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Laser Precision Cutting of High-Melting Metal Foils

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Abstract

The conventional processing of high-melting metal foils by means of wire eroding is time-consuming and thus cost-intensive. Other procedures such as e.g. milling cannot be realised at all or only with high efforts. Laser beam cutting is a more economical alternative, which is, however, technically very demanding due to the high melting point of the examined foil materials. Different cutting methods and types of laser were used in the examinations in order to achieve a distortion-low and high-quality cutting of the materials in the sintered and unsintered state at high process velocities.

Keywords: laser material processing; laser beam cutting; laser precision cutting; refraktory metal foils; high-melting metal foils

1. Preface

Within this project a procedure for the laser precision cutting of refractory metal foils, especially tungsten composite materials, was developed. So far, these metal foils have mainly been processed through wire eroding, which is, however, very time-consuming and thus cost-intensive.

Furthermore, examinations on the cutting edge quality of laser-cut tungsten foils were carried out on laser processing machines. It was differed between processing sintered and unsintered (green) foils. Prior to the examinations, a detailed catalogue of required quality parameters had been compiled in comparison to the conventional wire eroding in order to meet the requirements of the end users and to offer laser beam cutting as an economical alternative.

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The test pieces were processed on different laser machines. Several fibre lasers and other solid state lasers whose pulse duration ranged from continuous (cw-) to picoseconds were used. Wavelengths in the near infrared as well as the green and ultraviolet range were examined. In order to utilise the advantages of the laser beam cutting in terms of flexibility, rapidness and precision for these materials it is necessary to compensate the high heat input as otherwise problems with the cutting edge quality and foil deformations may occur.

With some approved procedures the cutting edges had to be post-processed in order to meet the quality requirements. Several different post-processing procedures were evaluated in terms of their suitability.

1. Material characteristics

High-melting materials can be used in many fields of application in the high temperature range. Tungsten has the highest melting point of all metals and its heat conductivity is also high. The tungsten alloy used in the experiments is made as a sintered metal (see table 1) and consists of 90 % tungsten (base material) and 10 % nickel and copper (binder matrix). The selected powder mixtures enable especially homogeneous materials with tailored characteristics. The sintered foils are 90µm thick and the unsintered ones circa 110µm.

Table 1. Material characteristics.

tungsten content in %	≥ 90
binding agent	NiCu
density in g/cm³	17.0 ± 0.2
melting temp. tungsten in °C	3410
melting temp. nickel in °C	1455
melting temp. copper in °C	1085
heat conductivity in W/mK	≥ 95

2. Selected results of the laser treatment

Due to the completely different process requirements, the experiments can be divided in cutting tests with sintered material and those with green material. Various laser machines with different wavelengths and cutting methods were compared. Particularly important is processing in the green state, as the heat impact zone and structural tensions, which occurred during the laser treatment, are eliminated through the following process step sintering.

2.1. Processing of sintered material

Cutting with the fibre laser can lead to a high-quality cutting edge only with nitrogen as cutting gas and a high gas pressure in order to avoid an oxidation of the cutting edge and to remove the viscous melt. The different processing methods, pulsed and cw-operation, are both suitable to achieve a high quality. The cw-operation, however, is the preferred method because of the higher feed rates. With both processing methods the upper surface is free of deposit; the burr formation on the lower surface could not entirely be prevented.

It could be observed in all tests that it is always the binder of the material that melts first and thus frees the tungsten grains out of the structure. Nevertheless, it is not exclusively the tungsten grains that form the cutting edge. Depending on the selected parameters the binder is influenced in different ways, which is reflected by the individual roughnesses. Figure 1a shows a typical cutting edge created by a fibre laser. The bright tungsten grains can be seen in the false colour image surrounded by the copper-nickel-binder. The quality of the manufactured test pieces requires a post-processing as their roughness is still too high and there is too much melt deposit.

The test results with the used picosecond lasers at different wavelengths (1064nm, 532nm and 355nm) are almost identical. The created cutting edges exhibited an extremely high quality but no heat impact, neither on the upper nor lower surface, owing to the short pulse duration. Burr was not formed either. Only at a wavelength of 1064nm a minimal ablation deposit on the upper surface could be detected. However, the process times were very long; process velocities of 3.75mm/s at 355nm up to 6mm/s at 1064nm were achieved. [1]

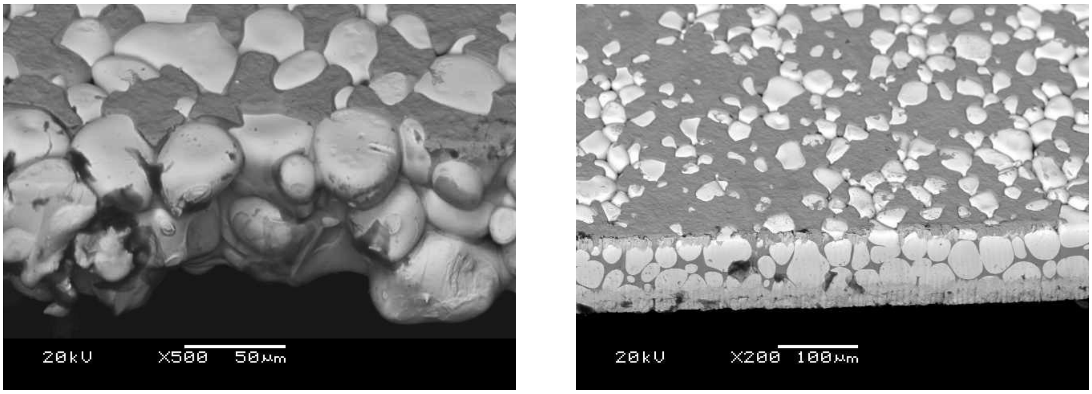

Fig. 1. Cutting edges created with (a) fibre laser, (b) picosecond laser.

Basically, it is possible to increase power and pulse frequency in order to accelerate ablation. At the same time the scan velocity has to be increased too in order to distribute the pulses sufficiently. Figure 1b shows the cutting edge as it was created by the picosecond laser. The special feature of the picosecond laser is its pulse energy which is so high that the single tungsten grains are ablated only in the area that is influenced by the laser. There is no heat conduction in the binder or grains as observed in the previous tests.

A feasibility study on the remote cutting of tungsten foils examined the high-speed scanner processing without cutting gas support. The examinations were carried out on sintered as well as on unsintered foil. Four different laser sources were selected (single-mode fibre laser, pulsed nanosecond solid state laser, UV-picosecond laser). All in all, quality increases the shorter the pulse duration as well as the wavelength are. The process velocity is highest with the single-mode fibre laser but the quality is lowest. The picosecond laser, which had a higher process velocity than the nanosecond laser, provides the best quality. [2]

2.2. Processing of unsintered (green) material

Examinations of unsintered material have shown that green foil can be processed very well. Test pieces could be manufactured with good edge quality and without heat impact zones and sublimate residues (fig. 2). Handling the cut pieces is difficult due to their mechanical instability.

Processing the green foil on the carrier foil was also successful which enabled the development of a process technology that can be handled and carried out very well. Using large material dimensions makes processing easier and reduces material offcuts. At the same time the carrier foil stabilises the material so that the foil cannot be damaged. This especially affects finer structures. Furthermore, an automated material feed and removal is conceivable. The 160mm wide foil is manufactured as endless sheet and then transported and stored wound on rolls. An automated conveying procedure could unwind the foil, feed it through the laser scanner, process it and finally wind it on rolls again. A manual feeding of the machine by the operator would no longer be necessary. Here significantly higher process velocities are achieved than in the previous examinations.

Sintering the green foil out of which the test piece geometries were cut was very successful. A good dimensional stability could be proven. The cutting edge quality is as good as that of the cut tungsten. If burr formation and grain structure of the cutting edge of laser-cut tungsten sheets is taken into consideration, it can be stated that the cutting edge quality of the sintered green pieces is significantly higher.

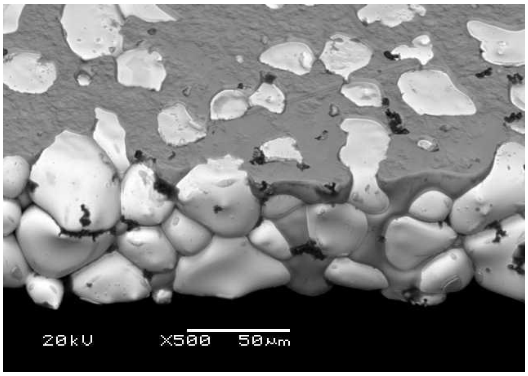

Fig. 2. Cutting edge after sintering.

3. Results of the post-processing procedures

The post-processing procedures are to create the required quality of the work piece if it has not been achieved by the laser treatment yet. This is true for all foils that were cut in the sintered state except those which were treated by the picosecond laser. For these cutting procedures a post-processing method has to be found which removes the burr and the sublimation residues. The procedures grinding, frictional grinding, ball peening, pickling and electropolishing were under examination. Additionally, annealing has to be examined which is to improve the planeness of the work pieces. [3]

The frictional grinding tests showed the best result of all tested procedures. The burr on the cutting edge as well as the sublimate residues were removed completely. Even the tungsten grains which formed the cutting edge are removed which leads to rounded edges (see fig. 3). The surface of the work piece is evened too and residues from the laser cutting are removed. Frictional grinding is an economical procedure which provides a very good edge quality.

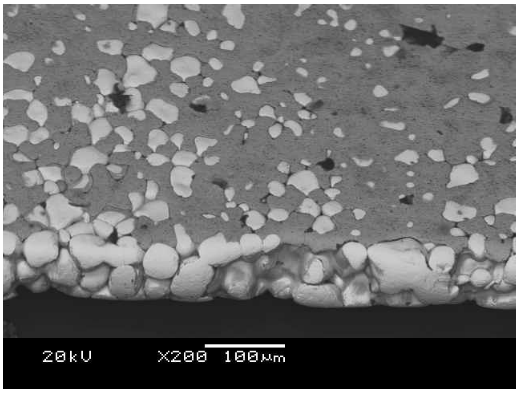

Fig. 3. Cutting edge after frictional grinding.

As measurements showed in the preexaminations, the test pieces must be annealed in order to meet the planeness requirements. Therefore a series of pieces were cut with our own fibre laser and their planeness was measured. Afterwards they were annealed and their planeness measured again. Whereas after the laser treatment an average planeness of 221µm with a standard deviation of 75.2µm can be achieved, this value can be reduced after the annealing to 56.9µm with 17.7µm standard deviation.

4. Summary

The findings of the project work can be used to improve the laser beam cutting of refractory metal foils in the sintered state significantly and to enable it in the unsintered state at all as well as to carry out laser treatment at a very high quality level.

The tests with the sintered materials showed that process quality increases with shorter pulse duration. Additionally, the results can be improved with shorter wavelengths. An exception are the picosecond lasers which always provided very good results in the three tested wavelength ranges. Only they also achieve such a high cutting edge quality so that a post-processing is not necessary. In terms of process duration the picosecond lasers can compete with the nanosecond lasers. They are, however, considerably slower than the used fibre lasers. The required cutting edge and surface qualities can be achieved through the post-process steps frictional grinding and annealing. The processing of the green foil proved its cuttability and the cutting edge showed a good quality. An automated processing is possible which reduces the process times considerably. It could be demonstrated that the cutting edge quality after the sintering is very good and the required dimensional stability can be achieved.

The finished research project offers several possibilities to process refractory metal foils with high demands on accuracy. The most suitable procedure can be used depending on the piece geometry or customers' wishes. So, laser cutting procedures have an advantage over the conventional eroding procedures. Adapted laser cutting procedures offer the chance to use metallic high-melting foils in different branches of industry, e.g. aeronautics, automobile industry, medical engineering and beam technology.

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