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OPTIMIZATION OF CUTTING PARAMETERS OF THE HAYNES 718 NICKEL ALLOY WITH GAS CO_2 LASER

OPTIMALIZACE ŘEZNÝCH PARAMETRŮ PŘI OBRÁBĚNÍ NIKLOVÉ SLITINY HAYNES 718 PLYNOVÝM LASER CO_2

Abstract

This article deals with the application of laser technology and the optimization of parameters in the area of nickel alloy laser cutting intended for application in the aircraft industry. The main goal is to outline possibilities of use of the laser technology, primarily its application in the area of 3D material cutting. This experiment is focused on the optimization of cutting parameters of the Haynes 718 alloy with a gas CO_2 laser. Originating cuts are evaluated primarily from the point of view of cut quality and accompanying undesirable phenomena occurring in the process of cutting. In conclusion the results achieved in the metallographic laboratory are described and analyzed.

Abstrakt

Článek se zabývá aplikací laserové technologie a optimalizací parametrů v oblasti laserového řezání niklové slitiny určené pro aplikaci v leteckém průmyslu. Hlavním cílem je nastínit možnosti využití laserové technologie, především pak její aplikaci v oblasti 3D řezání materiálů. Konkrétně je experiment zaměřen na optimalizaci parametrů řezání slitiny Haynes 718 na plynovém CO_2 laseru. Na hodnocení vzniklých řezů je nahlíženo především z hlediska kvality řezu a doprovodných nežádoucích jevů vznikajících při procesu řezání. Závěrem jsou popsány a zhodnoceny výsledky dosažené v metalografické laboratoři.

1 INTRODUCTION

Lasers found wide application in scientific work in astronomy, optics, in the investigation of material characteristics and other basic research areas. Other practical applications are, for example, laser use as an optical equipment for eye surgery, use in geodesy and seismography, in the welding of miniature parts from hard-to-melt materials, in chemistry and metallography during spectral micro-analyses and so on.

1.1 Development of Lasers

The idea to construct the first laser started with the Russian physicist V. A. Fabrikant who pointed out the possibility to use stimulated emission to amplify electromagnetic radiation passing through environment in 1939. He investigated the questions of microsystem energy level population inversion. Later (in 1951), together with M. M. Vudynsky and F. A. Butajeva, they patented the method of electromagnetic radiation (ultraviolet, visible, infrared, and radio wave range) amplification. The first molecular generator called MASER was constructed in 1954.

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The construction of MASER (Microwave Amplification by Stimulated Emission of Radiation) created a new scientific discipline – the quantum electronics. Basov, Prochorov and Townes won a Nobel Prize together for the invention of MASER in 1964.

Strong development of various types of lasers, together with the development of laser technology, has started in 1961. Currently the most important discovery is the fiber laser in the area of semiconductor lasers that are now being placed into industrial operations on mass scale. The main advantages of these lasers are high efficiency, air cooling, small size, high quality of the beam, and long service life.

Lasers can be classified according to various aspects, for example, active environment, wave lengths of optical radiation they transmit, types of quantum transitions (energy levels), types of excitation, and laser operational time regimens.

1.2 Division of Lasers

Traditionally, lasers are divided into five categories according to the types of environment:

- solid-state lasers;
- liquid lasers;
- gas lasers;
- plasma lasers;
- semiconductor lasers.

This experiment was performed on a gas laser. These are lasers with the active environment in a gaseous state. The inversion population of levels is created between the energy levels of some gas components (atoms, ions or molecules). Gas lasers usually operate in continuous regime; however, there were some lasers developed that work in impulse regime that achieve extraordinary high outputs.

2 GAS LASERS CO_2

Gas lasers have a lot of common characteristics due to the specific properties of gas environment, like:

- optical beam is less deformed during passing through active environment than in lasers with condensed environment (thanks to the generally higher homogeneity of gases);
- divergence of the output beam is small;
- spectral line widths are very small which allows to achieve high frequency stability of output radiation;
- the disadvantage of gas lasers is their low power caused by the comparatively small volume density of particles (that is why high powered gas lasers must be very large).

Excitation of gas lasers can be done by various methods, e.g., by:

- electric charge;
- chemical reaction;
- photodissociation;
- fast gas expansion;
- passing of fast electron beam;
- optically, etc.

The main parts of each laser are:

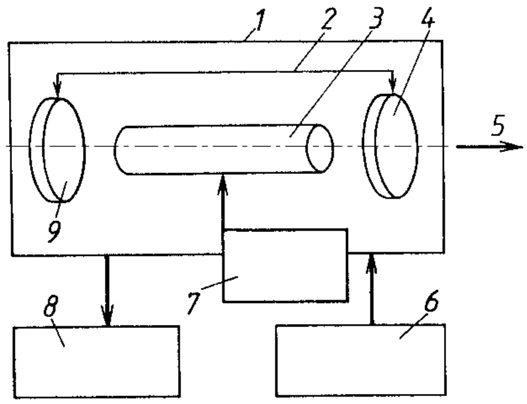

Fig. 1 The schema of laser [2].
1 – laser head, 2 – resonator, 3 – laser medium, 4 – semi-permeable mirror, 5 – output radiation, 6 – exciting energy source, 7 – exciter, 8 – cooling system, 9 – impermeable mirror

3 EXPERIMENTAL CUTTING OF MATERIALS BY GAS LASER

The most used lasers in the cutting area are continuous CO_2 lasers with medium power of up to 15 kW. Nd:YAG lasers with the output of 100 to 1 000 W are used for more exact cuts with smaller cutting gap.

Laser cutting can be:

- Sublimating – the material is removed primarily by evaporation due to the high intensity of laser radiation in the cut area;
- Melting – the material is melted by a laser beam in the cut area and blown away by auxiliary gas. Non-metal materials like ceramics, plastics, wood, textiles, paper and glass are cut this way;
- Burning – a laser beam heats the material to its ignition temperature, so it can then burn in exothermic reaction with the brought reactive gas (e.g., oxygen), the created slag is removed from the cutting area by auxiliary gas. Titanium, low carbon and corrosion resistant steels can be cut this way.

The basic characteristics of laser cutting are:

- Cutting speed – depends on the way of cutting, output power of laser beam, required quality of the cut, and thickness and type of cut material;
- Cut quality – evaluated according to the quality of cut plane;
- Width of cut gap – given by a laser type, and type and thickness of the cut material.

The goal of this experiment was to find suitable cutting parameters during cutting of 2.5 mm sheet metal of this type of alloy using the Winbro Delta laser system. The Winbro Delta manufacturer recommends using this machine for cutting of material with the maximum thickness of 6 mm. We also investigated the influence of cutting parameters on the resulting cutting structure from the point of view of shape deformations of the cutting gap and the creation of remelted layer that is an undesirable accompanying effect of laser cutting.

3.1 Laser system Vibro Delta

The experiment was performed on the Winbro Delta laser system designed for sizable parts with diameters up to 1,900 mm, height of 500 mm, and weight of up to 500 kg. The Delta system can be configured with up to four different types of laser sources in order to meet the requirements of specific applications of operational laser technology (e.g., cutting, drilling, or welding) (see Fig. 2).

Fig. 2 Vibro Delta laser system with the Heidenhain iTNC 530 control system [6].

The laser system has been completed with the Rofin DC 020 source, and equipped with the Heidenhain iTNC 530 control system. It is a gas CO_2 laser that operates in continuous regime.

3.2 Experimental material

Test samples were made from a high strength alloy Haynes 718 that belongs to the nickel alloy group. These alloys are suitable for operations under extremely demanding conditions. They are materials primarily resistant to high temperatures. These alloys are used in construction of land gas and aircraft engine turbines, then they are used for industrial furnaces, combustion chambers, etc. The alloy features outstanding temperature resistance to the temperatures from -253 °C to +705 °C, and also excellent resistance against oxidation up to 980 °C.

Tab. 1 Chemical composition of alloy Haynes 718

Elements	Ni	Co	Fe	Cr	Cb+Ta	Mo	Mn	Si	Ti	Al	C	B	Cu
Weight [%]	52	1*	19	18	5	3	0.35*	0.35*	0.9	0.5	0.05	0.009	0.1*

* Maximum

3.3 The cutting parameters

Samples were made from sheet metal with 2.5 mm thickness. The laser feed rate was set to 500 $mm.min^{-1}$ based on experimental experience, the distance of the jet from the surface was 0.9 mm, exciting frequency 2000 Hz, filling 75 %.

The laser source output was changed by 10 % for individual cuts, see Tab. 2.

Tab. 2 The parameters of power of laser

Number of cut	Power of laser 2kW [%]
Cut 1	90
Cut 2	80
Cut 3	70
Cut 4	60
Cut 5	50
Cut 6	55

The cut length was 10 mm. Placement or distances of individual cuts were empirically selected so the gaps between them would be sufficient from the point of view of possible temperature effects on the neighboring cuts.

4 REALIZATION OF EXPERIMENT

The cuts no. 1 to 5 were created according to the proposed cutting parameters. It was demonstrated that the metal was not completely cut through with the parameters set for no. 5. Therefore the output for the cut no. 6 was set to 55 %, that is for the average value between the cuts no. 4 and 5. However, the 55 % power was not sufficient for cutting of the metal again. The smallest power useful for this material thickness is 60 % of the maximum source output which corresponds to the laser source output of 1200 W.

Fig. 3 a) shows the cuts no. 1 to 6. The cuts no. 1 to 4 went through the whole metal thickness. The reason for unsuccessful cutting of two last cuts was insufficient laser source power.

Fig. 3 b) shows that apparent, temperature influenced, cutting area that is getting smaller with increasing output. Burnt-on slag is being created on bottom part of the cut, which can be considered an accompanying phenomenon of cutting process that is possible to influence by setting of the cut parameters. It can be generally stated that the height of occurring slag does not exceed the thickness of cut metal, is brittle and breaks.

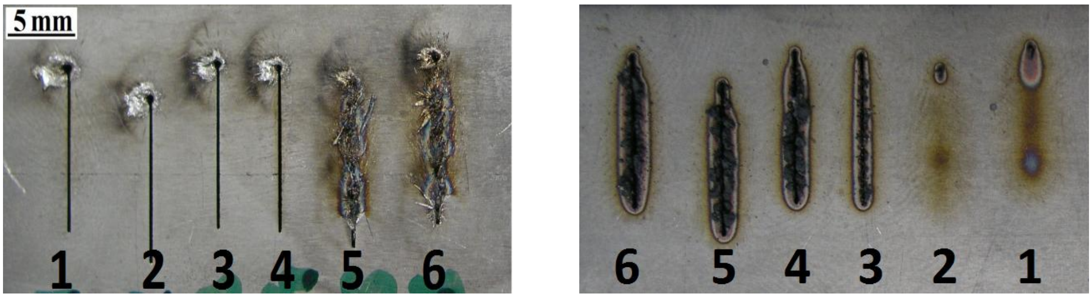

Fig. 3 The sample – sheet metal with 2.5 mm thickness (Haynes 718):
a) upper side of sample, b) underside of sample

Then we investigated suitable cutting speed using the cuts marked by no. 4a to 4f, in order to increase the cut quality. The source parameters were set to the values of the cut no. 4, with feed rate being the only variable. For each cut we increased the feed rate by 100 $mm \cdot min^{-1}$.

The cuts no. 4c and 4d were evaluated as the best from the point of view of cutting quality. These cuts correspond to the cutting speed interval <700;800> $mm \cdot min^{-1}$. In order to make the feed rate value more exact we performed the cut no. 4f with feed rate of 750 $mm \cdot min^{-1}$.

Tab. 3 The velocities of laser cutting with power 60 %.

Number of cut	Feed rate of laser cutting [$mm.min^{-1}$]
Cut 4a	500
Cut 4b	600
Cut 4c	700
Cut 4d	800
Cut 4e	900
Cut 4f	750

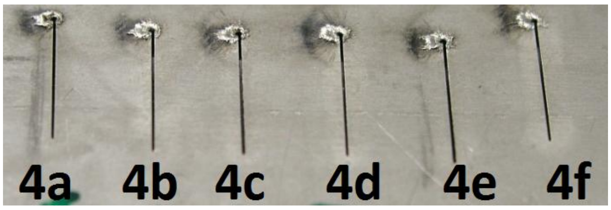

Fig. 4 The cuts of variable feed rate with constant power 60 %.

5 EVALUATION OF MEASUAREMENT RESULTS

We have made metallographic sections at the metallographic laboratory and compared the individual cuts. Fig. 5 shows the photograph of comprehensive view of the cut no. 1 (magnified 10 and 50 times, etching agent Vilella), with no remelted layer observable, except of the imperceptible layer on the cut walls that probably occurs always. The cut profile is symmetrical without larger shape deformations.

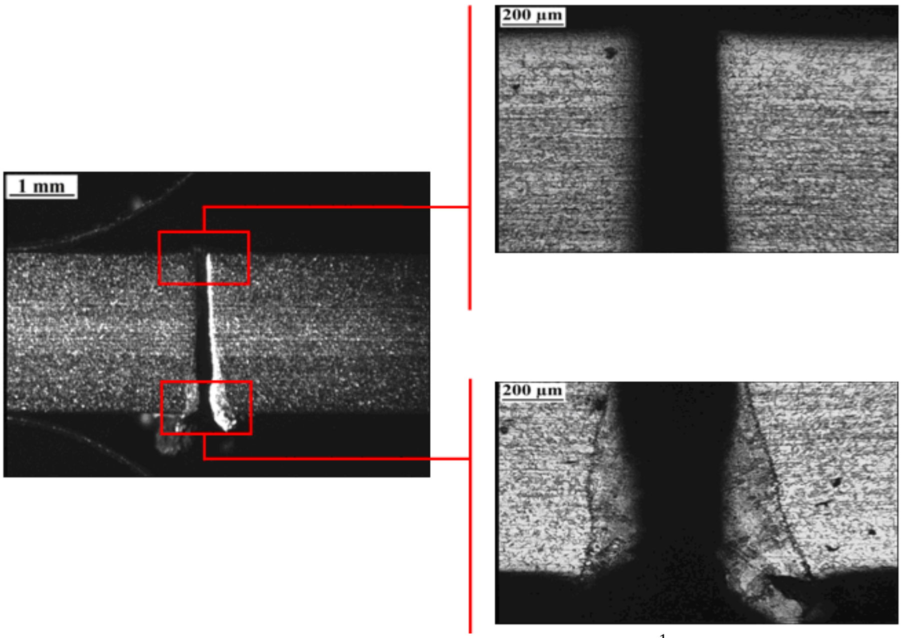

Fig. 5 The detail of cut no. 1 (power 90 %, feed rate 500 mm·min^{-1}, magnified 10× and 50×).

We can see originating asymmetrical distribution of the remelted layer at the bottom of the cut. The layer is caused due to the barrier that originates due to the melt concentrated in the bottom part of the cut. The melt after solidification manifests itself as burr on the bottom edge of the cut. Thanks to this the heat that originates during cutting, and does not have a chance to dissipate from the surrounding of the cut, accumulates in this location. As a consequence there is local overheating, change in the shape of cut, and increase in the volume of remelted layer.

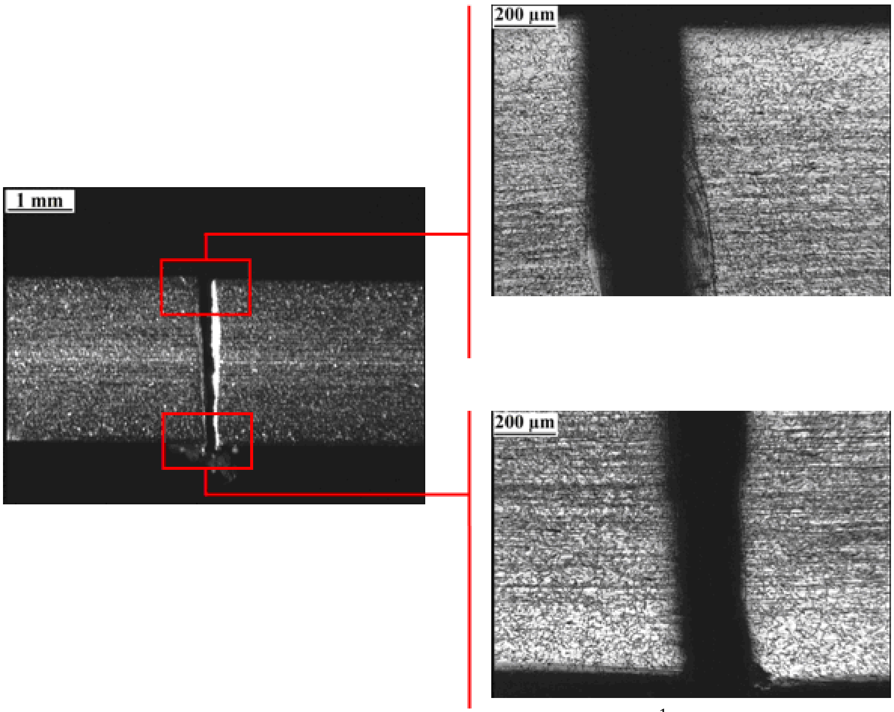

Fig. 6 The detail of cut no. 4 (power 60 %, feed rate 500 mm·min^{-1}, magnified 10x and 50×).

The cut no. 4 was selected as the best in quality after visual control. It can be seen that it appears satisfactory even from the point of view of the size of remelted layer.

The cluster of particles on Fig. 7 in the cutting gap on the black background is not anything unusual in laser cutting. This is a blemish in the sense of cutting perfection that can appear in certain cut locations after the creation of metallographic section. This can be caused by the short term decrease of auxiliary gas pressure during cutting process, for example.

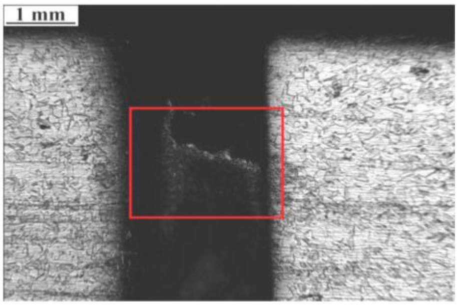

Fig. 7 The detail of cut no. 4c (power 60 %, feed rate 700 mm·min^{-1}, magnified 100×).

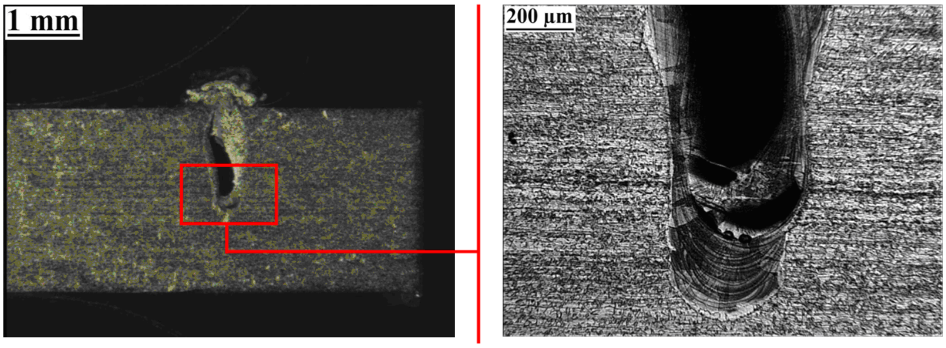

Fig. 8 The detail of cut no. 6 (power 55 %, feed rate 500 mm·min^{-1}, magnified 10x and 50×)

Fig. 8 shows the photograph of the cut no. 6, in which the metal was not completely cut. This is unacceptable state caused by insufficient output of the laser.

6 CONCLUSIONS

Based on performed experiments we have found that suitable parameters for cutting of the Haynes 718 alloy and the metal thickness of 2.5 mm are 60 % (1200 W) of laser output and 750 mm·min^{-1} feed rate according to the cut no. 4f. From the standpoint of possible influence of the cut by surrounding atmosphere it is suitable to measure the remelted layer by a microprobe and then perform a microchemical analysis. We recommend paying increased attention to the study of the remelted layer and its increase in dependence on cutting parameters. It would be suitable to perform the measurement of micro-hardness at the boundary of melting of original material and more importantly at the remelted layer itself.

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