LASER CUTTING OF THIN PARTS

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Abstract: *Laser beam machining is a machining method based on the physical and chemical effects exerted in the workpiece material by a laser beam having certain energetic, temporal and spatial characteristics. A systemic analysis was developed in order to obtain a clearer image about the factors able to influence the possibilities of obtaining parts by using laser beam cutting. Some theoretical considerations are presented in connection with the phenomena specific to the laser beam cutting and slot generation. In order to test some of the theoretical considerations, an experimental research was designed by taking into consideration diode laser fiber equipment that uses a laser beam with a wavelength of 1060 µm. A test piece having zones of various thicknesses was machined imposing a trajectory of the spot so that parts are detached from the workpiece.*

Keywords: *beam cutting, energy distribution, material removal, heat affected zone*

1. Introduction

The laser beam cutting is a machining method based on the physical and chemical effects exerted at the contact of a laser beam having certain energetic, temporal and spatial characteristics with the workpiece surface layer [2, 5, 6].

Essentially, there are three groups of processing methods based on the above mentioned effects:

- Processing methods supposing *the material removal* from the workpiece; along the time, machining methods such as laser beam cutting, engraving, drilling, milling etc. were developed;
- *Additive processing methods*, when various materials are added to the workpiece material, by direct deposition or as a result of some chemical reactions developed between the workpiece material and materials dedicated to be added to the workpiece material. Such processing methods could be considered the laser beam welding, laser stereolithography, deposition by chemical reactions initiated by means of laser beam etc.;
- Processing methods which *do not generate significant changes of the workpiece mass*; the heat treatment, the exposure of the photoresist etc. could be included in this group.

Beresna et al. (2008) investigated [1] the temperature distribution in cases of machining some non-metallic materials (glass, silicon and sapphire). They appreciated that the information concerning the 3D temperature field could be used in order to estimate the internal stresses able to develop during processes of laser writing, dicing, cutting and finally, in order to optimize such machining processes.

Wee and Li (2005) established an analytical model which explains the striation formation during the laser cutting process [7]. As factors which could exert a significant role in such processes, they took into consideration the laser beam power, the scan speed and spot size. The mathematical model could be also used in order to highlight the effect of material oxidation.

Dubey and Yadava (2008) developed a research aiming the multi-objective optimization of laser beam cutting, by applying a hybrid Taguchi method [3]. They considered as input parameters assist gas pressure, the pulse width, pulse frequency and cutting speed; the objective factors

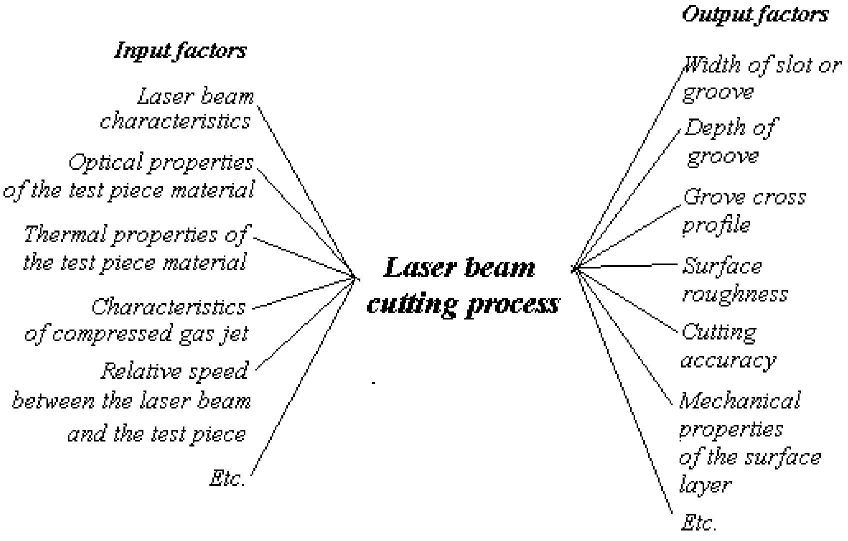


Figure 1: *Systemic analysis of obtaining slots and groves by laser beam machining*.

(quality characteristics) were the kerf width and the material removal rate.

Kovalev and Zaitsev elaborated (2005) a physical model concerning the multiple reflection of the laser beam radiation, valid in case of processes such as laser drilling, cutting, welding [4]. They considered that this model could be used in order to explain the generation of the machined surface by interaction of the laser beam with the workpiece material.

2. Theoretical consideration

The systemic analysis of the laser cutting process can be used in order to highlight the main groups of input factors and output factors (fig. 1).

In case of laser beam cutting and engraving, one may suppose that the energy distribution in the laser beam corresponds to the graphical representation from figure 2, where d_B is the diameter of the laser beam and d_{aj} is the diameter of the compressed air jet.

The researchers accept that the energy is not uniformly distributed, but in accordance with the so-called Gauss's law. Thus, if one takes into consideration the variation of the energy density W along the radius r of the laser beam, the following relation could be written:

$$W(r) = \frac{1}{\sigma\sqrt{2\pi}} \int_{\infty}^{+\infty} e^{-\frac{(r-\mu)^2}{2\sigma^2}} dr \quad , \qquad (1)$$

where σ is the square mean deviation (standard deviation), e – the base of natural logarithm, μ - the arithmetic mean; in accordance with the Gauss's law, the beam radius r could have values from $-\infty$ to $+\infty$, but practical considerations determined the researchers to consider the variation of r from -3σ to $+3\sigma$.

At the contact with the workpiece, a part of the laser beam energy could be reflected; other part of the energy could penetrate the surface layer and the photons could give their kinetic energy to the atomic structures found in the workpiece surface layer.

As a consequence, the amplitude of the normal oscillations of the atomic structures round of their balance position increases; this means an increase of the surface layer temperature. If the energy distribution in the laser beam corresponds to the Gauss's law, it is expected that a similar distribution could characterize the variation of the temperature in the workpiece surface layer. The similitude could be that highlighted by the so-called excess coefficient:

$$E = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^4}{ns^4} - 3 \quad , \qquad (2)$$

where x_i are the measured values, $\bar{x}$ is the arithmetic mean of measured values, n is the

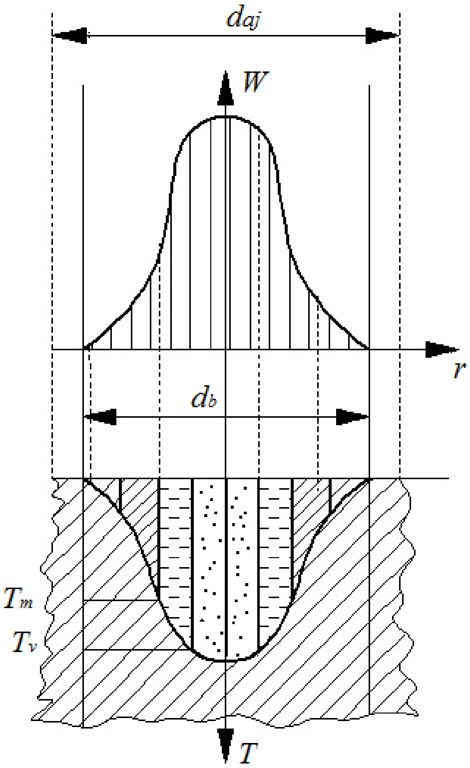


Figure 2: *Energy distribution in laser beam and temperature distribution in workpiece.*

number of the measured values and s is the square mean deviation of the measured values.

In case of the graphical representation from figure 1, the variation of the temperature was highlighted under the workpiece surface.

One could notice that if the energy density in the laser beam is high enough, the temperature in the surface layer could reach values of the temperature higher than those corresponding to the melting temperature T_m or even vaporizing temperature T_v.

In case of a high enough laser beam source power, it is expected that along the laser beam axis, the value the material temperature exceeds the vaporizing temperature; the workpiece material is affected by a micro explosion effect; both the vaporized material and melted material could be removed and a small crater appears. If there is a relative motion with a relative speed v between laser beam and workpiece and there is a laser source with continuous action or a pulse laser source with a high pulses frequency, the successions of the craters could determine the generation of a groove.

Generally, such a process is not the most convenient for a laser beam machining process, since the surfaces thus generated are not characterized by a high machining accuracy and a low surface roughness.

In order to remove or to diminish such a disadvantage, along the laser beam axis, a jet of compressed air is sent; in this way, the melted and the vaporized material from workpiece is immediately removed as a consequence of the pressure exerted by the air jet. It is clear that only the melted and the vaporized material could be removed the air action.

From the physical point of view, one could take into consideration that in the case of the metallic alloys, there is a zone where the workpiece material could reach a high plasticity (due to the high temperature generated by the action of the laser beam) and a part of this plastic material could be also affected by the action of the compressed air jet.

If the laser beam energy is high enough and there is a high pressure of the compressed air jet, the groove could became a slot and a laser cutting process is thus materialized.

Practically, one noticed that a good correlation between the laser beam energy distribution, the laser beam spot dimensions, the position of laser spot to the workpiece surface, the material thermal properties etc. could ensure an acceptable quality and surface roughness of the machined surface.

Due to the energy distribution in the laser spot, the width of the generated slot could be lower than the diameter of the laser spot and sometimes, narrow slots could be materialized by means of the

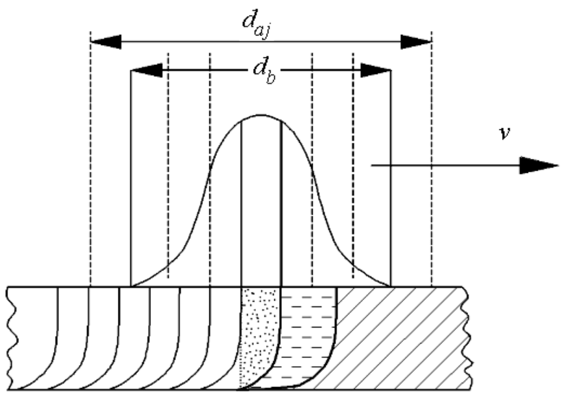


Figure 3: *Energy distribution along the direction of the relative motion between laser beam and workpiece.*

laser beam.

The influence of the thermal action of the laser beam is not limited to melting and vaporizing phenomena; in the vicinity of the zone where the workpiece material was melted and vaporized, the temperature of the material could exceed the temperatures corresponding to the structural changes; this could means, for example, an austenitization process.

When the workpiece material is cooled, after the action of the laser beam, processes of structural changes could also develop. Thus, if the workpiece material has medium or high carbon content, the heat could be relatively fast dissipated in the mass of the metallic material and the conditions for a hardening process could be materialized; as a consequence, one can notice a layer characterized by a high hardness.

If the workpiece material is characterized by a lower dissipation of the heat in the mass of the workpiece material, this could lead to the materialization of the conditions specific to an annealing process and in the same case, of medium or high carbon content steel, a surface layer with a low hardness could appear.

In case of a relative motion between the laser beam and the workpiece, the phenomena could correspond to the graphical representation from figure 3.

One can notice that if the thickness of the material is higher, the action of the laser beam could not be constant along the whole this thickness; the temperature is lower once the distance from the laser spot increases, the plasticity of the workpiece material diminishes and the material removal does not develop in conditions similar to those which are characteristic to the zone placed immediately under the surface layer.

The surface roughness is dependent on the constant maintaining of the laser beam dimensions and on the geometrical and physical characteristics of the compressed air jet.

For example, if the pressure of the compressed air is not constant, it is expected that the melting of the material does not develop along a right line and this fact will correspond to an increased surface roughness. Such phenomena could appear when the workpiece thickness is high and the pressure of the compressed air is not high enough.

Other aspect of technological interest could be the width of the heat affected zone as a consequence of the laser beam action.

As above mentioned, a part of the laser beam energy is absorbed by the workpiece material, without melting or vaporizing temperatures being reached. This absorbed energy is dissipated by phenomenon of thermal conduction; when the workpiece thickness is higher, the heat dissipation in a higher volume of metallic material will generate a relatively low width of the heat affected zone, in contrast with the situation of low thickness of the workpiece, when the width of the heat affected zone could be higher (fig. 4).

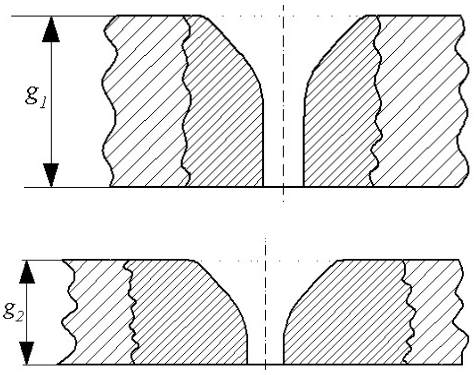


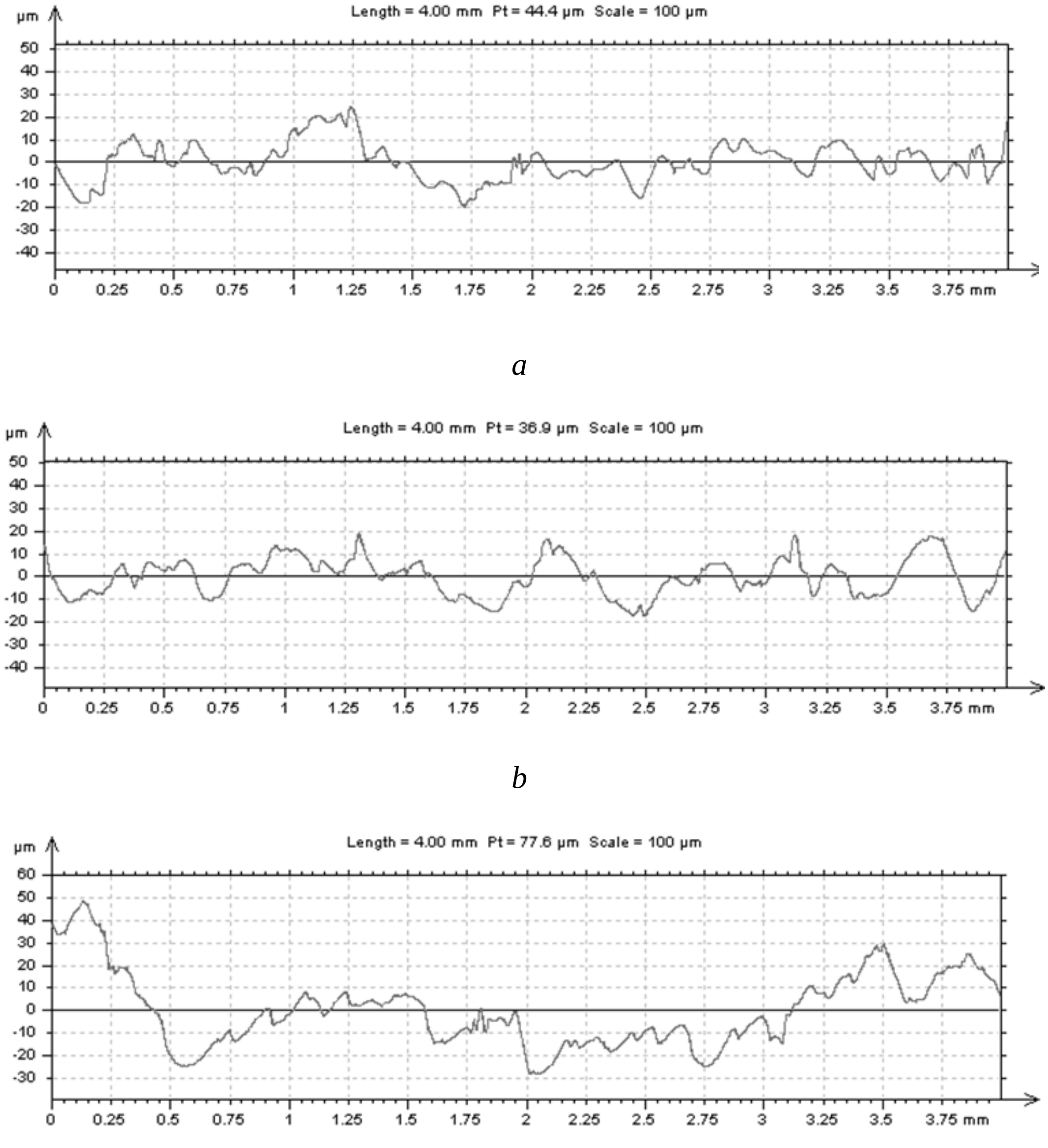
Figure 4: *Variation of the heat affected zone width in case of workpieces having two distinct thicknesses, g_1 and g_2.*

3 Experimental results

In the laboratory for nonconventional technologies from the “Gheorghe Asachi” Technical University of Iaşi, there is laser beam equipment which can be used in order to materialize laser cutting and welding processes. The laser source is a laser diode; a laser fiber is used as amplifier. The output power is of 300 W and the wave length of the laser beam is of 1060 nm. In the structure of the laser beam equipment, there is a computer numerical control subsystem, made by Isel (Germany); this subassembly ensures the programming of the trajectories of the relative motion between the laser beam and workpiece, in a plan coordinate system.

Other experiments were developed on laser equipment made in China; this equipment is found in an industrial company.

As a result of applying a laser beam cutting process in case of a plate having various thicknesses (maximum thickness of 7 mm) and made of medium carbon content steel, one may notice that three distinct zones could be highlighted:



a

b

c

Figure 5: *Surface profiles corresponding to various zone of the machined surface obtained by laser beam cutting: a – profile corresponding to the zone where the laser beam acted on the test piece material, Ra=3.82 µm, Rz=20.4 µm, Rt=25.0 µm; b – surface profile corresponding to the zone where oxidation process developed, Ra=4.46 µm, Rz=22.4 µm, Rt=27.1 µm; c – surface profile corresponding the zone where high striations could be observed, Ra=4.54 µm, Rz=21.9 µm, Rt=28.4 µm.*

- A first zone is situated just near the workpiece surface and it is characterized by a good surface roughness;
- A second zone is placed under the above mentioned zone and its color could be considered as a result of the surface oxidation process;
- A third zone highlights the presence of curve grooves, appeared near the output surface, where the laser tool succeeded to penetrate the workpiece material.

A surface roughness meter type Taylor Hobson was used in order to highlight the surface profile and to estimate the values of some surface roughness parameters.

The image from figure 6 was obtained in case of investigation of the influence exerted by some input factors in the laser beam process in case of

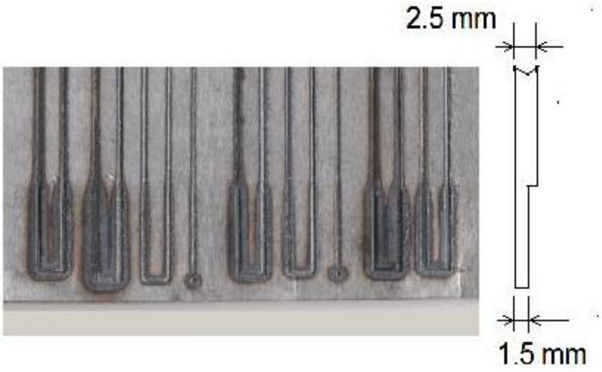


Figure 6: *Variation of the heat affected zone with when the test piece thickness changes*.

cutting / grooving workpieces having zone of various thicknesses.

In accordance with the theoretical considerations, one can directly observe the increase of the heat affected zone width in case of the thin zone of the workpiece when the heat dissipation determined a larger width of the heat affected zone.

4 Conclusions

The laser beam machining is one of the machining methods characterized by a very dynamic evolution. The laser beam cutting allows obtaining parts having various shapes from plates workpieces. The analysis of the surface generation process shows that there are many factors able to affect the surface roughness and accuracy of the machined surface.

Complex phenomena of melting, vaporizing and developing of zone with high plasticity under the action of laser beam facilitate the material removal from the workpiece, within the cutting and grooving processes.

Taking into consideration an energy distribution in the laser beam in accordance with the Gauss's law normal law, the distribution of the heat into the workpiece material could be considered as developing also accordingly to a Gauss's law, but affected by an excess coefficient.

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