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NUMERICAL MODEL OF THE DIODE LASER OVERLAPPED REMELTING OF STRUCTURAL STEEL

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This paper presents a simulation of laser surface remelting with the SYSWELD finite element method software. Micro-structural changes, increase of hardness, and surface profile modification of the remelted samples are evaluated. The model input file was edited to involve laser track overlapping with a time delay. Temperature field distribution and metallographic phase proportions were extracted from output data in graphical form to demonstrate the influence of repeated melting on phase development in the overlapped region. The stored model is ready to be modified for other materials or process parameters.

Key words: steel, remelting, laser, microstructure, model

INTRODUCTION

Laser surface remelting is one of the surface treatment technologies used to enhance the mechanical and chemical resistance of functional machine parts by means of thermal induced micro-structural changes in the thin sub-surface layer [1]. Apart from conventional technologies (arc, plasma), heating and cooling rates can reach as much as 10^5 K·s^{-1}, which causes a very thin remelted layer, followed by a hardened one [2]. Various metal and non-metal materials have been investigated in experiments in recent years using both a flash pumped Nd:YAG and a CO_2 laser, or newly developed fiber, disc and diode lasers [3, 4]. Some attempts were made to predict the depth and phase distribution of the remelted and hardened zones using analytical or numerical models to ensure safe treatment of the expensive workpieces [5]. An optimal overlapping of the laser tracks and the rectangular laser beam profile, with uniform intensity distribution, is necessary to remelt larger areas [6]. The assumption is that lower hardness and wear resistance are expected in the overlapped regions due to repeated melting.

A simulation of the remelting process on structural steel samples was carried out by means of the SYSWELD FEM model to obtain temperature field distribution in any pre-defined time and phase distribution of the treated zones, which have been remelted and heat affected.

EXPERIMENTAL PROCEDURE

Samples which were 150 mm long and 80 mm wide were prepared from the 15 mm thick plate of S355JR (1.0045) steel with carbon content of ≤ 0,24 % (Table 1).

Table 1 **Chemical composition / wt. %**

Chemical composition of S355 JR (1.0045) / wt. %			
C	Si	Mn	P
≤ 0,24	≤ 0,55	≤ 1,6	≤ 0,035
S	N	Cu	Fe
≤ 0,035	≤ 0,012	≤ 0,55	bal.

This hypo-eutectoid non-alloy structural steel with pearlitic and ferritic structure is widely used for constructions in various branches of the civil engineering (buildings, bridges, towers, ship decks etc.), so it is suitable for welding. Thus normalizing annealing is only used after heat treatment of the material. Surface remelting can be compared to heat conduction welding with a low power density source. The high power fiber coupled diode laser, Laserline LDF 3600-100, was used in the MATEX PM facility for experiments. A processing head with a 200 mm focusing lens and a homogenizer provided a rectangular beam profile with uniform intensity distribution and dimensions (5 mm × 23 mm). A 2 800 W laser power and a robotic processing head velocity of 1,5 mm·s^{-1} were set. Two tracks with a 15 mm axis shift were applied to the sample. The focal plane was positioned on the sample's surface, which was temperature controlled with a pyrometer, not to exceed a temperature of 1 550 °C. The experiment was carried out in natural atmosphere without any shielding gas.

The sample's cross sections were investigated using the LEXT OLS3100 laser scanning confocal microscope and the GX-51 optical microscope. Hardness was measured with Vickers' hardness test along the vertical axes of the second track and in the overlapped area. The purpose of the test is to detect differences between regions, which were remelted once and twice, respective-

H. Chmelíčková, H. Šebestová, M. Havelková, H. Hiklová, J. Tomáštík, RCPTM, Joint Lab. of Optics, Faculty of Science, Palacky University, Olomouc, Czech Republic

ly. Surface profile modification was measured by means of the TALYSURF contact profilometer.

Experimental data were set to the pre-processing module of the SYSWELD software developed for computer simulations of heat treatment and welding [7].

RESULTS AND DISCUSSION

Three different microstructures can be observed in the sample cross section. The zone with the Widmanstätten structure is visible in the 1 mm thick remelted zone of the 2nd track (Figure 1 b) that passes to the coarse-grained structure of the heat affected zone, which can be described as bainitic - martensitic with a small amount of ferrite (Figure 2). This structure decomposes to base material and changes into alternating bands of the pearlite and ferrite created during hot rolling of the steel plate (Figure 3) [8]. The measured hardness in the remelted zone close to the surface has a lower value (180 HV) than in the heat affected zone (267 HV) and has an even lower value than in the base material (204 HV). A similar trend was found in the overlapped region possessing a lower value of hardness (Figure 4).

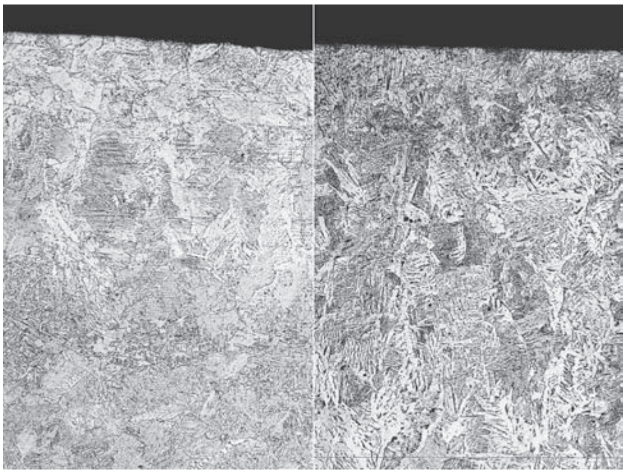

Figure 1 Microstructure of the laser remelted zone: a) in the 1st track, b) in the 2nd track (100x)

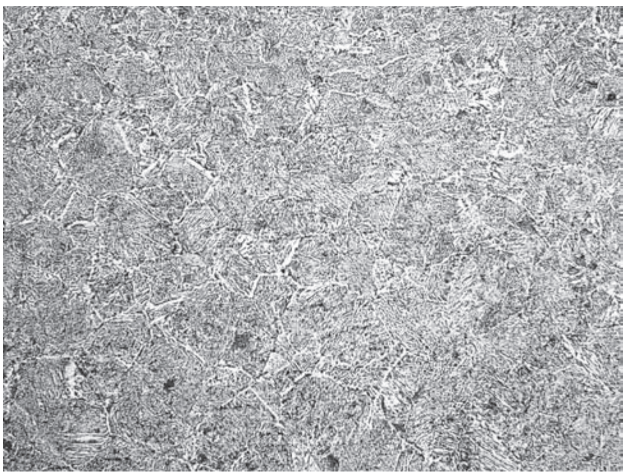

Figure 2 Microstructure of the heat affected zone (100x)

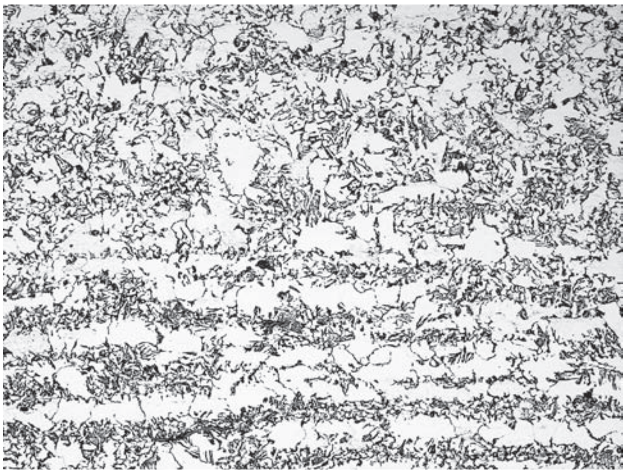

Figure 3 Microstructure of the transition to base material (500x)

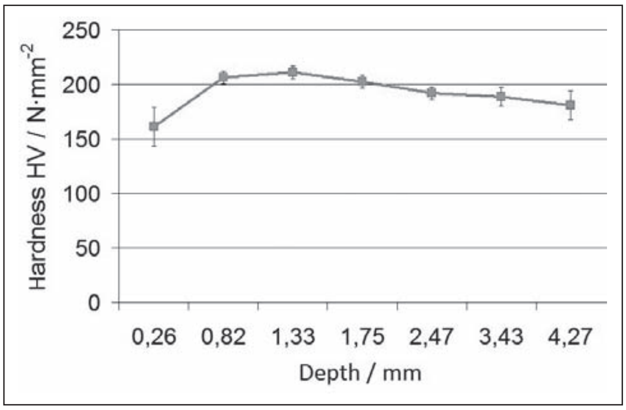

Figure 4 Hardness in the vertical axis of the overlapped region

A volume increase due to phase transformations became evident on the sample surface, observable as a raised, glossy, re-solidified layer with prominent wrinkles (Figure 5). The real surface deformations can be measured with an accuracy of +/- 0,01 μm using the TALYSURF contact profilometer. It is possible to display obtained data by means of various graphs and pictures in various 2D or 3D view [9]. The average profile taken from a 10 mm segment of the track surface shows both mass elevation and declination in the cross section (Figure 6).

Welding Wizard, one of the applications of the SYSWELD software, was used to simulate the laser remelting process. The heat source is defined by a FORTRAN function as the volume density distribution of absorbed

Figure 5 Glossy surface of the sample

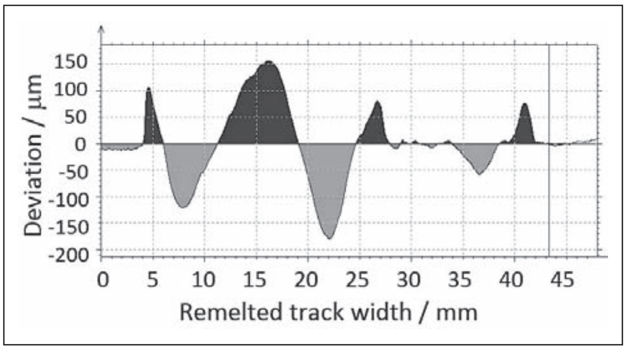

Figure 6 Average profile of the remelted region in a 10 mm segment

power. The users can modify some pre-defined sources or can edit their own functions. A homogenized laser beam with uniform intensity distribution was described simply by a thin block with a slightly parabolic bottom side. Energy density was tuned in correspondence with the actual dimensions of the remelted and heat affected zones [10]. Two parallel trajectories were defined with a 15 mm off-set, and the velocity was set to 1,5 mm·s^{-1}. The results of the model are stored and can be displayed in various options in the post-processing module. The temperature field distribution on the surface in the 490th sec. was shown with colored iso-contours. The heat source passed through the weld line of the second track (Figure 7).

A temperature histogram can be created for an arbitrary group of nodes. The curves for the five nodes, nos. 25 190 – 25 198, which are separated by 1,07 mm and laid at the central axis of the overlapped area, are displayed in the time interval of the laser passing over the 2nd track (Figure 8 a). Heat affecting of the 2nd track vertical axis, node nos. 25 307 – 25 513, during the time interval of the 1st track exposure is displayed in the same way (Figure 8 b).

A temperature peak of 412 °C was achieved at the surface node.

At the end of the process the phase proportion can be displayed for each phase separately in the selected cross section (Figure 9). Ferrite and bainite are measured in scale A, whereas scale B, which utilizes ten times finer color scale, is used to measure martensite in order to display the noticeable difference in proportion. The increase of the bainite content in the 2nd track is probably the result of a lower cooling rate. Development of the phase proportions over time can be graphically displayed in any selected node of the remelted and HAZ regions. To predict phase development in the twice re-

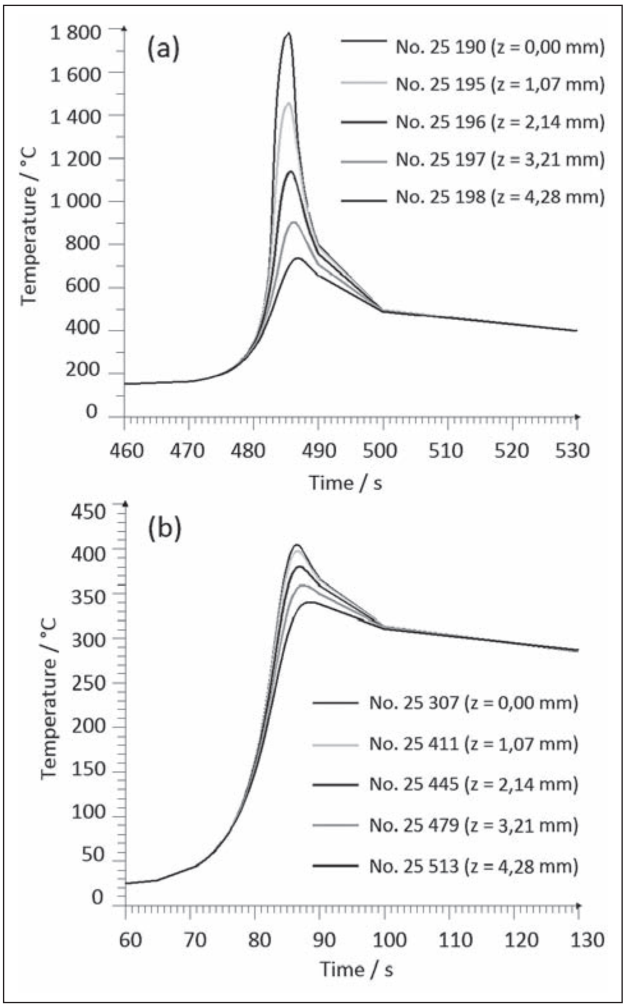

Figure 8 Temperature histogram at five nodes of the vertical axis: a) an overlapped region, b) the 2nd track

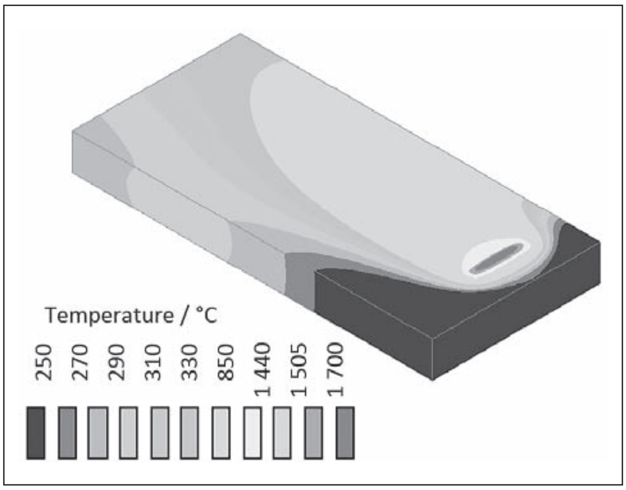

Figure 7 Temperature distributions on the sample surface in the 490th sec.

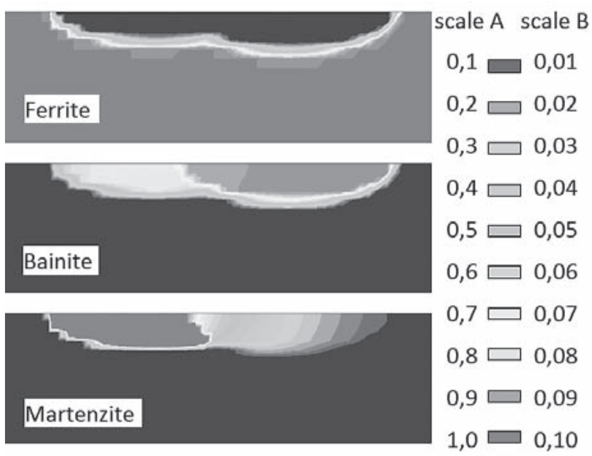

Figure 9 Final ferrite, bainite (scale A) and martenzite (scale B) proportions in the cross section

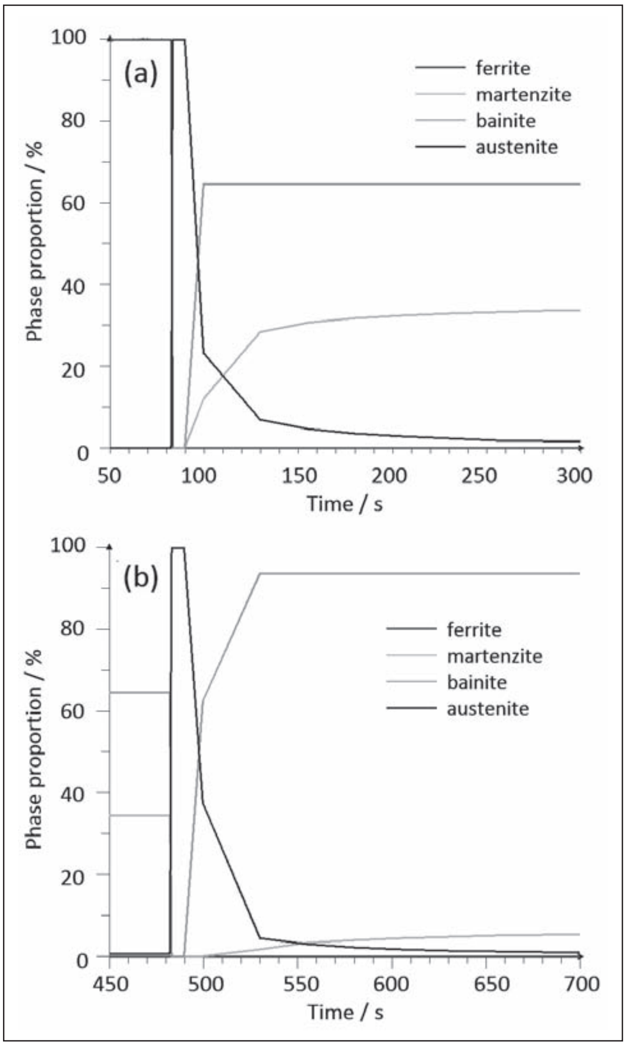

Figure 10 Phases proportion development in node no. 25 190: a) after the 1st track, b) after the 2nd track

melted area, the surface node of its centre, no. 25 190, was chosen to display development of phase proportion over time after application to the 1st (Figure 10 a) and the 2nd (Figure 10 b) tracks, respectively.

Time development graphs for the specific phases can be created, similar to the temperature histograms. The curves for the martensite proportion in the above mentioned five nodes, nos. 25 190 – 25 198, was extracted during the period from 50 to 1000 sec. while the sample was being remelted twice, showing a decrease of approximately 28 % of the phase contained in the remelted zone (Figure 11).

CONCLUSIONS

The possibility of simulating previously achieved overlapped laser remelting of structural steel was investigated with the FEM SYSWELD software. This is accomplished using real process parameters, a self-defined uniform heat source, and dimensions of the remelted and heat affected zones in both tracks, measured in the cross section. Selected model results were displayed and saved. Comparison of temperature development in the selected nodes of each track and the overlapped zone indicated pre and post heating of the remelted zones during laser application to the second track. Repeated remelting of the overlapped region resulted in martensite content decreasing. Model project files are stored and can be modified for other materials, and process parameters can be changed to simulate various time delays between subsequent track applications.

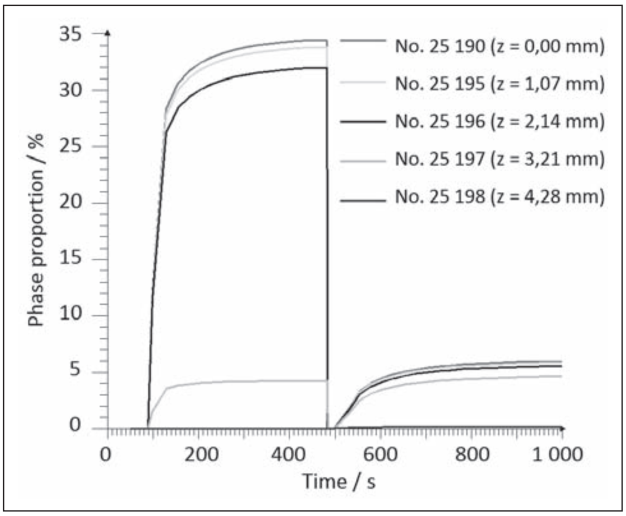

Figure 11 Development of martensite proportion in the vertical axis of the overlapped region

Acknowledgements

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Note: The responsible translator for English language is Mick Thompson, Olomouc, Czech Republic