RESEARCH ON SURFACE ROUGHNESS BY LASER CUT

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ABSTRACT

Laser cutting is one of the most industrial applications. Laser cutting with oxygen is used primarily for cutting of mild and low-alloyed steels. Cut surface quality is a very important characteristic of laser cutting that ensures an advantage on other contour cutting processes. This paper gives results of the experimental research referring to the determination of surface indicators obtained by laser cutting. The relationships between roughness parameters are given by linear and exponential equations.

KEYWORDS: Laser, laser cutting, surface, surface roughness.

1. INTRODUCTION

Laser technology is a very young technology which has not even reached an age of 40 years. For a long time it has been a development searching for industrial applications. For most engineering applications, the laser may be regarded as a device for producing a finely controllable energy beam, which, in contact with a material, generates considerable heat. The heat energy is supplied by a laser beam that allows tool-free machining with active heat energy. The energy of light contained in the laser radiation is absorbed by the workpiece and transformed into thermal energy. Laser beam is becoming a very important engineering tool for cutting, welding and heat treatment.

Laser cutting is rather well introduced than new attractive process for thin sheet cutting especially of mild steel. It is one of the most important applications for industrial lasers. Laser cutting is thermal, non-contact, mechanized process capable of cutting most materials with a high degree of precision and accuracy. Laser cutting is the process of melting or vaporizing material in a very small, well defined area. Processes of heating, melting, and evaporation are produced by the laser beam affecting a workpiece surface. A desired cut is obtained by moving the laser beam along a given contour. Laser beam is a cutting tool able to cut all materials, focused into a very small spot of 0.1…0.2 mm in diameter concentrating thousands of Watts. The power density for cutting steels typically is $10^7...10^8$ W·cm^{-2}. There is no other way to concentrate so much energy into such a small spot. The high power density of the focused laser beam in the spot melts or evaporates material in a fraction of a second. Since our desire is to remove the evaporated and molten material from the affected zone as soon as possible, the laser cutting is performed with a coaxial current of the assist gas – gas assisting laser cutting, figure 1. In laser metal cutting a gas assisting is normally applied. In gas assisted laser cutting, the gas is usually introduced coaxially with the focused laser beam into the cutting area. The gas cools the cut area, thus lowering the heat affected zone, and also removes molten dross from the cut.

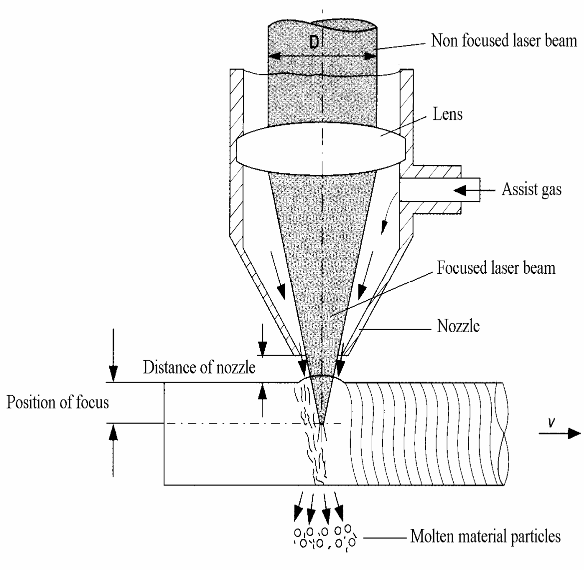

Fig. 1. Gas assisting laser cutting.

There are three different methods of cutting with a laser:

- sublimation cutting,
- fusion cutting and
- flame cutting.

In laser sublimation cutting, the material is removed by metal evaporating. This requires light densities obtainable by appropriate adjustment of the laser radiation and focusing, thus a material removal exclusively occurs by means of evaporation. The metal vapour emitted is blown out of the cut by the cutting gas jet. Generally, either argon or nitrogen is used in order to avoid oxidation of the cut edge. Since almost no melting occurs, smooth cuts can be obtained.

Laser fusion cutting requires lower power than laser sublimation cutting as the material is only melted and then blown out of the cut with an inert gas jet.

By laser flame cutting, instead of inert gas, pure oxygen is used. The material is heated beyond its ignition temperature until a highly exothermal reaction is generated which supplies energy for the cutting process. The liquid material is burned by oxygen and blown downwards out of the cut by the help of the assisting gas jet. Laser flame cutting and laser fusion cutting are predominant in the precision cutting of metals.

Laser cutting of mild steel with oxygen - laser flame cutting is predominant in the precision cutting of steels. Oxygen is the predominant assist gas for mild steel. The material is heated beyond its ignition temperature until a highly exothermal reaction is generated, which supplies energy for the cutting process. The liquid material is burned by the oxygen and blown downwards out of the cut by the help of the assisting gas jet.

Laser cutting with oxygen is used primarily for cutting of mild and low-alloyed steels. The laser beam is focused onto the material surface and anneals the material. Oxygen reacts with the material, resulting in very high feed rates due to the additional energy input. The assisting gas pressure is normally set at 0.5 MPa to cut thinner material of 1...3 mm and is lowered to 0.1 MPa for thick section material of 10 mm, and even below 0.1 MPa for thicker ones. At these low assist gas pressures the cutting process becomes highly sensitive to pressure variations, which should be prevented with suitable regulators. The assisting oxygen quality also impacts the cutting speed. Impurities in the oxygen impede the oxidation process, and therefore reduce the cutting speed. Consequently, the higher the assisting oxygen quality, the higher the cutting speed. The heated material is oxidized by the assisting gas jet and the oxygen blows the melt and the slag out of the kerf. Since oxidation is an exothermic process, a considerable amount of energy is added to the process, resulting in high cutting speed and the ability to cut increased material thicknesses. Assisting gas pressure must be reduced with increasing material thickness to avoid self-burning effects.

Carbon steels of up to 16 mm are well cut by laser cutting with oxygen. The kerfs are narrow (as little as 0.1 mm for thin material) and the resultant heat affected zones (HAZ) are negligible, particularly for mild and low carbon steel. At the same time, the cut edges are smooth, clean, and square. As such, the use of low impurity steels will result in improved edge quality as compared to the results obtained with hot-rolled material. A higher carbon content within the steel does yield to a slight improvement in edge quality, yet it will make the material subjected to an increased HAZ. Figure 2 shows the laser cut.

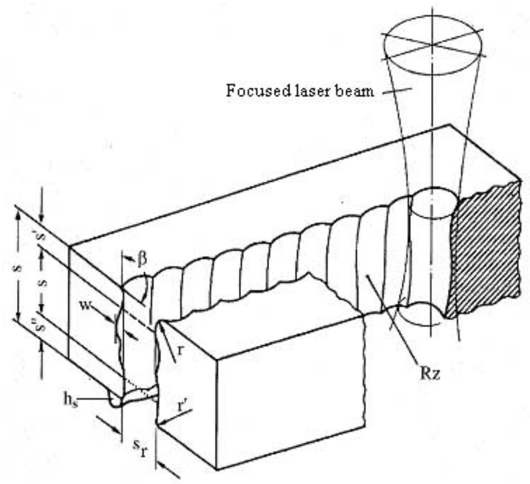

Fig. 2. Laser cut.

Lasers have been shown to be viable cutting tools for the fabrication of sheet metal components made from stainless steel. The controlled heat input of the laser beam serves to minimize the HAZ along the cut edge, thereby helping the material to maintain its corrosion resistance. Since stainless steel does not react with assisting oxygen as efficiently as does mild steel, cutting speeds for stainless are slightly slower than those for comparable thicknesses of plain steel. As for the resultant cut quality, martensitic and ferritic stainless steels provide clean smooth edges. The presence of nickel within austenitic stainless steels affects the energy transfer within the material. Specifically, the viscosity of molten nickel generated during the cutting action causes it to migrate and to adhere to the backside of the cut. While the use of high velocity gas jets can effectively eliminate slag for material up to 1.0 mm thick, slag deposits up to 0.5 mm are generally present on thicker cross sections. Since care is taken to control the amount and distribution of additives to the base iron, most alloyed steels are considered ideal candidates for the laser cutting process. High strength materials such as chrome steel and chrome nickel steel display exceptional laser cut edges that are square and clean. Similar in many ways to alloyed steels, most tool steels respond reasonably well to the cutting action of a laser.

Due to its high thermal conductivity and high reflectivity to a CO_2 laser's wavelength, aluminium requires considerably higher laser energy intensity in order to initiate cutting as compared to steel. This means the need for a laser possessing exceptional beam quality and capable of outputting peak powers of at least 500 Watts, in addition to precise focus control. During the cutting process, the assist gas serves primarily to blow the molten material from the cut zone. Copper has less ability than aluminium to absorb energy from a CO_2 laser. Due to its high reflectance, copper generally cannot be cut. On the other hand, brass can absorb some energy, essentially behaving like aluminium.

By contour cutting of thin sheets the cut surface quality is very important. The standard DIN EN ISO 9013:2000 gives terminological definitions and describes criteria for evaluating the quality of cutting surfaces, quality classification and the dimensional tolerance. It applies in the case of laser beam cuts for a material thickness of 0.5...40 mm. Evaluation of laser cut quality bases on: geometry of cut, surface of cut, burr formation and characteristics of material in zone of cut.

2. SURFACE OF LASER CUT

The laser cut surface reveals a specific form of unevenness. As either semicircular grooves or proper grooving are the consequence of the focused laser beam shape, the cutting velocity and formation process, as well as of the removal and hardening of the molten material at the cut place. Observation of the cut surface can reveal two zones: the upper one in the area of the laser beam entrance side and the lower one, in the area of the laser beam exit side. The former is a finely worked surface with proper grooves whose mutual distance is 0.1…0.2 mm while the latter has a rougher surface characterised by the deposits of both molten metal and slag. That is why it is determined to measure roughness of the cut surface at the distance of one third of sheet thickness from the upper cut edge. There is a difference between the cut surface roughnesses in the direction of the laser beam fand that in the direction perpendicular to the laser beam axis that is in the cutting direction. The former is of no crucial importance in considering the problem of the cut surface roughness due to the fact that the laser is applied to thin sheet cutting. The latter is a more obvious phenomenon that can be observed and analysed. Figure 3 show picture (a) and profile (b) of laser cut.

In laser cutting, the edges of the workpiece have a characteristic grooved pattern. At low cutting speeds, the grooves run almost parallel to the laser beam. As the cutting speed increases, the grooves bend away from the direction of cutting. Groove lag refers to the greatest distance between two drag lines in the direction of the cut. The groove lag is evaluated visually. The evaluation is carried out on a picture of cut with the aid of a magnifying glass or a microscope.

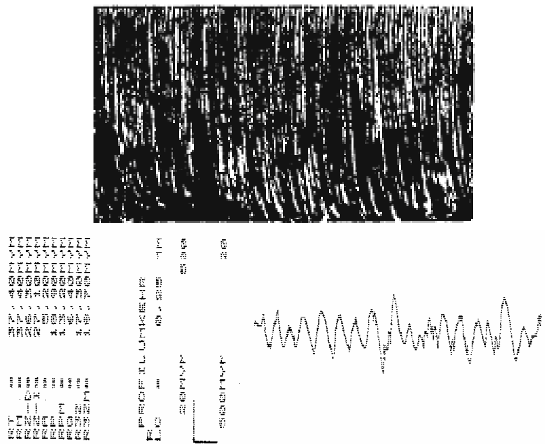

Fig. 3. Picture and profile of laser cut.

Parameters that are most often used for accessing the surface roughness are the standard roughness (ten point height of irregularities) R_z. and the mean arithmetic profile deviation R_a. The standard roughness R_z is the arithmetic mean calculated from the roughness (scallop height) of five consecutive, representative, individual measured sections. The standard roughness R_z is measured e.g. with a brush analyzer corresponding to ISO 3274. The measuring itself is carried out at continuous distances in the cutting direction, in accordance to ISO 4288. The point at which the roughness is measured is dependent on the sheet thickness and the material type.

3. EXPERIMENTAL RESULTS

The experiments have been performed on the CO_2 laser cutting machine with the CNC control. The technical characteristics of the CO_2 laser are: radiation wavelength 10.6 μm, zone of the continual power regulation 0.2…1.3 kW, continual work regime, beam divergence less than 4 mrad, mode TEM_{00}, circular polarization. The optimal laser power is 800 W. The focusing system lens is of 28 mm in diameter and of focal distance 125 mm. The nozzle con opening is 1.6 mm. The material used for examination is low carbon steel Ust 13/Werkst.No 1.0333.5 (DIN). The work process is carried out by the oxygen process of 98% in purity. Working conditions are: the assisting gas is O_2 with pressure of 80 kPa, laser power is $P_L=800\ W$, laser spot is on top of the plate surface.

Equations for determining surface roughness parameters: the standard roughness R_z and the mean arithmetic profile deviation R_a are obtained, based to experimental results, in the form:

$$R_z = 12.528 \cdot \frac{s^{0.542}}{P_L^{0.528} \cdot v^{0.322}} \tag{1}$$

$$R_a = 2.018 \cdot \frac{s^{0.670}}{P_L^{0.451} \cdot v^{0.330}} \tag{2}$$

where: $P_L(kW)$ – the laser power, $s(mm)$ – the sheet thickness, $v(m/min)$ – the cutting speed.

In figure 4 it is shown the surface roughness change for various sheet thicknesses, by cutting with CO_2 laser power of 500 W and 800 W. Standard roughness R_z increases along with the sheet thickness, but decreases with increase of laser power. By cutting with laser power of 800 W, the standard roughness R_z is 10 µm for sheet thickness of 1 mm, 20 µm for 3 mm, and 25 µm for 6 mm.

The mathematical models of correlation between standard roughness R_z and mean arithmetic profile deviation R_a are done, with linear form:

$$R_z = 5.3985 \cdot R_a \quad (R = 0.97868) \tag{3}$$

and exponential form:

$$R_z = 7.07166 \cdot R_a^{0.811087}\ ;\ R = 0.99931 \tag{4}$$

In the proposed mathematical models, there is a very strong correlation between observed parameters.

The graphical interpretation of regression lines for standard roughness (ten point height of irregularities) R_z versus mean arithmetic profile deviation R_a for linear mathematical model is given in figure 5. The graphical interpretation of regression lines of standard roughness (ten point height of irregularities) R_z versus mean arithmetic profile deviation R_a for exponential model (in bilogarithmic scale), is given in figure 5,.

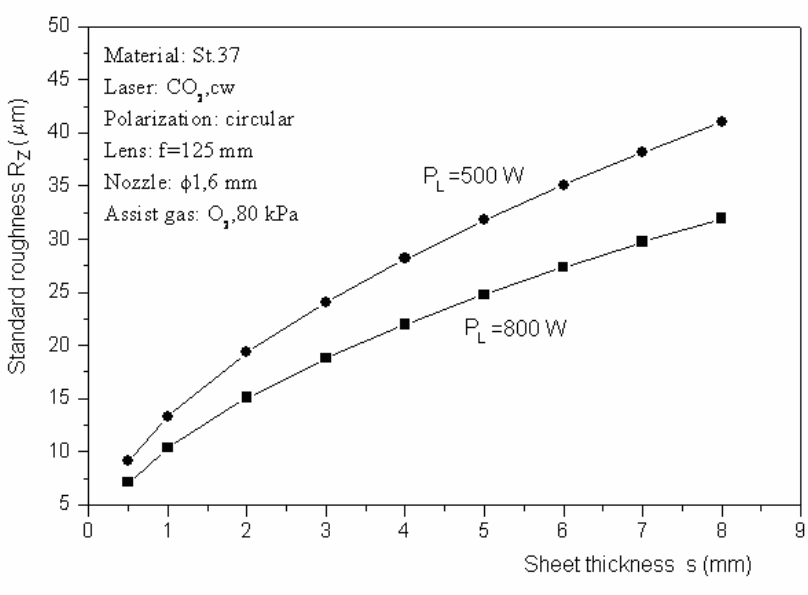

Fig. 4. Surface roughness in dependence of sheet thickness.

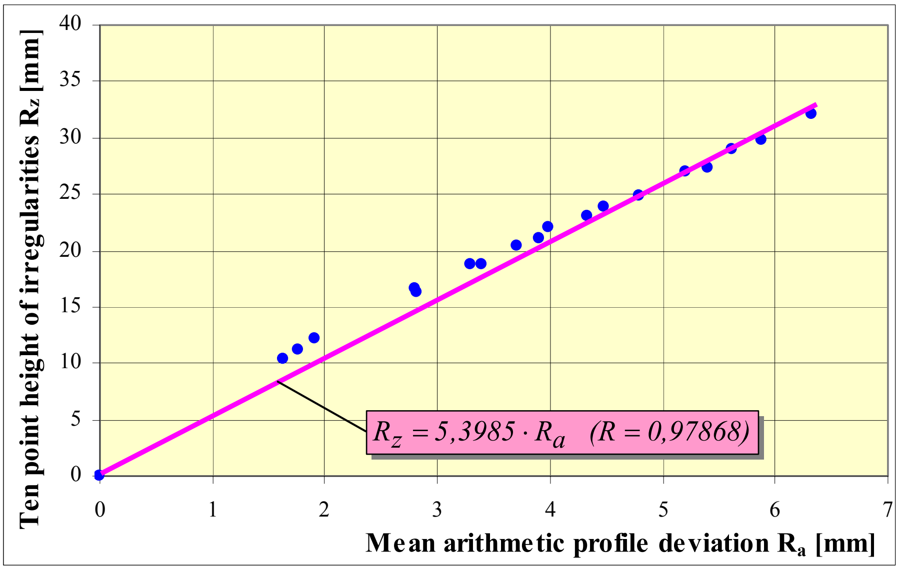

Fig. 5. The ten point height of irregularities R_z versus mean arithmetic profile deviation R_a for linear mathematical model.

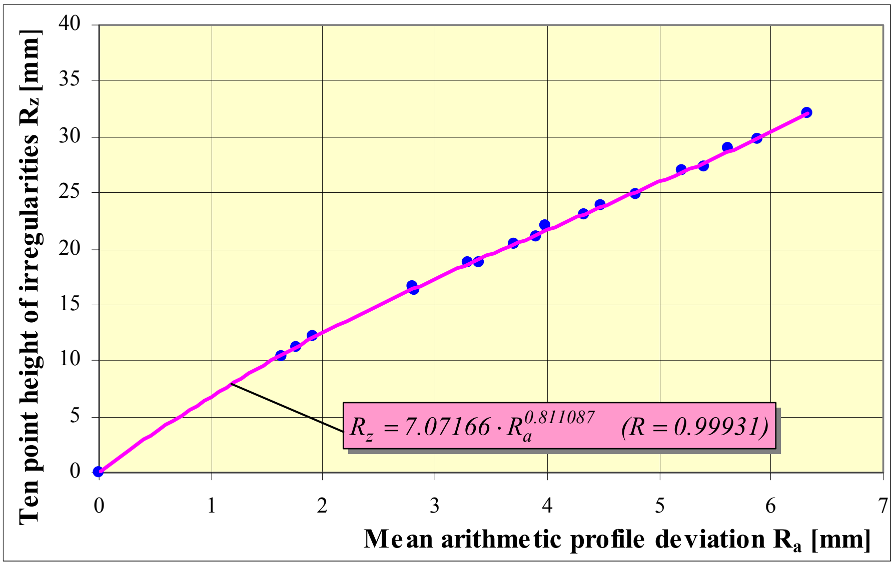

Fig. 6. The ten point height of irregularities R_z versus mean arithmetic profile deviation R_a for exponential mathematical model.

4. CONCLUSION

By contour cutting of thin sheets the cut surface quality is very important. Observation of the cut surface can reveal two zones: the upper one in the area of the laser beam entrance side and the lower one, in the area of the laser beam exit side. The former is a finely worked surface with proper grooves whose mutual distance is 0.1...0.2 mm while the latter has a rougher surface characterized by the deposits of both molten metal and slag. Standard roughness R_z increases along with the sheet thickness, but decreases with increase of laser power. By cutting with laser power of 800 W standard roughness R_z is 10 μm for sheet thickness of 1 mm, 20 μm for 3 mm, and 25 μm for 6 mm. Correlation which connected the standard roughness (ten point height of irregularities) and mean arithmetic profile deviation, the linear and exponential relationships can be used.

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