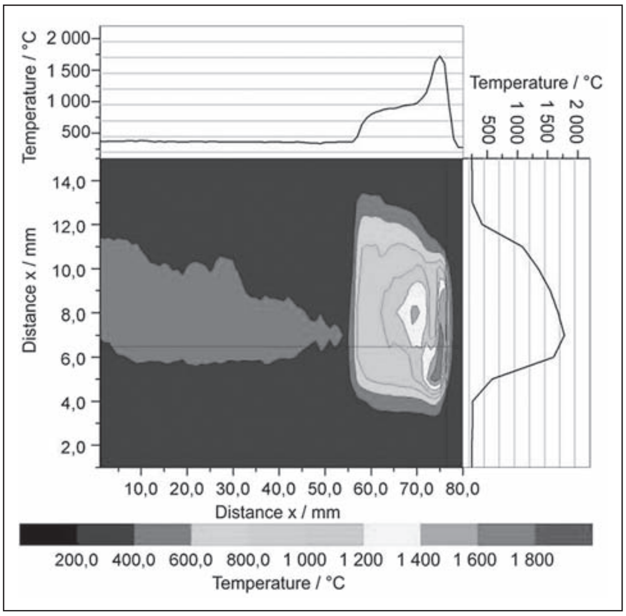

Figure 3 Temperature distribution recorded with thermal camera on the specimen surface during laser alloying of high speed HS 6-5-3-8 steel alloyed with SiC particle with the laser beam power of 1,4 kW

Temperature distribution maps for the analysed areas of the material were created based on the calculations made. It was concluded, by analysing the temperature distribution maps produced in computer FEM simulations (Figure 2) of the remelting and alloying process, that the shape of the remelted area and the heat affected zone is largely consistent with the shape recorded on the specimen surface with a thermal camera and with a shape and size of a solidified pool observed in a light microscope.

Figure 3 shows the selected thermograms registered with a thermal camera during the alloying process of the analysed high speed steels. The camera, as recommended by the manufacturer, is placed within one meter from the specimen surface on which a beam of HPDL laser was focussed. The data registered by the thermal camera, in form of a matrix, allowed to precisely determine the temperature values in selected points, to determine temperature profiles along the registered image and also such reflecting the actual distribution of temperature on the alloyed surface.

CONCLUSIONS

The results of numerical calculations for the laser alloying process are largely consistent with the shape registered on the specimen surface by means of a thermal camera and with the shape and size of the solidified pool observed in a light microscope. The calculated depth of the remelting zone and heat affected zone - depending on the laser treatment parameters applied - is comparable to the depth of the zones observed in the surface layer obtained in an experiment on steel specimens. The time for optimum selection of alloying process parameters with a high performance diode laser (HPDL) is greatly shortened by applying a numerical FEM model for simulating a technological laser surface treatment process, thus the necessity to employ costly and long-lasting experimental tests is limited.

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Note: The responsible translator for English language is Michał Lisek Gliwice, Poland