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Determination of temperature distribution during laser alloying process with the use of FEM analysis

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Introduction

Investigations include FEM simulation model of alloying the commercial tool steels PMHSS6-5-3, HS6-5-2-5, HS6-5-3-8 surface layer with the carbides and ceramic powders, especially WC, VC, TiC, SiC, Si3N4 and Al2O3 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 was performed on five different 3-dimesional models. The model assumed nonlinear change of thermal conductivity, specific heat and density that were depended on temperature. The heating process was realized as heat flux corresponding to laser beam power of 0.7, 1.4 and 2.1 kW. Latent heat effects are considered during solidification. The molten pool is composed of the same material as the substrate and there is no chemical reaction between alloying material and base metal. The simulation included different materials properties of base metal as well as alloying WC, VC, TiC, SiC, Si3N4 and Al2O3 powders. The absorptivity of laser energy was dependent on the simulated materials properties and their surface condition of the base metal and feed materials. 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. The simulation was applied to determine the shape of molten pool and the penetration depth of alloying surface. Simulated penetration depth and molten pool profile good mach the experimental results. The depth values obtained in simulation are very close to experimental data. Regarding the shape of molten pool the little differences have been noted. The heat flux input considered in simulation is only part of the mechanism for heating, thus the final shape of solidified molten pool will be depended of more variables.

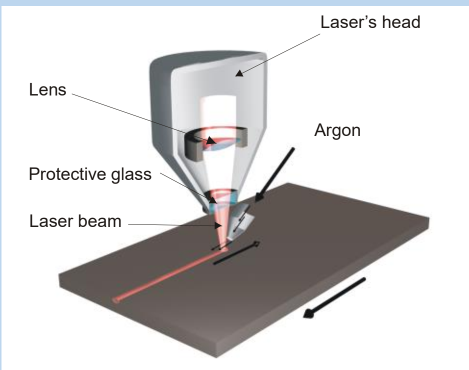

Fig. 1 Alloying process of ceramic particles of tool steel using high power diode laser HPDL Rofin DL 020.

Results and discussion

The specimens were austenitized on the salt bath furnace and tempered in the chamber furnace in the protective atmosphere-argon. The specimens were gradually heated to the austenitizing temperature with the isothermic stops at 650 and 850°C for 15 min. Further they were austenized for 30 min at the temperature of 1180 °C and cooled in hot oil. The specimens were tempered twice after quenching, each time for 2 hours, at the temperature of 560 °C and next at 545 °C. It was found out in the preliminary investigations made using the HPDL Rofin DL 020 high power diode laser that the maximum feed rate at which the process is stable is v=0.5 m/min. Therefore all experiments were made at the constant remelting rate, varying the laser beam power in the range from 0.7 to 2.5 kW. It was established experimentally that the argon blow-in with the flow rate of 20 l/min through the 12 mm circular nozzle oppositely directed in respect to the remelting direction provides full remelting zone protection. Figure 2 presents numerical model with determined vector of thermal flux which is removed from the surface of remelt metal. The way and insensitivity of heat removal has essential meaning during correct locating of a sample in the time of laser alloying process. Fig. 3-5 shows 3 different simulations dependent on elaborated 3-dimensional model.

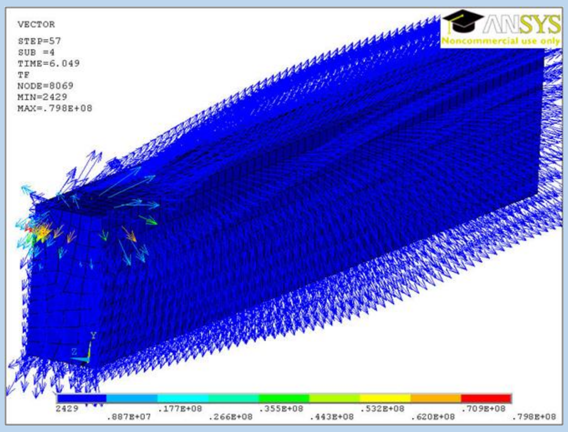

Fig. 2. Temperature distribution from sample surface during laser alloying process of alloying high speed steel HS 6-5-3-8 alloying with TiC powder with the help of laser beam power of 1.7 kW and scanning speed rate of 0,5 m/min.

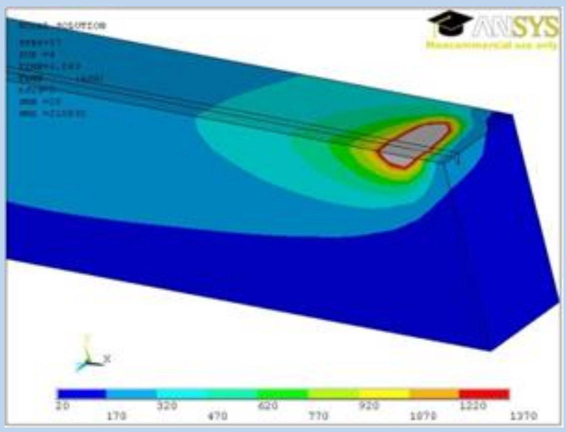

Fig. 3. The spatial distribution of temperature in a cross-section of sample during laser alloying with SiC powder, stainless HS 6-5-3-8, laser beam power of 1.4 kW.

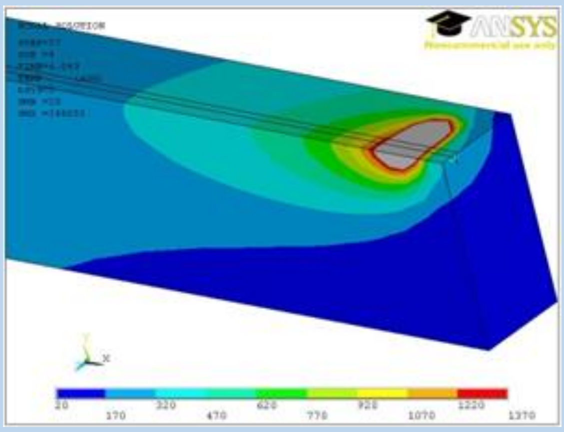

Fig. 4. The spatial distribution of temperature in a cross-section of sample during laser alloying with WC powder, stainless HS 6-5-3, laser beam power of 1.7 kW.

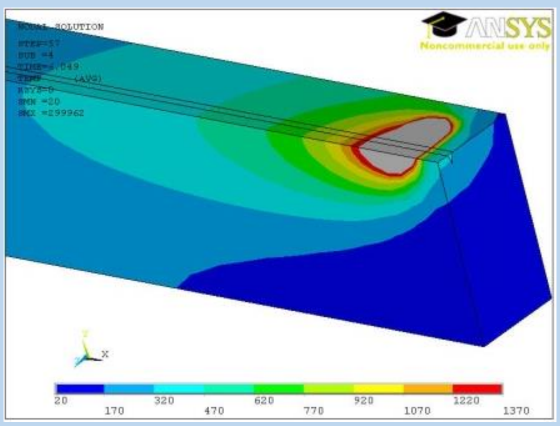

Fig. 5. The spatial distribution of temperature in a cross-section of sample during laser alloying with VC powder, stainless HS 6-5-2-5, laser beam power of 2.1 kW.

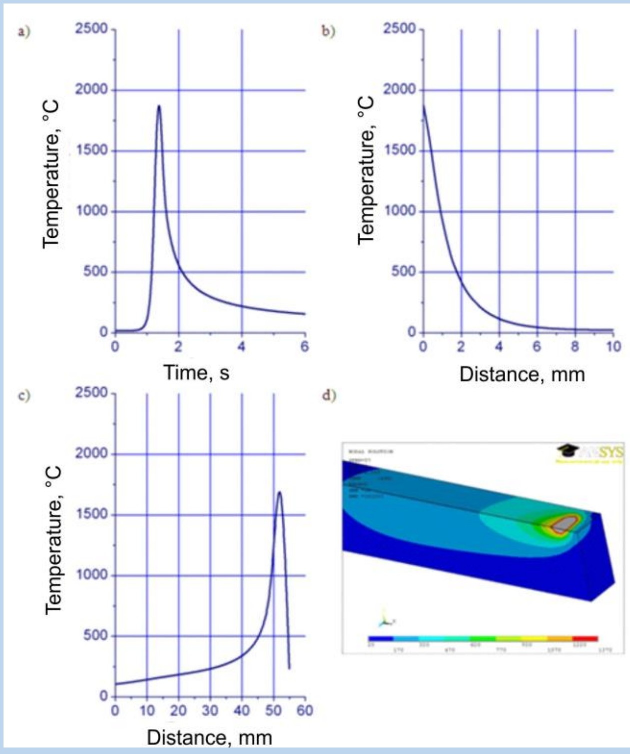

Fig. 6. Temperature distribution in high speed steel HS 6-5-3 during surface treatment with the help of diode laser with high power HPDL with laser beam of 1.4 kW and scanning speed rate of 0,5m/min in function a) time b) depth c) distance d) 3 dimension map of temperature distribution .

In the fig. 6 is presented temperature change of selected model numerical knots in distance function and depth of the sample and also temperature change in time function of laser surface treatment process. Data obtained on the basis of analyzed numerical model with connection to diagram of phase equilibrium and diagrams of time-temperature- change (CTP) allow to inference about the structural changes which are carried out inside of analyzed material. Analysis of relationships between temperature and depth function on selected mash knots of numerical model which are in the zone of welding puddle of fluid metal what made possible determining of maximum depth influence of temperature during the laser treatment process.

Sumary

In worked out numerical model the main focus was on determining of temperature distribution in analyzed zone and maximum depth of remelting and determining depth of influence heat zone, on which convection movements of fluid metal has small influence. The biggest depth of weld penetration during laser alloying process obtained for steel HS6-5-3-8 alloyed A1203 with the help of laser power of 2,1 kW, but the biggest depth of weld penetration during laser alloying process for steel HS6-5-2-5 and HS6-5-3. Computer simulation shows high compatibility of obtained results of depth measurement of weld penetration, what confirms the correctness of made assumptions during the process of numerical model preparation. Comparison of penetration depth data obtained from the FEM simulation with the values obtained experimentally showed significant compliance and confirmed the validity of adopted FEM boundary conditions.

References

1. Bonek M.: The investigation of microstructures and properties of high speed steel HS6-5-2-5 after laser alloying, Archives of Metallurgy and Materials, 59(4), 2014, pp. 1659-1663
2. Bonek M.: Effect of high power diode laser surface alloying of tool steels, Chiang Mai Journal of Science, 40(5), 2013, pp. 849-856