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Investigations of Surface Laser Melting of Tool Steel

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Abstract

This study investigates the laser re-melting process that occurs during laser polishing (LP) of tool steel. LP is a method to improve the surface finish of workpieces. Contrary to most polishing methods, it does not remove material but melts a thin layer of the surface and redistributes material in the liquid state. The quality of the LP is influenced by the stability of the melt pool and is affected by local changes in the absorption or in the material thermal properties as well as the evolution of the surface tension with temperature (Marangoni effect). In this study, the melt pool produce by a CW NIR laser on rough tool steel surfaces was observed in situ with high speed camera and after solidification using confocal microscopy. The results were then compared with a numerical model including solving of the thermal problem as well as the flow of the liquid.

Keywords: Laser Polishing; Surface re-melting; Hard tool steel; High-speed camera

1. Introduction

Laser polishing (LP) of metals consists of re-melting by laser irradiation a thin layer of the surface of the sample in order to decrease the roughness (Temmler et al., 2011). Indeed, aided by the surface tension and low viscosity of the liquid metal, the material will flow form the high asperities to fil the valleys in between. LP was developed in the last 2 decades and is an alternative to the time consuming manual polishing especially for hard metals (Ramos-Grez et al., 2004, Shao et al., 2005, Ukar et al., 2010). The final roughness

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will be counterbalanced by other effects such as convective flows or the Marangoni effect that will have a tendency to perturb the flatness of the melt pool and so the final roughness after re-solidification. As noted by Nüsser *et al.*, 2015, the LP process itself creates some surface structures. These defects require antagonist actions to avoid their appearance. In other words, it is not possible to create a surface without roughness with LP alone. This is the main reason why LP is not widely used at the moment as to obtain a mirror polish it still needs a final polishing step such as electro polishing. Another approach is to perform several steps of LP as proposed by Temmler *et al.*, 2012. They proposed to polish first a rough sample with a relatively large melt pool (10-80 µm deep) obtained with a CW laser. This is referred as macro polishing (Temmler *et al*., 2012 and Nüsser *et al.*, 2015). The second step, called micro polishing is achieved by pulsed laser to create a very thin melt pool (<5 µm deep) (Perry *et al*., 2009 and Nüsser *et al.*, 2015). The micro polishing can help reduce the structures created by the macro polishing.

This work focused on the macro polishing of hard rough tool steel. The observation in situ of the melt pool with high speed imaging as well as roughness measurement obtained after LP are used to better understand the process. These observation are used to validate a numerical model of the process and helped refined the model. The final aim is to obtain the best possible roughness after only one macro polishing and thus reducing the need for a second polishing step for most technical application where mirror polish is not required.

2. Experimental Method

A continuous wave (CW), high power diode laser LDM 1000 from Laserline GmbH with a 980nm wavelength was employed in this work. A fixed focusing head was placed in focus 297 mm above the sample. This provides a spot size of 900 µm at the focal point with a flat top intensity distribution. As a fixed head is employed, the sample is mounted in a chamber located on an x-y table that allows movement in both directions. To avoid oxidation during the process, the chamber is filled with argon. A schematic drawing as well as a picture of the setup is shown in Fig. 1.

To observe in situ the experiments, a motionpro Y4 high speed camera from Videal was used. The camera was mounted with a Moritex ML-Z07545 telecentric objective. The camera was mounted as shown in Fig. 1 and allows observation of the melt pool with a small angle compared to the laser beam. The objective was fitted with low pass filter (cut-off 800nm) in order to block the laser light from entering the camera. Additional light in the visible range was provided by a light mounted on the side of the sample. In these conditions and with the size of the melt pool observed, the frame rate was 10 kHz.

For each line experiment, the motion of the sample was started first in the x-direction. Once the sample reached constant speed, the laser and high speed camera were triggered together. The laser stayed on for a displacement of 20 mm. After the laser was stopped, the table was decelerated to a stop. Then, the table was moved for a defined distance in the y-direction and the process could start again in the opposite direction along the x-axis.

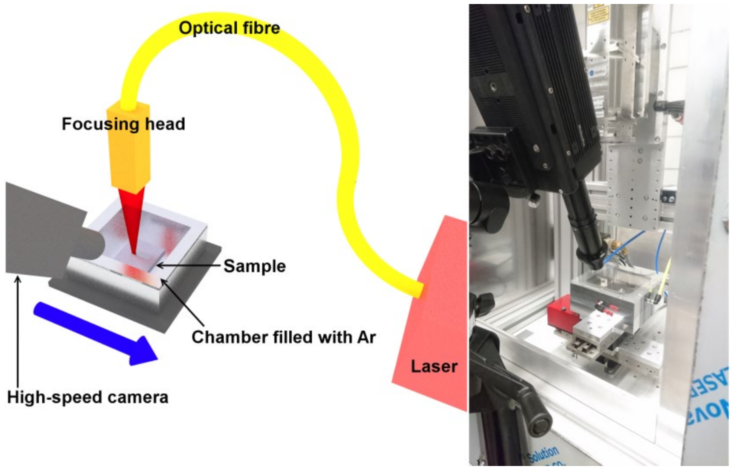

Fig. 1. (a) Schematic representation of the setup; (b) Picture of the setup

We also investigated the effect of laser melting without motion. For these experiments, the laser was simply switch on for a given time at a given power.

The samples were made of X38CrMoV5-1 hardened tool steel with a size of 70x70x7mm^3 and a Rockwell hardness (HRC) of 53±1. On the top surface, a region of 50x50mm^2 was prepared by electric discharge machining (EDM). The finishing state of the surface was CH30 on the Charmilles scale for EDM which corresponds to a roughness Ra of 3.15 µm.

3. Results and discussion

3.1. Static source

The evolution of the melt pool for a static experiment is shown in Fig. 2. The first image (top left) shows the situation before the laser illumination. The bright spots scattered on the surface represents regions that reflects the external light towards the camera. As the surface is rough most of the surface is dark as the light is reflected in a random direction and not towards the camera. The second frame from the left shows the beginning of the laser illumination. As most of the laser light is filtered out, not a big difference is visible compared to the first frame. Some bright spots are visible inside the red circle that represents the position and size of the laser beam. The third frame approximately 12 ms after the start of the illumination shows some modification of the surface inside the beam area. The bright spots become blurry and may be a sign of the melting of the surface. The fourth frame after 33 ms shows more clearly the apparition of the melt pool. From then on the melt pool extend (frame 5 60 ms of illumination) or 6th frame (first image of the bottom line) after 300 ms or 7th frame after 900 ms. The size reach a diameter of 1.2 mm just before the end of laser illumination. As the time increase the centre of the melt pool becomes lighter, a sign of an increase of temperature and thus increase of thermal emission. The 8th frame shows the time 1.3 ms after the end of illumination. The cooling is very fast and the thermal emission is reduced and the melt pool is almost completely dark with just a small emission in the centre. The 9th frame shows the progress of solidification from the side. The solidified region appears brighter as most light from the external source is then reflected towards the camera. This is a clear sign of the polishing effect achieved by surface re-melting. The last frame shows the end of solidification approximately 4 ms after the end of laser illumination. The surface is flat and reflecting most of the external light towards the camera with a much reduced roughness as compared to the initial state.

3.2. Moving experiment

A similar approach was applied with a moving sample. The high speed imaging allows tracking the

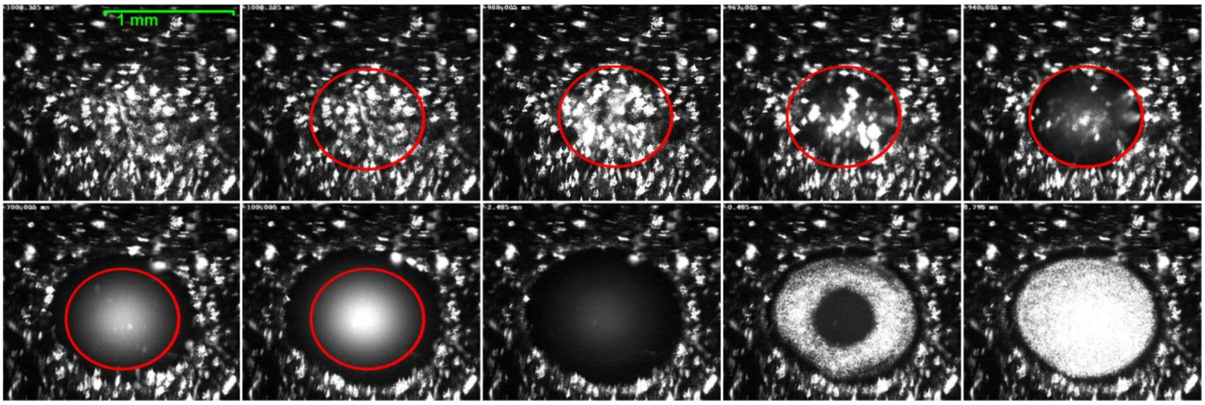

Fig. 2. Evolution of the melt pool for a static experiment, with a laser power of 317W for 997ms. Laser is started on the second frame (from top left) and was stopped just before the middle frame of the bottom line.

position and size of the melt pool for different speed and laser power. It can be seen that an increase of the speed decrease the aspect ratio of the melt pool as illustrated in Fig. 3. In this figure, the ellipse shape of the melt pool does not come from the angle of the camera as this was corrected. An increase of the speed shows also an increase delay of the melt pool in comparison to the laser spot position. The power of the two experiments is varied in order to keep approximately the same maximum temperature (based on numerical simulation). This means that the gradient of temperature for the high speed experiment is expected to increase especially laterally as the width of the melt pool becomes narrower.

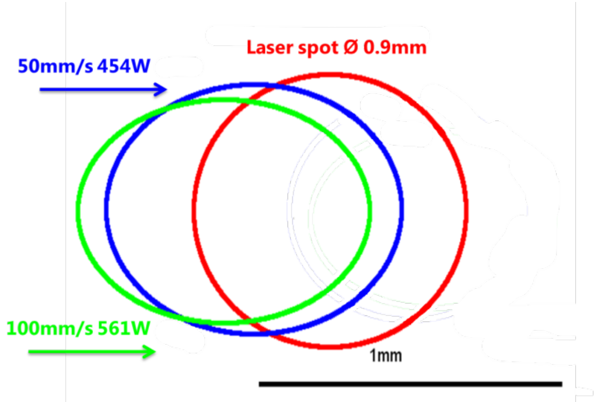

Fig. 3. Schematic representation of the size and position of the melt pools for a moving sample based on the high speed imaging. Blue ellipse, melt pool for the sample speed of 50 mm/s and 454 W. Green ellipse, melt pool for the sample speed of 100 mm/s and 561 W.

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