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ISSN 0543-5846
METABK 50(4) 235-238 (2011)
UDC – UDK 621.9.048:621.7.019.1 =111

LASER GROOVING OF SURFACE CRACKS ON HOT WORK TOOL STEEL

Received – Prispjelo: 2010-09-23
Accepted – Prihvaćeno: 2011-01-20
Original Scientific paper – Izvorni znanstveni rad

The paper presents the analysis of laser grooving of 1.2343 tool steel hardened to 46 HRC. The effect of laser power and grooving speed on groove shape (i.e. depth and width), the material removal rate and the purity of produced groove as a measure of groove quality was investigated and analyzed using response surface methodology. Optimal parameters of laser grooving were found, which enables pure grooves suitable for laser welding.

Key words: laser beam machining, laser grooving, 1.2343 tool steel, thermal cracks

Lasersko žljebljenje površinskih pukotina na alatnom čeliku za vrući rad. U radu je prikazana analiza laserskog žljebljenja alatnog čelika 1.2343 poboljšanog na 46 HRC. Ispitani i analizirani su učinci laserske energije i brzine žljebljenja na dubinu i širinu žljeba, brzinu skidanja materijala i čistoće izrađenih žljebova, kao mjerilo kvalitete žljeba pomoću metodologije odziva površine. Pronađeni su optimalni parametri laserskog žljebljenja, što omogućava izradu čistih žljebova pogodnih za lasersko zavarivanje.

Ključne riječi: laserska obrada, lasersko žljebljenje, 1.2343 alatni čelik, toplinske pukotine

INTRODUCTION

Repair welding (RW) with wire cladding is a common procedure to extend the in-service life of heavily loaded tool parts for die and mould industries [1-5]. The main advantages of repair welding are short downtime and cost efficiency compared to production of new tool part. Repair welding in general lowers the tool cost in the final part and enables higher added value to the die casting and injection moulding industry.

The in-service life of die casting dies and injection moulding tools is correlated with the thermo-mechanical loads during production. The production of 300000 castings is a common series for die-casting industry and 1000000 mouldings for injection moulding industry. The in-service tool life is affected by (a) thermal fatigue, which causes heat marks on the surface of the die, (b) corrosion and soldering of aluminium to the die surface, (c) erosion due to melt flow, and (d) catastrophic failures [6-9]. Generally the tool steels are considered as non-weldable or hard to weld materials due to its high carbon and alloying element composition. A repair welding of dies and mould tools, which are made of tool steels, are done using tungsten inert gas (TIG) welding or a new technology called laser cladding by wire (LCW), which is a new alternative technology for repairing of small failures.

For a quality laser RW a clean welding surface is necessary beside suitable welding wire. In many cases when RW is done on surfaces of the dies and moulds, the cracked surface must be removed and/or cleaned. The cracks are usually filled with oil or grease and/or the casting materials and oxides [6-8]. To prepare the surface for LCW a laser grooving (LG) or laser beam machining (LBM) could be used.

The LBM has many variants: drilling, cutting and grooving, turning and milling, and micromachining [10, 11]. The mechanism of material removal during LBM includes three different stages i.e.: (i) melting, (ii) vaporisation and chemical degradation, at which chemical bonds are broken, which causes the materials to degrade. When a high energy laser beam is focused on work surface the thermal energy is absorbed. That heats and transforms the work volume into a molten, vaporised or chemically changed state that can easily be removed by flow of high pressure assisted gas jet. This jet accelerates the transformed material and ejects it from machining zone [10, 11]. The effectiveness of LG depends on thermal properties and partly on the optical properties of the grooved material, whereas less on mechanical properties. The materials that exhibit a high degree of brittleness i.e. hardness and have low thermal diffusivity and conductivity are well suited for laser machining, since they are not so easily machined conventionally [10, 11]. Another benefit of LG is that there are no cutting forces generated by the laser, therefore any machine vibration, tool ware or mechanical damage is induced to the material. The main obstacles in LG are the changing of groove geometry (GG) with LG param-

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eters [10-16], slag or dross formation on the surface by groove or inside the groove due to inability to remove it from it, and thermal damage of the material by the groove by formation of oxidized layer, recast layer and heat affected zone (HAZ).

Many researchers studied the LG and micromachining on sapphire, silicon, alumina ceramic, carbon fibre, titanium alloy, stainless steel, and mild steel [10], but no research was done on the tool steels. The aim of this study was to analyze the material removal rate (MRR), GG and metallurgical characteristics. The response surface methodology (RSM) was used to develop the models for prediction of GG and its surface as well as MRR. The results showed that with the proper LG parameters clean grooves with suitable groove geometry for further laser repair welding can be made.

EXPERIMENTAL WORK

Material

For LG experiments 1.2343 (X38CrMoV5-1) tool steel was used with the chemical composition: 0,38 % C, 5,1 % Cr, 1 % Si, 0,4 % Mn, 1,25 % Mo, 0,4 % V and the rest Fe. The workpiece dimensions were 110 x 50 x 10 mm. The specimen was quenched and tempered to 46 HRC, similarly as die casting tools.

Laser grooving

The experimental configuration is shown in Figure 1. A Lasag KLS-522 Nd-YAG laser was used for LG. The movement of the workpiece was done by a computer controlled motorised moving table. The laser beam was conducted through the optical fibre to the focusing head with a blow through nozzle. The focal point of laser beam was held constant at 2 mm above the workpiece surface, and the angle between the focusing head and workpiece surface was 80°. With the preliminary trials the basic LG parameters were determined according to the laser power source. The grooving length was 20 mm, repetition rate (ν) 70 Hz and pulse duration time (τ) was 0,7 ms. A compressed air at 6 bar was used to remove the remelted material out of the groove.

A plan of experiments was prepared using RSM at which laser beam pulse energy (LBPE-E_p) varied between 1,05 and 2,15 J and the grooving speed (v) from 0,59 and 3,4 mm/s (Figure 2). These values were chosen regarding the laser power and the moving table capabilities. After the grooving the specimens were transversally sectioned and microsections were prepared for observation on the microscope. These samples were finely grinded, polished and etched in a 4 % Nital (4 % HNO_3 in ethyl alcohol) solution. Specimens were examined on a light and scanning electron microscope (SEM). The transversally sectioned samples (without grinding and polishing) were also examined on SEM from the top and the side view to determine the interactions between the LB and material during LBG.

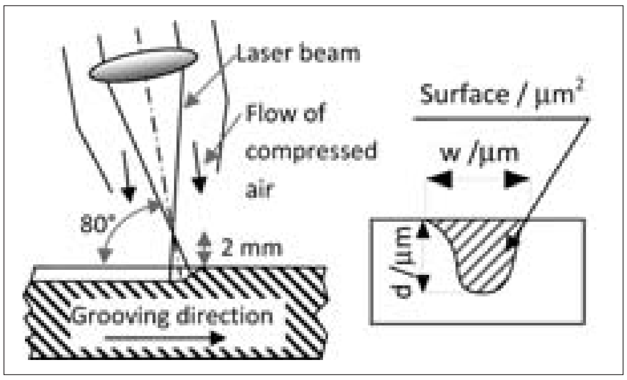

Figure 1 Experimental setup for LBM

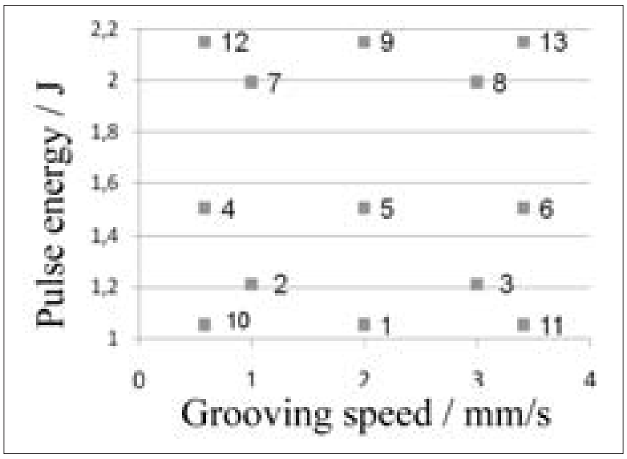

Figure 2 Plan of experiments

For each groove sample a groove depth (d), width (w) and groove area (A) were measured. The material removal rate (MRR) was calculated as a quotient of groove surface (A / mm^2), grooving speed and material density (ρ) / 0,0078 g/mm^3:

$$\mathrm{MRR} / \mathrm{g/min} / = \mathrm{A} \cdot \mathrm{v} \cdot \rho \qquad (1)$$

The average LB pulse power (P_a) was calculated like a product of ν and pulse energy (E_p / Ws):

$$\mathrm{P_a} / \mathrm{W} / = \nu \cdot \mathrm{Ep} \qquad (2)$$

The average LB energy per unit length (P_{amm}) was calculated as quotient of a average pulse power (P_a) and grooving speeds (v):

$$\mathrm{P_{amm}} / \mathrm{Ws/mm} / = \mathrm{P_a} / \mathrm{v} \qquad (3)$$

We defined the grooving efficiency as quotient between MRR and P_{amm}:

$$\mathrm{E_{ff}} / \mathrm{g\,mm/J\,h} / = \mathrm{MMR} / \mathrm{P_{amm}} \qquad (4)$$

The RSM was used to develop the models for prediction of groove geometry and its surface as well as for MRR, P_{amm} and E_{ff}.

RESULTS AND DISSCUSION

To determine suitability of LG parameters on the quality of the groove, the grooves were examined using SEM. Figure 3 shows the SEM pictures of the grooves

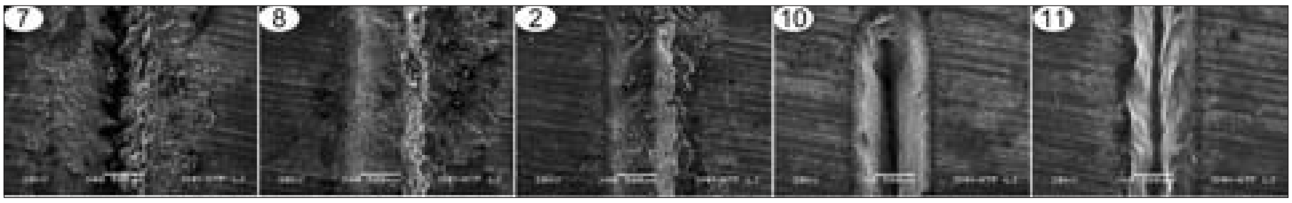

Figure 3 The SEM top views of the grooves produced with different LG parameters

from the top view. The grooves produced with the parameters 10 and 11 shows clean grooves without any traces of slag. They were produced at pulse energy 1,05 J i.e. average power of 73,5 W and at different grooving speed. At the LG made with higher pulse energy 1,21 J, some traces of slag is present on the top right, beside the groove. More slag is present beside the groove and inside of it if LG is done with the parameters 8 i.e. pulse energy 2,15 J and grooving speed of 3 mm/s. If at the same pulse energy, grooving speed is reduced to 1 mm/s, the groove is filled with slag (Figure 3(7)). The produced slag is similar to the products from the process of atomisation, which is used for extraction of powders for powder metallurgy. The micro-section pictures of experimental grooves are shown on Figure arranged according to the plan of experiments (Figure 2). The result shows that clean grooves are obtained at lower values of pulse energies. At the lowest energy pulses the examined grooving speed has no influence on slag formation, only on the groove shape. At higher pulse energies, more slag is observed at slower grooving (Figure 4 (4, 5)). At higher pulse energies more slag is present in the groove and beside the groove. If grooving with this pulse energy, clean grooves can be obtained, if the grooving speed is higher than 3,4 mm/s.

The LG parameters have an influence on the groove shape. Grooving with higher speeds produces shallower grooves. Increasing of LB peak power produces deeper grooves, similarly as decreasing of grooving speed. An approx. 30 to 80 μm thick heat affected zone is observed in LG with various parameters.

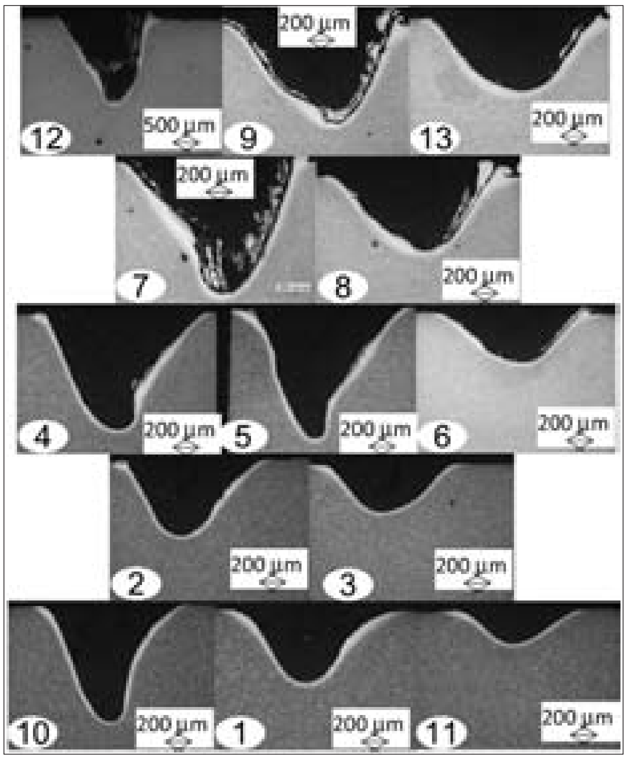

Figure 4 Microsections of laser grooves

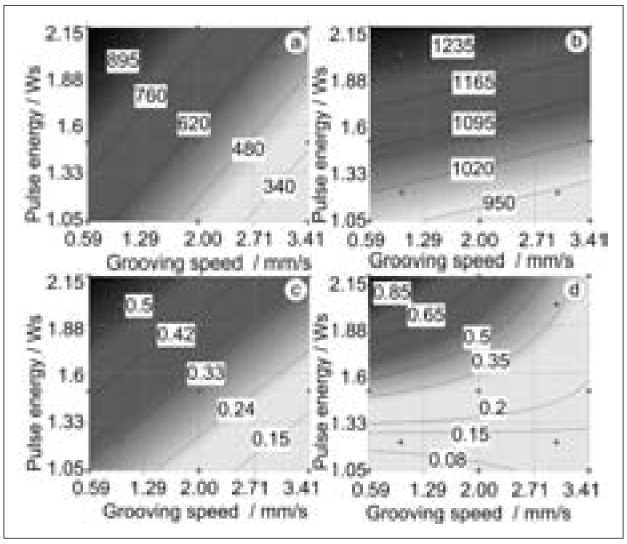

Figure 5 The influence of LBPE and grooving speed on: a) groove width / μm, b) depth / μm, c) surface / μm^2 and d) MMR / g/min

Developed RSM models

The experimental results of groove geometry and MMR were statistically evaluated with RSM. The models for prediction of groove depth, width and removed area as well as MRR were developed. They are presented graphically in Figure 5. Grooving speed increase decreases groove width, depth, area and MRR, while increasing of LB pulse energy increases all observed parameters. The influence of LB pulse energy on groove width is one time higher than grooving speed and approx. ten times higher as weld depth.

Figure 6 shows how the average LB energy per unit length changes according to pulse energy and grooving speed. More P_{amm} is located at the left side of the plot at slower grooving speeds.

Model for grooving energy efficiency is presented on the Figure 6b. It shows that more material is removed quicker and with less energy if higher pulse energy and grooving speed is used. If the quality aspect of the produced grooves is considered (grooves without slag), it is better to use lower pulse energy or at least higher groov-

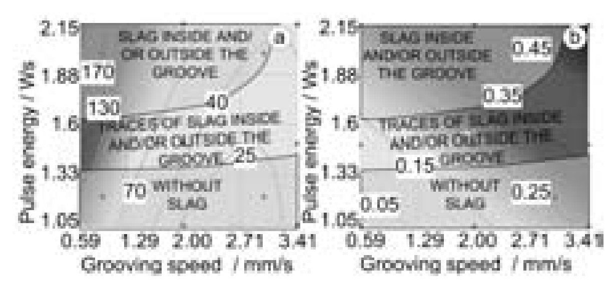

Figure 6 The influence of LBPE and grooving speed on: a) P_{amm} / Ws/mm and b) E_{ff} / gmm/Jh

ing speeds (Figure 6b). If the ability to make a sound laser cladding is considered the grooves with small traces of slag are good enough. However grooving parameters must be properly selected to completely remove the cracks and make a clean groove.

CONCLUSIONS

Laser grooving is an appropriate technology for elimination of surface irregularities as cracks. The following conclusions can be summarized:

- With the proper selection of laser grooving parameters surface cracks can be eliminated and at the same time appropriate grooves can be made for the following LCW.
- LG with high laser pulse energy (higher than 1,8 J and grooving speeds up to 2,6 mm/s) produces deep grooves with the slag stuck at the bottom and at the surface by the groove.

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Acknowledgments

The authors wish to thank Dr. Andrej Horvat, Dr. Aleš Gorkič and Prof. Dr. Ladislav Kosec for the help at this research.

Note: The responsible translator for English language is Urška Letonja, Moar. Prevajanje, Slovenia