Possibilities of Laser Assisted Machining Application in Hard-to-Machine Materials Turning

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Abstract: The paper presents the discussion about possibility of optimizing the cutting condition via laser assisted machining (LAM). It is common knowledge that mechanical properties of materials depend on temperature. Nevertheless a knowledge about exact material properties during and after laser heating is required. This paper presents surface characteristics of LAM operations. The discussion of sequential and continuous variations of laser assisted turning is highlighted. It was proven that for sequential LAM dendritic structure appears in laser affected zone of Ni-based alloy and grain fragmentation for wolfram. Such microstructures cause better machinability of these materials.

Keywords: turning, laser assisted machining, Inconel, tungsten

1 INTRODUCTION

Thermally enhanced machining is one of the emerging fields in advanced manufacturing [1, 9]. The main application of this process concerns the hard-to-machine materials such as Ni-based super alloys [1], metal matrix composites [7], cemented carbides [8] or even stainless steel [5]. These materials can be found in an aircraft elements, medical equipment and energy installations of power. Nevertheless, they are believed to be hard-to-machine due to ineffective cutting operations connected with high insensitivity of tool wear, high probability of cutting edge chipping and mechanical destruction, adverse residual stress of the surface layer, cutting force fluctuation that may cause a vibration during machining, high cost of manufacturing, and poor surface quality [1–5, 7–9]. Improving the processing capabilities of these materials is associated with the development of new technologies to support the conventional solutions. Technologies related to thermally enhanced machining is a technology that are commonly used in the aircraft industry and one of the most developed is laser assisted machining (LAM).

Laser assisted machining is a method of metal shaping that is obtained via laser beam heating and machining application in the same and unchanged mounting of the element during the unit time at the one stand. The tool in LAM is considered both as a cutting insert and a laser optic that interact with the material. The LAM operations implemented on a lathe are defined as laser assisted turning (LAT).

It is not usually considered that laser assisted machining can be divided in two groups according to kinematics of the process. The first one is continuous laser assisted machining (Fig. 1a). A laser beam is heating the surface-to-be-machined in order to decrease its hardness in close distance of cutting insert. This method of LAM is one of the most popular and might be applied for most types of materials. The second type of kinematics is sequential laser assisted machining (Fig. 1b). The laser beam is heating the layer of material to change its microstructure in order to improve the machinability.

It is a common knowledge that mechanical properties of materials depends on temperature. Nevertheless knowledge about exact material properties during and after laser heating is required for sequential and continuous laser assisted machining.

2 RESEARCH METHOD OF SLAM

Sequential laser assisted tests were conducted in dry conditions using TUR560 lathe. The longitudinal – nose radius and oblique turning operations were applied. Trials were carried out with Kennametal ceramic inserts, coded KY1540. Cutting inserts had the following geometry: tool major cutting edge inclination angle (in oblique turning) $\lambda =$60°; nose radius of insert $r_c=0.8$ mm. Detailed effects and comparison of those type of turning processes were presented in Ref. [3]. Laser heating processes were carried out on TUM30D lathe with CO2 Trumpf laser of maximum power $P_{\text{CO}_2}=2$ kW. The test were conducted with $P_{\text{CO}_2}=1.2$ kW with traverse speed of 5 m/min.

The tungsten heavy alloy (W 99.5%, Ni 0.35%, Fe 0,25%) was heated with diode laser with 3000 W of maximum power with continuous wave (CW mode), and 1030μm wavelength (TruDiode 3004: Trumpf). Laser was set to obtain $d_s=1$ mm spot’s diameter with 2,1 kW laser’s power. No processing gas was used. A traverse...
speed \( v_l \) was used (scanning speed) ranging from 1.44 to 2.98 m/min.

The preliminary samples were ground, in order to obtain similar roughness parameters and then covered with absorbing layer: gouache for pure tungsten and Acheson for Inconel 718.

### Table 1. Specifications of machining and SLAM process conditions

<table>
<thead>
<tr>
<th>Surface</th>
<th>Turning type</th>
<th>( V_c ) [m/min]</th>
<th>( f ) [mm/rev]</th>
<th>( f_l ) [mm/rev]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>nose radius</td>
<td>100</td>
<td>0.05</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>oblique</td>
<td>0.25</td>
<td>0.25</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>oblique</td>
<td>0.45</td>
<td>0.25</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>heating</td>
<td>-</td>
<td>-</td>
<td>0.25</td>
</tr>
<tr>
<td>A - D</td>
<td>heating</td>
<td>-</td>
<td>-</td>
<td>0.25</td>
</tr>
</tbody>
</table>

### 3 EXPERIMENTAL PERFORMANCE EXAMPLES OF SLAM

In the heat radiation phenomena there are two main factors that have a great influence on reflectivity and absorption. The first one is roughness, the second one is wavelength (in CO2 lasers it equals 10.6 \( \mu \)m). To improve absorption and decrease the level of reflectivity, technological operations are carried out. One of the easiest is a detail preheating and covering with additional absorbing layers, in order to increase of roughness parameters values. Surfaces with different roughness parameters before heat treatment of LAM (coded as A, B, C, D – table 1) were investigated in terms of future turning process conducting. The results are shown in the Fig. 3.

![Fig. 2. Surface roughness parameters Ra comparison for different surfaces after turning](image)

![Fig. 3. Surface roughness parameters Ra and RSm ANOM comparison for different turned surfaces](image)

Hardness in the distance from the surface is decreasing (Fig. 4c). For set ups used in the experiment, the dendritic structure was obtained in the depth up to 300 \( \mu \)m. This structure is shown in the fig. 4a and 4b. The unchanged part of surface has the same hardness as surface before laser treatment. This fact is relevant in terms of future laser-assisted machining process planning, especially in case of Ni-based materials cutting. Machining of such layer might result with longer tool life and decreased values of cutting forces. The exact effect of surface roughness after SLAM is also presented in paper [2].

The different type of material is tungsten and its alloys. Research revealed that laser heating caused a melting of tungsten’s surface. During fast cooling the new microstructure is obtained with a clear boundary between base material and laser beam affect zone – heating zone. The grain size decreased due to high temperature. This effect can be compared to that, shown...
in [11]. Smaller grain size induced smaller crack zone and shear dislocation during cutting (Fig. 5).

Therefore the determination of scanning speed $v_l$ direction is not possible (Fig. 6). Surface roughness generation mechanisms after laser beam heating are not the same as in Ni-based alloys (e.g. Inconel).

![Fig. 6. Comparison of pure tungsten’s surface after heating with diode laser $v_l=2.98$ m/min](image)

4 CONCLUSIONS

A comparative study with regard to the effect of laser’s heating, during surface treatment of Inconel 718 and pure tungsten was investigated. Different scanning speeds were investigated to determine the mechanism of sequential laser assisted machining. On the basis of the research results, it is concluded that LAM applied to the heating of work piece’s surface should be concerned. Therefore, the next analysis will be focused on the temperature’s control, hardness of melted structure’s surface and subsurface, as well as LAM of elements with complicated shapes. The main conclusion of this paper is that laser assisted machining can be implemented in a step-by-step variant, which is cheaper and easier to obtain than continuous LAM, investigated in [1, 7, 9].

REFERENCES


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