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Effect of laser surface treatment on structure and properties of a commercial tool steels

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Investigations include FEM simulation model of remelting of PMHSS6-5-3 high-speed steel surface layer 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 1.4, 1.7 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. The absorptivity of laser energy was dependent on the simulated materials properties and their surface condition. 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 remelting process. The simulation was applied to determine the shape of molten pool and the penetration depth of remelted 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.

Keywords: *Computer simulation, Finite Element Method, Laser remelting, High-speed tool steel*

1. Introduction

The exceptionally intensive development of laser technique dates from the beginning of development of the physical fundamentals of functioning and design of lasers. Not unaptly they are regarded as one of the greatest scientific and technical achievements of our time. Lasers are used in many spheres of life and technique. They are successfully used in surface engineering, and also in medicine, surveying, cartography, rocket and space technique, civilian and military technique. Laser may carry out many functions by changing process parameters, like laser power, beam diameter, or scanning rate. Therefore, lasers have many interesting applications in manufacturing processes and materials processing, like cutting, welding, glazing, alloying, or coating. Surface laser treatment is a new technology of changing the properties of the surface layer of materials without any significant change of the properties of their core. Lasers find their applications in every branch of industry and services, as the demand for new technologies grows [1-5].

Since several years the HPDL high power diode lasers are used in many centres in the world specialising in materials engineering, as one of the state-of-the-art heat energy sources, characteristic of the high radiation absorption coefficient (about 20-40% for steel), other than the CO2 gas lasers with the continuous mode and Nd:YAG with the pulsed mode [6].

Lasers of this type are the most modern energy source nowadays and only since 1998 are used on the industrial scale in the materials engineering (in metals cutting, and also in cutting of plastics). The HPDL laser power reaches up to 6 kW in the beam focus. The significant advantages of these lasers are: they make it possible to obtain the rectangular, square, linear, or circular shape of the laser focus with the power density of up to 105 W/cm2, they are stable, easy to control, are low priced and have the high radiation absorption coefficient, small overall dimensions, they do not require guiding the laser beam through the complex optical systems causing energy losses from 10 to 30 %, they are characteristic of the high power efficiency reaching 50 %, robotization of technological processes is easy, they are reliable and versatile – that is why they become the very attractive tool in surface engineering [5].

2. Experiment

The experiments were made on specimens made from the high speed steel PMHSS6-5-3. On specimens surface two parallel grooves, deep for 0.5 of triangular shape (with angle of 45°) were machined. The grooves were located along sample axis and distance between them was ca. 1.0mm. It was found out in the preliminary investigations made using the HPDL Rofin DL 020 high power diode laser, with parameters presented in Table 2, that the maximum feed rate at which the process is stable is v=0.5 m/min.

Table 2. Specification of the HPDL ROFIN DL 020 diode laser

Wavelength of the laser radiation, [nm]	808 ± 5
Maximum output power of the laser beam (continuous wave), [W]	2300
Power range, [W]	100-2300
Focal length of the laser beam, [mm]	82 / 32
Laser spot size, [mm]	1.8 × 6.8
Power density range in the laser beam focal plane, [kW/cm^2]	0.8-36.5

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. At low laser power values, i.e., 0.4 to

0.7 kW, no remelting was observed for powders mentioned above. 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.

Numerical analysis of termophysical processes occuring during the laser surface treatment was done with the Ansys software package 12.0. Temperature distribution in tool steel surface layer, shape and size of liquid pool, heat affected zone, heating and cooling time during remelting by the use of HPDL laser were subjected to analysis. During construction of numerical model all essential parameters of technological laser process concerning surface treatment were taken into consideration. Among other things power and scanning speed of laser beam, shape and distribution of power focusing on the surface of laser spot. Numerical model mesh for remelting variant was presented in the Figure 1.

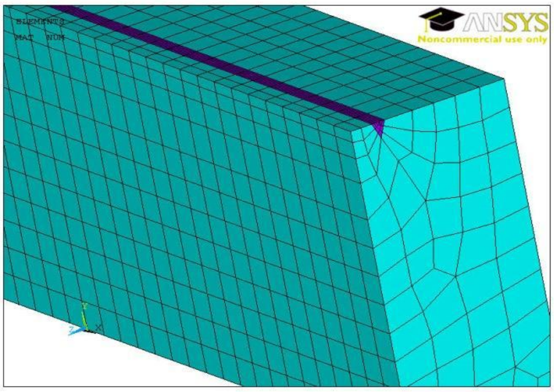

Figure 1 Analyzing 3- dimension numerical model after meshing

During construction of numerical model was made an assumption that initial temperature of sample and surrondings temperature on the level 20 °C (293,15 K). Heating of simulated material was carried out with the help of heat flux, that met the requirements of used laser beam power which in analysed processes were corrensponding1y 1.4, 1.7 and 2.1 kW. Shape of heat flux which relocates on the model surface was similar to shape and dimension of laser HPDL spot focused on sample surface and was 1.8x6.8 mm. Heat flux relocated on the surface of the simulated sample in uniform motion in accordance with laser move with velocity 0,5 m/min. In analysed model material cooling to surronding temperature is carried out through convections and radiation.

For the sake of the fact, that the process was performed in laboratory, in numerical model assumed convection of closed room which was 800 J/kg. Radiation from surface of sample was obtained with the help of additional element of SURF152 type. In order to present in more effective way the heat affective zone and the shape of liquid metal pool in numerical model, cross section sample axis was used. Symetry condition consists in perfect isolation (in cross section did not occure heat convection through convection and radiation) so there was not a need for establishing consecutive edge conditions. It was assumed, that energy of laser radiation is supplied to material in uniform way on the whole area of HPDL laser focus.

Steel PMHSS6-5-3 was obtained in the result of powder metallurgy. In order to obtain correct calculation in numerical model there was taken in consideration its evaporation that is about 2%. It assumed, that the space of closed pipings is fulfilled with atmospheric air. Numerical model process was built using 20 nodal elements of second type assigned to termical analysis Solid 90. In almost whole model the hexadrical element form occurs. During construction process of the model not linear change of density and termophysical conditions such as thermal conductivity and proper heat in temperature function. For determination of edge conditions and material properties in described SI model system. Grey color in maps of temperature distribution present areas, in which temperature is higher than liquidus temperature and steel is only in liquid state. In worked out model was used function “death” and function “birth” of elements in places, in which temperature exceeded liquidus line of given steel. The death element behaves as liquid and has zero stiffness. When temperature decrease below liquidus temperature occurs stepping birth of elements and the material regains original stiffness.

3. Results

Structural examinations consist in comparing the effect of parameters of heat treatment and remelting of the tool steel with the diode laser on the run shape and remelting depth. The gradient layer developed in this way is not free from defects like numerous micro-cracks and cracks, which is shown in Figure 2a and 2b.

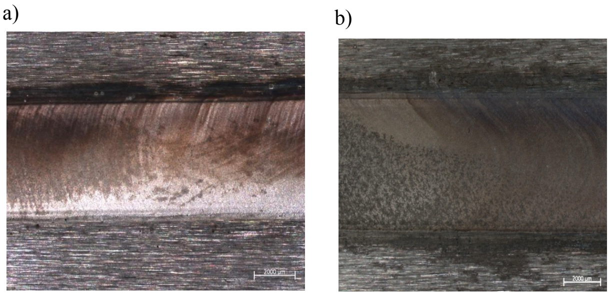

Figure 2. Part shape of bead face of the PMHSS6-5-3 high speed steel surface remelted with laser power values: a) 1.4 kW, b) 2.1 kW

Table 3. Influence of the laser power on the average remelted zone thickness of the high speed steel PMHSS6-5-3 after laser remelting.

	Laser power, [kW]	1.4	1.7	2.1
Average remelted zone thickness, [mm]	examinations	0.49	0.62	1.05
	numerical calculation	0.50	0.72	1.01

Strong circulation of the liquid metal was discovered with rapid solidification after the laser beam has passed, leading to freezing of the structure. It was found out, basing on metallographic examinations, that the structure of the material solidifying after laser fusion is characterized by occurrences of areas with the diversified morphology connected with crystallization of the steel. Thickness of the gradient layer changes for the laser power sequence is between 0,49 mm to 1.05 mm.

Structural examinations compared the effect of parameters of heat treatment and remelting of the high speed steel with the diode laser on the run face shape and remelting depth. The results of experiments are illustrated in Table 3.

It was found, that thickness of the analysed layers, evaluated supported on the computer image analysis made on pictures from the light microscope and confirmed by examinations on the scanning electron microscope, falls within the broad range and is a function of laser beam power. Metallographic examinations carried out on the light microscope and on the scanning microscope confirm that the structure of the material solidifying after laser remelting is diversified, which is dependant on the solidification rate of the investigated steels. Occurrence of structure with big dendrites was revealed in areas on the boundary of the solid and liquid phases. Protective gas impact on the molten steel surface plays a meaningful role in the remelting process, as it is flowing in the area of the developing surface layer and protecting steel in the liquid state from exposure to air and also participating in forming the crystallizing bead face on the remelting surface. Strong circulation of the molten metal occurs then, followed by sudden solidification when the laser beam has passed. Packing of the solidified crystals' bands is consistent with the schema of convection motions in the molten metal pool. In areas where the highest accuracy of calculation was required that is in areas close to surface: on remelted zone and on heat affected zone and also mesh of the Finite Elements Methods was compressed. The process lengthened time of simulation calculation but also meaningfully corrected accuracy of calculation. On the basis of performed numerical calculation map of temperature distribution were worked out in analyzed area of material. The analysis of temperature distribution map obtained in the result of computer simulation MES using in remelting process revealed that shape of remelted zone and heat affected zone are too high degree compatible with shape recorded on the sample surface with the help of thermal imaging camera and also with the shape and size of remelted zone observed using light microscope. In the Figure 3 presented selected thermograms recorded with the help of thermal imaging camera during remelting process of analysed steel.

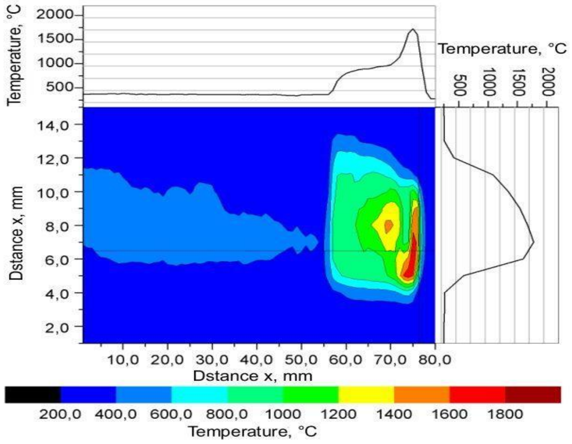

Figure 3. Temperature distribution recorded with the help of thermal imaging camera on surface of PMHSS6-5-3 high-speed steel.

The camera, according to producent's recommendation, was placed in one meter distance from sample surface on that HPDL laser beam was focused. Data recorded using thermal imaging camera in the form of matrix allowed on precise determination of temperature values in selected points, determining temperature profiles along recorded picture, and also reflecting actual temperature distribution on the surface of remelting steel.

4. Conclusion

Remelting the investigated PMHSS6-5-3 high-speed steel causes development of the surface layer, in which one can point out the fused zone, heat affected zone, and interface zones. Their thickness is closely connected with the fusion parameters changes significantly along with the laser beam power increase. A fine-grained, dendritic structure was obtained in the fused zone, with the crystallographic orientation connected with the dynamical heat abstraction from the laser beam impact zone. Results of performed numerical calculations of remelting process presented full compatibility with results obtained from thermal imaging camera and experimental researches. The shape of remelted zone and heat affected zone are similar with shape recorded on the sample surface with the help of thermal imaging camera and also with the shape and size of remelted zone observed using light microscope.Applying of numerical model MES for simulation of technological process of surface laser treatment meaningfully shorten time of selection of optymum parameters in remelting process HPDL laser what also meanwhile limits necessity of using valuable and long-lasting experimental tests.

Acknowledgments

The research presented in this work received great support from the EU-project H2020-MSCA-RISE-2018 Number 823786, i-Weld, and international project co-financed by the programme of the Ministry of Science and Higher Education entitled "PMW" in the years 2020 - 2023; contract No. 5107/H2020/2020/2.

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