EXPERIMENTAL OPTIMIZATION OF STEEL LASER CUTTING WITH OXYGEN

A.G. Malikov, A.M. Orishich, V.B. Shulyat’ev.

Khristianovich’s Institute of Theoretical and Applied Mechanics SB RAS,
630090, Novosibirsk, Russia

Introduction

Reactive laser cutting of mild steel is widespread in practice. High processing speed is the feature of the laser cutting, with high quality of laser cut is of interest. The laser cut quality is characterized by dross attachment, surface roughness, the width of heat affected zone, side walls perpendicularity, cut width. In spite of large amount of theoretical and experimental investigations, the completed and explicit picture of physical processes, responsible for cut quality, is not exist at present time [1, 3]. Especially it is right for thick sheet region. Laser cutting models for thick section region are developed inadequately. The interrelationship between optimum cutting parameters is not substantiated by these models in most cases. A lot of models are based on the substantial simplifications [1, 2]. The experimental investigations [4-6, for example] dealing with the conditions of getting of high quality cut are made in majority for thin sheets (no more of 10 mm) [1,7]. Also laser cutting database is concerned of thin sheets mostly.

The maximum thickness to be cut is increased with laser power increase. Then, the search of empirical lows of high quality cutting of thick sheets is of great value. This is urgent for estimation of limiting potential of laser cutting, and for theory development too.

All above mentioned have been stimulated the comprehensive, detailed investigation. The goal of investigations is, in particular, the search of energetic conditions of high quality laser cutting for giving a possibility to forecast the optimum parameters of cutting in thick sheet region. The possibility of using of similarity methods for laser cutting describing is investigated too. A fair amount of attention has been given to the searching of dimensionless parameters for using as similarity numbers.

Generally speaking, optimum cutting conditions for individual cutting characteristic (roughness, perpendicularity and so on) may be different [8]. In this work minimal roughness in connection with dross absence is used as quality criterion.

Experimental procedure

The experiments were carried out using developed in ITAM SB RAS laser cutting system. The facility comprises CW CO2 laser of up to 8 kW power with BPP = 4.5 mm*mrad [9] and X/Y table with beam delivery and controlling systems. Self-filtering unstable optical resonator is used in this laser.

The cutting was made by laser beam with circular polarization under the traditional scheme - radiation was focused by a single ZnSe lens, the jet of assisted gas moved in a kerf zone coaxially with a beam. The distance between a cutting head and a cut sheet was stabilized by system of a feedback on the basis of the capacitor sensor. Oxygen with purity of 99.999 % was used as an assisted gas. The sheets of mild steel were cut.

The idea of optimization was based on minimization of cut surface roughness Rz. The roughness was measured on distances of 1/3 and 2/3 thickness from the top surface of a sheet by means of confocal scanning microscope Olympus LEXT and profilometer Rank Taylor Hobson.
Section V

series Form Talysurf. The worst (i.e. greater) value of these two was considered as characteristic value. Really, in most cases the worst roughness was observed in the bottom part of the cut.

Experiments were carried out as follows. For the chosen thickness of metal \( t \), beam power \( W \), a focal length of a lens \( f \), pressure of oxygen \( P \) were fixed. Then the cutting speed and waist position corresponding to minimum \( R_z \) was determined. The range of change of set parameters is presented in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t ), mm</td>
<td>1.5, 3, 5, 10, 16, 20, 25</td>
</tr>
<tr>
<td>( W ), kW</td>
<td>0.5-1, 0.5-3, 1.2-3, 1.7-3, 3-4.5, 4-4.5</td>
</tr>
<tr>
<td>( f ), mm</td>
<td>127, 127, 190, 190, 190, 254</td>
</tr>
<tr>
<td>( P ), bar</td>
<td>1-2, 0.5-1, 0.5-1, 0.4-0.5, 0.4-0.5, 0.4, 0.35</td>
</tr>
</tbody>
</table>

Change in \( \Delta f \) caused as well change of kerf width. Then cutting speed was changed and optimization \( R_z \) by means of position of focus with the control of width \( \text{реза} \) was made again. After determination of optimum speed all process of optimization repeated for other laser power. Thus, great volume of the information has been received, allowing to make optimization on parameters \( W, \Delta f, P, v \) and to define the conditions of cutting of material of the given thickness with minimal \( R_z \). Fig. 1 presents the sample of cut surface at thickness of 25 mm.

Fig. 1. Photo of cutting surface, \( t = 25 \) mm.

Results of experiments.

Dependences of optimum cutting speed on beam power at sheet thickness of 5 mm and 10 mm are shown on fig. 2. As it seen, the growth of cutting speed is slowed down with power increase. On fig. 3 values of optimum speed are resulted at various values of beam power at thickness 5, 10, 16, 20 and 25 mm. On fig. 4 the same data are presented in coordinates \( W/t, vb \). Dimensionless variables \( W/\lambda t T_m \) and \( vb/\gamma \) can be compared to \( W/t \) and \( vb \), respectively, here both \( \lambda, \gamma, T_m \) - heat conductivity, heat diffusivity and melting temperature of cut material, respectively, \( b \) – kerf width at beam input. The value \( vb/\gamma \) is Peclet number \( Pe \) and it can be
considered as dimensionless speed, value $W/\lambda t T_m$ - dimensionless Power. dependence of kerf width on beam power at $t = 5$ mm is shown on fig. 5.

Fig. 2. Optimum cutting speed vs beam power, a – $t = 5$ mm, b – $t = 10$ mm.

Fig. 3. High quality cutting data in axes laser power – cutting speed.

Fig. 4. High quality cutting data at dimensionless variables.

Fig. 5. Kerf width vs laser power, $t = 5$ mm.

Fig. 6. Surface roughness vs beam power, $t = 5$ mm.
Section V

Discussion and conclusions

As it evident from fig. 4, in coordinates $W/\lambda T_m$, $vb/\gamma$ the experimental data, corresponding to minimal surface roughness (for the given beam power), are approximated by linear dependence every good in all range of thickness. Such character of dependence means, that in all range of thickness the value $W/vtb$ is constant, $W/vtb$ is equal to the laser energy input in unit of volume of the removed material. Roughness value depends on beam power, and there is a minimum for thickness of 5 mm and 10 mm at $W/t$ approximately equal 200 W/mm. (has fig. 6). The minimum corresponds to Peclet number 0.5, if to accept $\gamma = 20$ mm$^2$/s, as for pure iron at 300 K. It was marked by a number of authors (for example, [3], [10]), that god cut quality is reached at cutting speed, corresponding to Pe of the order of several units. However, not always the criterion of quality is underlined clearly. In the present work the roughness of a cut surface is accepted as quality criterion. Dependence of kerf width on beam power at $t = 5$ mm is close to linear, and $b/W$ is constant at cutting power, much exceeding threshold power. As size $W/t$ is constant for optimum cutting conditions, it is possible to assume, that will be a constant and size $b/t = \beta$.

The experimental data obtained do not allow to establish character of dependence of a roughness and kerf width on beam power at $t = 16$ mm and more because of small range of laser power at which the laser cut it is possible. This is connected with the limited power of the laser and with increase of threshold power of cutting at increase of sheet thickness. It to assume, that the laws found for thickness 5 ... 10 mm are hold for greater thickness, then cutting conditions for the minimal roughness can be characterized by three dimensionless parameters: $W/\lambda T_m$, $vb/\gamma$ and $b/t$. Kerf' width $b$ can be excluded, then parameters $W/\lambda T_m$ and $vb/\gamma$ firmly define laser power $W$ and cutting speed $v$, at which minimum roughness is reached for given thickness.

REFERENCES