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Laser Cutting of Austenitic Corrosion-Resisting Steels

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Abstract

Cutting of thick austenitic stainless steel sheets with a disc laser is not fully developed. In this research were investigated the surface of holes made on 3.25 mm thick stainless-steel cut with CO_2 laser beam and disk laser beam. Using optical microscope and electron microscope to examine the cutting surfaces, were observed that the cutting with the CO_2 laser result high quality surface (cutting 3,25 mm thick plates), but holes made with solid-state laser has microcracks on the inner side. These cracks are not acceptable to the customers.

Keywords: *laser cutting, austenitic steel, CO_2 laser, solid-state laser.*

1. Introduction

One of the great achievements of the 20th century was the discovery of the laser that opened new perspectives in many disciplines. The great advantage of lasers used in the material processing is that the process provides very precise, quick machining and low heat input, but all machining requires unique parameters. These parameters are for example: Power, wavelength, cutting speed, focus line distance. Many researchers have been involved in cutting with CO_2 laser. The laser cutting of austenitic stainless steels above a certain thickness is not fully developed. In recent years, the increase in the power of fiber lasers has resulted the possibility of the cutting of higher-thickness stainless steel sheet, Seon and his associates succeed in cutting a 60 mm thick sheet with a 9 kW laser, but the surface is very drossy **[1]**. A particular problem is the curved cutting of thick steels **[2, 3]**. In addition to laser power, Berkmanns and Faerber examined the effect of curvature on cut surface quality **[2]**. Parthiban and his associates achieved a curved surface with sufficient quality, on 2.5 mm thick on X5CrNi18-10 type material with CO_2 laser beam **[3]**.

Kotadiya and his associates studied the effects of the laser beam cutting parameters on surface roughness. The authors found that both laser power and gas pressure significantly affect the surface roughness using CO_2 laser source **[4]**, but in the case of fiber laser beam, power and cutting speed are decisive for corrosion-resistant steels **[5]**.

The quality requirements for the surface of the laser-cut holes depends on the use of the parts. The part I have tested must meet very stringent requirements, because it will be used in gas turbines. The cuts were made with CO_2 laser and solid-state laser. For the CO_2 laser, we used the company-approved reference parameters, while for the solid state laser, we used the parameters of our choice, as the proper values for the process variables are not yet worked out. In the case of CO_2 laser cutting, the surface of the cut was as specified, but with regard to solid laser cutting, the number of cracks exceeded the maximum amount of cracks specified by the customer. The aim of our research is to examine the surface of holes made during trial cuts and to evaluate the set parameters.

2. The laser

Considering the laser as radiation, it is based on stimulated emission that occurs in the laser medium when a photon strikes an already excited state atom and the incoming photon captures the excited atom's photon, and collectively moving on, the arrival going parallel to its direction. The laser beam is generated in the resonator, where the laser medium, the pump, the closing and the semipermeable mirrors are located. The laser medium may also be a solid, liquid or gas medium. The basic condition of the stimulated emission is that there should be more atoms in excited state than in non-excited state, this is called Populationversion. [6]

2.1. The CO_2 laser

One of the most common lasers used in the industry was the CO_2 laser, which was mainly used for cutting and welding. The first used high-performance industrial lasers were CO_2 lasers. The laser medium in this case is a gas mixture which flows in quartz glass tubes. To excite the gas without contact they uses electrodes from outside of the tubes. The used laser gas is a gas mixture that is blended with carbon dioxide, helium and nitrogen in an appropriate proportion. The wavelength of the created laser beam/laser radiation: $\lambda = 10{,}6$ μm. [7]

2.2. The fiber laser

The fiber-laser is a very complex but powerful solid-state laser which were designed to circumvent the unfavorable excitation properties of rod lasers. It is a solid-state laser as the laser medium is a solid quartz glass contaminated with rare earth metals, in which the high-power laser beam is generated by excitation of the polluting atoms. The medium is a thin fiber which is 8–10 μm diameter, this core has the largest refractive index, surrounded by a coating with a lower refractive index. The low-power pump laser beam (diode laser) that will perform the excitation is propagates in the coating. The outer cladding, which has the smallest refractive index, ensures that the excitation laser does not get out. The excitation laser easily enters the core, but it can not get out so easily, and the laser created by the induced emission is almost impossible to get out. In this case for the laser beam mirroring they use Bragg grating instead of mirrors. This grating are placed perpendicularly to the optical axis on the two end of the core. In these bands (grid lines), the refractive index differs from the core refractive index, and the bands thickness are periodically variable. [7]

2.3. The disk laser

The disk laser uses a thin circular disk as a medium instead of a thin fiber. The excitation diode laser which guided through the laser medium in several times with mirrors, causing the population inversion, the excited laser beam then exits from the resonator and can be led by an optical cable. The quality of the laser beam produced in this way achieves the quality of the CO_2 laser and provides greater efficiency, and also has the great advantage of the fiber laser being used to transmit the beam with an optical cable. The Disk laser wavelength $\lambda \simeq 1$μm which means that it is smaller than a CO_2 laser [7], and it plays an important role in heat input and has a decisive influence on the results of the sample The parameters that we used have been adjusted to this effect.

3. Description of the experiments

The test material is austenitic stainless steel of type X5CrNi18-10. The test cuts were made on a 3.25 mm thick plate. The first reference cut is a 4 kW CO_2 laser of the Truflow 4000 type, while the other cuts were made with a TruDisk 3000 type 3 kW disk laser. The surface of the holes was first inspected visually after the cuts, and then the inner surface of the holes and the rim using a Dino-Lite Digital portable light microscope. The detailed examination of the laser-cut surfaces and possible defects were examined with a Jeol JSM 5310 scanning electron microscope (SEM).

4. Test results

First, we made images of the holes surfaces using a simple portable light microscope to provide the basis for the future studies. These images clearly show the laser beam entry / exit point, focus spot location and spattering on the edges of the cut, and the so-called "adherent slag" on the bottom edge of the hole, but the cracks in these images are not visible.

The "adherent slag", as shown in Figure 1. was typically visible on the surface of the hole cut with the CO_2 laser. For these cuts, were used the reference parameters previously accepted by the company, which are used to make existing parts. The metallographic pattern shows a uniform melting zone of about 40 μm (Figure 2.), which in some cases overflowed in approximately the same degree with the direction of cutting.In contrast, the disc laser-cut pieces did not exhibit this amount of adherent slag. At first glance, the edge of the cut is rough, but the roughness of its inner surface is

Figure 1. *Adheerent iron-oxide on the hole surface cut with CO_2 laser(∅ 6,2 hole)*

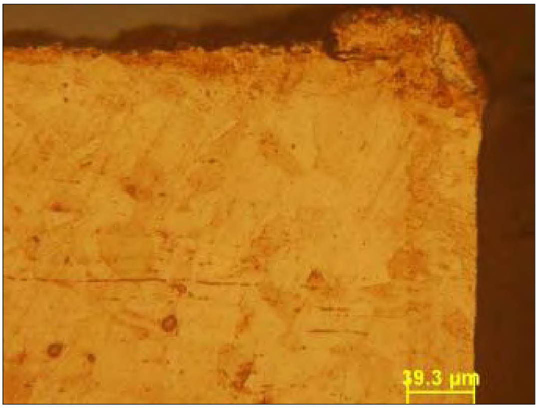

Figure 2. *Near the hole surface area after CO_2 laser beam cutting. Etching material: aqua regia*

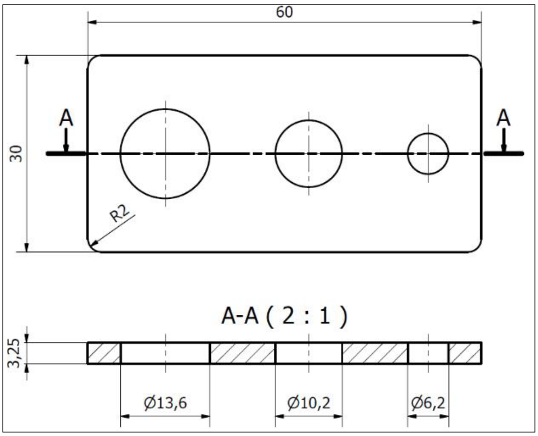

Figure 3. *Cutted sample geometry*

Figure 4. *Hole made with Disk laser (ϕ 13,6 hole)*

adequate. The reference cut was followed by the cutting with a disc laser. During the test cuts, we changed the parameters by reducing the energy intake. The holes shown in **Figure 3.** were made with different speeds and power. Because of the much smaller wavelength, the heat absorbed by the material was higher when using similar parameters, so the disc laser cut was significantly faster. This is very important for productivity. On the test pieces, it can be clearly seen that the quality of the hole edge is much better, the quality of the piece during the visual inspection was far superior to the quality of the reference piece. However, some parameters also had splashes. **Figure 4.** clearly shows the surface quality of the hole, with no splashes or adherent slag is visible on it. The thickness of the melt layer is below the 60μm permissible value. This is also evidenced by the metallographic image of the hole shown in **Figure 5.** For visual inspection, both the rim and the surface of the hole are suitable. However, with reduced performance, spatter appeared on the surface. Lower power cuts resulted a significant amount of post-work removable splattering.

The cutting gas was not able to properly blow out the melt everywhere, causing spatter. The result of this shown in **Figures 6.** By changing the focus distance, a drastic reduction in hole surface quality can be seen in **Figure 7.** It can be seen that the roughness of the surface has increased, and spatter has appeared on both the hole edge and the surface of the sample.

In total, visual inspection and light microscopy show that the surface roughness of most of the holes made with a disc laser is lower than that of the holes made with CO_2 laser, but since these components will be expose to cyclic heat load, the result of light microscopy is not enough, because

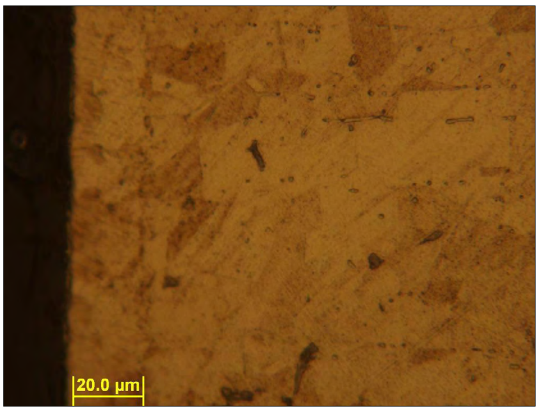

Figure 5. *Melted zone of the hole cut with disc laser*

the microcracks are not detectable with it, so in the following I took pictures with a much higher resolution and depth of field scanning electron microscope. The holes were cut with water jet cutting to minimize heat input. The surface of the cut holes was ready to examined under a scanning electron microscope, which is capable of producing images of much larger magnification and resolution. High-resolution images can also detect segregation, cracks, and material defects that are not visible under a light microscope.

These pictures show that the holes made with the disc laser has a high quality on the outside but has a small and dangerous defect. There are microcracks transverse to the surface of the hole centerline. Such defects can propagate under cyclic heat stress and can even lead to component failure. We also found cracks in the cuts made by the CO_2 laser, but they are so small and so few that they are within the tolerances specified by the customer. However, in the case of disk laser, the number of cracks is above the value accepted for a CO_2 laser, so these cuts do not correspond. **Figure 8.** clearly shows that there is a relatively large number of cracks on the surface of the remelted zone, all transversely located, often at the center of the sheet thickness.

To determine the length and width of the cracks, I took pictures at a higher magnification. **Figure 9.** clearly shows that the length of the cracks ranges from 30 to 80 µm and their width is from 2 to 4 µm.

Figure 6. *Spatter on the rim of the laser cut hole in the disc (ø 6,2 hole)*

Figure 7. *The cut made with disc laser, with changed focus distance from the centerline(ø 13,6 hole)*

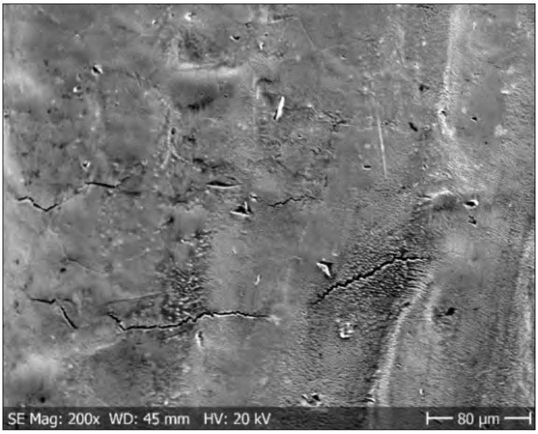

Figure 8. *Cracks on the surface of the cut after cutting with disc laser (SEM recording)*

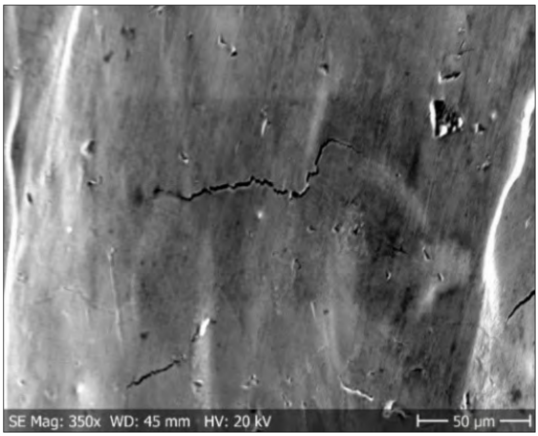

Figure 9. *Cracks on the surface of the cut after cutting with Disk laser (SEM recording)*

Images of the cuts examined by electron microscopy show a similar tendency, with cracks between 30 and 100 µm in length and 2–4 µm in width. However, the depth of the cracks cannot be determined from microscopic images. So far, only CO_2 laser cuts and a disc laser variable has been investigated. Further destructive material testing of the other process variables will also be performed. Based on the available data and the literature, I was able to determine the cause of the cracks.

Referring to the literature, one of the possible cause of cracks appearing on laser-cut surfaces is the formation of layers formed during the rolling of the raw material, which would explain the transverse cracks perpendicular to the holes in the bore. However, in higher magnification, it became apparent that the cracks are essentially fragmented (**Figures 8.** to **9.**) and are not bound to a certain zone in the case of disk laser cutting, but are scattered across the entire surface of the hole so the probability of this option is low.

The second option is the so-called liquation cracking. John C. Lippold **[8, 9]** dealt with this topic in depth. In highly alloyed materials may can forming of different types of carbides in the partially melted zone during welding or cutting, depending on the composition of the raw material. These carbides, such as niobium carbide, titanium carbide, or chromium carbide, have a higher melting point than the material around them, so carbides are not melted in the partially melted zone they cause cracks in the melt during solidification, but neither the Nb nor Ti are present in the material we investigate, the chromium carbide precipitation may appear as the rightmost crack in **Figure 8**, but typically the carbide characteristic was not detected in the cracks. in Austenitic steels if the seam ferrite content it reaches 5-10% usually no cracks occur if the heat input is not too high and the surface is not concave **[10]**, but unfortunately there is no consumables in our samples, the surface is concave, and we have high nitrogen intake which is austenite formation.

Most of the cracks on the surface of the holes were in the middle zone of the sheet thickness, so the shrinkage of the molten zone during cooling may play an important role.

5. Summary

On the basis of the examinations it can be stated that the holes made by disc laser were visually superior, the melt zone thickness was less than 40 µm in all samples, but no cracks was found during the metallographic examinations. Only scanning electron microscope shows the presence of cracks. The surface and edge of the hole made with CO_2 laser were of lesser quality, but there were no micro-cracks on the surface of the hole. Although it looks inferior in quality to visual inspection, on the surface of the hole is much less crack can be seen. Spatter and adherent slag can be eliminated with minimal post-working.

Parameter modifications can reduce heat input when using a disk laser to achieve a better surface quality, but to reduce the amount of micro-crack by the modified parameters requires additional testing. On the basis of the present studies, it has been found that components made by a CO_2 laser for industrial use can be used with the present parameters.

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