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A DETERMINATION OF SPECIFIC WOOD MASS REMOVAL ENERGY IN MACHINING BY CO_2 LASER

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ABSTRACT

This article discusses the determination of energy which is necessary to remove a unit quantity of cut material (specific wood mass removal energy) in wood cutting by the CO_2 power laser. The experiment was performed on dry samples of spruce (*Picea Abies*, L.). The effect of parameters influencing the size of specific cutting energy of wood mass was investigated. The research was done at two levels of output power of laser beam (45 W and 90 W), at nine values of feed speed of laser beam (increasing in the range of 12 to 80 $mm \cdot s^{-1}$) and at three positions outbreak of focusing lens relative to the surface of the sample. The largest value of the specific energy was found in the location of the focus lens on the surface material (7.4×10^6 $J \cdot kg^{-1}$). The largest value of the loss of wood was observed in a position of focus lens above the surface material and also below the surface material.

Key words: spruce, CO_2 laser, irradiation energy, moisture.

INTRODUCTION

Unconventional technologies have gradually found its place in wood machining. The justification for their deployment increases with the increasing demands for quality, machining accuracy and efficiency. CO_2 laser as a suitable tool is often used in industry for cutting of metals and nonmetallic materials. Its application in the wood industry is primarily in the cutting using a power laser beam (BARCIKOWSKI *et al*. 2004) and wood engraving (CHITU *et al*. 2003). Lasers used for wood treatments may induce desirable colour (KUBOVSKÝ, BABIAK 2009) and chemical changes in the wood structure (KAČÍK, KUBOVSKÝ 2011).

Laser can be regarded as a versatile tool for the cutting. It is suitable for serial as well as for small series production. The principle of using the laser machining of the materials lies in focusing the laser beam on the surface of the material. Part of the radiation is absorbed on the surface and converted to heat. When sufficient energy is absorbed then there is destruction of the material - melting and its subsequent evaporation (ARAI *et al*. 1979). The advantage is that the laser cutting tool does not destroy and that laser beam can be focused to the diameter of several micrometers (READY, FARSON 2001). This makes it possible to achieve high irradiance (10^6–10^8 $W \cdot cm^{-2}$) using small quantities of total energy. At the same time reduce heat stress of the work piece to a minimum (BARCIKOWSKI *et al*. 2006).

Modern CO_2 power lasers are able to reach several tens of kW power. Use of this kind of laser in the wood is affected by the fact, that wood very well absorbs radiation wavelength of 10.6 μm. The effect of heating, evaporation and combustion of wood occurs rapidly (HÁBOVČÍK 1990). The prerequisite for optimal and efficient use of specific properties of the laser radiation is to clarify the interaction of wood with this kind of radiation in various levels of energy.

The wood removal energy is one of parameters we are considering in this process working with the wood. The wood removal energy represents the amount of energy needed to remove unit quantity of cut material. Assuming local action of laser beam the quantity removed (evaporated) compounds is directly proportional to the amount of the energy supplied. An important parameter is also material moisture content (ORECH, JŮZA 1987). The amount of incident energy is affected by the laser output power, by the feed speed of laser beam and by distance from the surface of the test piece and focusing lens (DULEY 1976). All these parameters can be reliably determined and measured (ZHOU, MAHDAVIAN 2004). Related factors of the work piece include a thickness, density, moisture content (KÄLLANDER, BENNGTSSON 2004, FRÜHWALD 2007), portion of extractives and main components of wood (POŽGAJ *et al*. 1997).

The aim of this work was to determine the specific wood mass removal energy depending on the feed speed of laser beam and laser beam focusing lens positions in laser machining of wood.

MATERIAL AND METHODS

Experimental material

Samples were prepared from spruce (*Picea Abies*, L.). The specimens were of the dimensions 100 × 35 × 15 mm (length × width × thickness). For the research 54 samples was collected. Moisture content of the samples during tests was 8 %.

Work Procedure

The conditioned samples were selected six pieces to obtain the moisture content. Moisture was determined by gravimetric method using the formula:

$$MC = \frac{m_w - m_0}{m_0} \cdot 100 \quad (1)$$

where *MC* (%) is the moisture content, m_w (kg) is the weight of sample before drying at 103 ± 2 °C and m_0 (kg) is the sample weight after drying.

After marking, weighing and measurement of the dimensions we determined the density of the oven dry samples according to the formula:

$$\rho = \frac{m_0}{a \cdot b \cdot c} \quad (2)$$

where ρ (kg·m^{-3}) is the density, and a, b, c (m) are dimensions of the sample. Samples were weighed on an analytical balance with with precision of 0.001 g (SARTORIUS), sample sizes were measured using a digital slide caliper with the precision of 0.01 mm (TESA).

Subsequently, in each of samples was made 50 parallel notches by laser (across the entire width of the sample). Incisions were created by laser equipment LCS 400 (producer TST Strojárne Piesok in cooperation with VEB Feinmechanische Werke Halle, Germany). The device includes a CO_2 laser emitting at a wavelength of 10.6 μm (TEM_{00} - Transversal

Electromagnetic Mode) with maximum power output of 400 W, positioning table system (permitting the laser head to position itself and raster of the laser beam) and the PC control system.

During the transition, the laser beam stroked perpendicularly on the sample surface, and the laser head carriage moved along the width at a certain scanning speed. Feed direction beam was across fibers on radial section. The whole procedure is illustrated in Fig. 1.

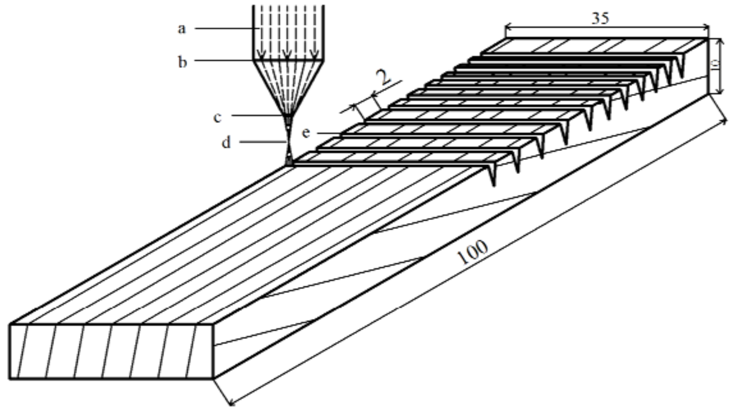

Fig. 1 Schematic drawing of the samples treatment
(a –laser beam, b – laser head, c – jet, d – focus, e –notch).

Of the total number of 54 samples were (randomly) created two equal groups of 27 samples. As optional parameters we been chose laser output power, feed speed of laser beam and distance between the surface of wood and focus of lens. Their values were determined experimentally. The goal was to choose the extent that it did not completely cut material. Samples from the first group were cut with power of 45 W and samples from other group with power of 90 W. The power was measured on the sample surface. The notches were made at the following positions of the focusing lens material due to wood surface:

- focus at the sample surface (denoted as FS),
- focus 6 mm above the sample surface (FO),
- focus 6 mm below the surface of the sample (FU).

To create notches for each sample were determined own parameter values as a combination of power, position of lens and feed rates (Tab.1 a Tab. 2). Focal length (12 mm) and nozzle diameter (1.5 mm) were constant.

Value of the power laser beam was measured by a laser power meter No 201 (Coherent Radiation, Palo Alto, USA) with a measuring range up to 100 W. A sensor was placed at the sample surface and laser beam was directed perpendicularly to its center. The measured data represent the values of effective power.

Notches were made in 2 mm intervals to avoid overlapping of neighboring edges (Fig. 2). The ratios of gas in the resonator were at an output power of 45 W - CO_2 : N_2 : He (2 : 0.8 : 0.7) at electric current of 330 mA. With an output power of 90 W values were as follows 2 : 1.5 : 0.7 at electric current of 450 mA.

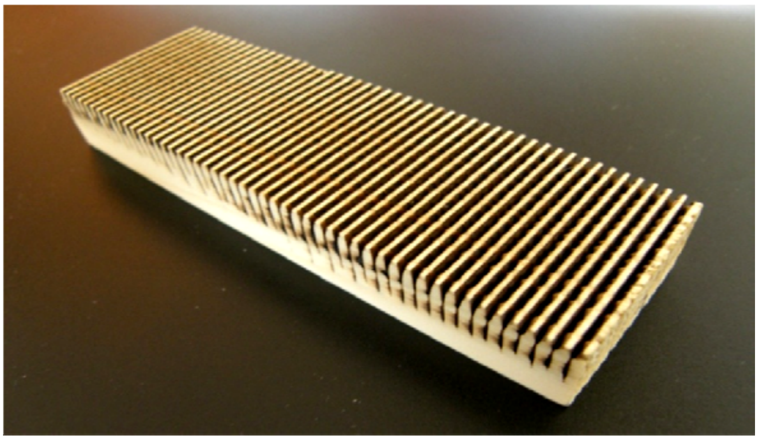

Fig. 2 The example of the samples with notches.

After laser treatment all samples were weighed again. On the basis of weight loss, calculated from the difference in weight before and after machining, was determined specific wood mass removal energy E_c (J·kg^{-1}) (ORECH, JŮZA 1987):

$$E_c = \frac{P}{\rho \cdot v \cdot h \cdot s} \tag{3}$$

where P (W) is the output power of the laser, v (m·s^{-1}) is the feed speed of laser head, ρ (kg·m^{-3}) is the wood density, h (m) is the depth of the cut notches and s (m) is the width of the notch.
Formula (1) after adjustment will be:

$$E_c = \frac{P \cdot l}{v \cdot \Delta m} \tag{4}$$

where l (m) is the length of the notch for all 50 notches and Δm (kg) is the weight loss.

Finally were measured the depth and the width of the notches. These values were measured using by the microscope Nikon DS - U1 Color Camera.

RESULTS AND DISCUSSION

The results of measurements at the power of 45 W

In Table 1 are calculated values of energy E_c and weight loss Δm depending on the feed speed of laser beam and positions of the focus of lens for the first group of samples.

Tab. 1 Values E_c at 45 W (27 samples).

v (mm·s^{-1})	12	15	17	20	22	24	28	40	80
Δm (g) FS	0.92	0.79	0.64	0.60	0.49	0.46	0.38	0.27	0.17
$E_c.10^6$ (J·kg^{-1}) FS	7.13	6.65	7.24	6.56	7.31	7.13	7.40	7.29	5.79
Δm (g) FO	1.08	0.78	0.69	0.68	0.56	0.53	0.45	0.33	0.24
$E_c.10^6$ (J·kg^{-1}) FO	6.08	6.73	6.71	5.79	6.39	6.19	6.25	5.97	4.10
Δm (g) FU	1.20	0.79	0.85	0.72	0.65	0.58	0.49	0.35	0.21
$E_c.10^6$ (J·kg^{-1}) FU	5.47	6.65	5.45	5.47	5.51	5.66	5.74	5.63	4.69

The results of measurements at the power of 90 W

In Table 2 are calculated values of energy E_c and weight loss Δm depending on the feed speed of laser beam and positions of the focus of lens for the second group of samples.

Tab. 2 Values E_c at 90 W (27 samples).

v (mm.s^{-1})	12	15	17	20	22	24	28	40	80
Δm (g) FS	2.06	1.67	1.61	2.38	1.21	1.11	0.92	0.65	0.40
$E_c.10^6$ (J·kg^{-1}) FS	6.37	6.29	5.75	3.31	5.92	5.91	6.11	6.06	4.92
Δm (g) FO	2.54	2.04	1.85	2.70	1.44	1.37	1.18	0.84	0.56
$E_c.10^6$ (J·kg^{-1}) FO	5.17	5.15	5.01	2.92	4.97	4.79	4.77	4.69	3.52
Δm (g) FU	2.15	1.75	1.81	2.80	1.37	1.20	0.99	0.69	0.41
$E_c.10^6$ (J·kg^{-1}) FU	6.10	6.00	5.12	2.81	5.23	5.47	5.68	5.71	4.80

Focus position also affected the size of the notches. Width and depth of the notches depending on its location and feed speed are in Table 3 and Table 4.

Tab. 3 Width and depth of the notches at 45 W and for selected feed speeds.

v (mm·s^{-1})	12	22	40
Depth (mm) FS	7.545	4.527	2.269
Depth (mm) FO	4.486	3.448	3.315
Depth (mm) FU	4.601	2.228	2.243
Width (mm) FS	0.263	0.208	0.174
Width (mm) FO	0.386	0.358	0.311
Width (mm) FU	0.437	0.365	0.331

Tab.4: Width and depth of the notches at 90 W and for selected feed speeds.

v (mm·s^{-1})	12	22	40
Depth (mm) FS	11.311	7.353	4.054
Depth (mm) FO	8.947	6.939	2.839
Depth (mm) FU	7.828	4.743	2.668
Width (mm) FS	0.477	0.392	0.214
Width (mm) FO	0.689	0.587	0.517
Width (mm) FU	1.070	0.622	0.637

Values of the specific removal energy for spruce (*Picea Abies,* L.) at moisture of 8 % moving the laser output power 45 W in the range of 4.1×10^6 J·kg^{-1} to 7.4×10^6 J·kg^{-1} and at laser output power 90 W in the range of 2.8×10^6 J·kg^{-1} to 6.4×10^6 J·kg^{-1}. These energy values are roughly consistent with values reported in the literature (ORECH, JŮZA 1987). With increasing feed speed of laser beam the removal energy decreases. The greatest values of energy are at focus position on a surface (FS), where most energy is concentrated. The highest losses of wood mass are achieved for the focus position above the material surface (FO) and for focus position below the surface (FU). This is probably caused due to of penetration of the unfocused laser beam into the material which has a larger diameter than focused beam. This causes subsequent evaporation of the wood. Maximum depth of notches was observed at the position of the focus on the surface (FS), at lower feed speeds (ZHOU, MAHDAVIAN 2004). Maximum width was observed at the focus position below the surface (FU), also at lower feed speeds.

CONCLUSIONS

Experimental results obtained in this work bring the following conclusions:

- focused laser beam causes greatest values of the mass removal energy
- unfocused laser beam causes highest losses of wood mass
- both of these parameters increase at low feed speed of laser beam
- position of the focus lens also affects the geometry of notches.

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