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The Effect of CO_2 Laser Scan Speed on the Properties of Groove Created on Stainless Steel Plate

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Abstract

In this study, grooves were created on dual-phase steel with a 30 W CO_2 beam at different scanning speeds. The geometric and structural properties of the grooves obtained were investigated. Measurements were made from detailed optical microscope images of the grooves created by laser on the material. In the measurements, the molten region of the groove and the width of the Purple-Brown heat tint, which is one of the heat bands seen in the steel materials during the heat increase, were examined. As can be seen from the graphs of variation of the molten region and the Purple-Brown heat tint against the scanning speed, both the width of the heat band and the width of the melted region decreased linearly as the scanning speed increased. The width of the molten zone remained constant when the scanning speed was 15 mm/s, and the width of the heat tint remained constant when the scanning speed was 25 mm/s.

Keywords:Stainless Steel, CO_2Laser, Laser material interaction, Heat affected Zone, Molten Zone.

1. *Introduction*

In many sectors, especially in the transportation sector, materials that have several features at the sametime are preferred. The most desirable features of materials with such superior properties are that they are light, durable and easy to process. Of course, due to the nature of the materials, for example, if more durable material is desired, it is heavier. Or the more durable material is also not easy to process. For this, alloys and composite materials suitable for different purposes are being developed. The surfaces of the materials can be processed to change their properties such as friction, adhesion or water retention. For surface texturing to be beneficial, careful design of the patterns created on the surface is required, and cost-effective surface texturing methods must be selected (Costa and Hutchings 2014). Gao et al simulated the effect of geometry of dimple patterns created on a polymer material surface on product appearance and scratch resistance (Gao 2018). In many engineering applications, especially in the automobile sector, patterns with different geometries have been created on the surfaces to increase the abrasion resistance of the rubbing surfaces. The production of grooves with micro-dimensional widths can increase the wear resistance of friction pairs. Xu et al. reported that micro-surface tissues of various shapes and depths reduce friction (Xu 2016).
Surfaces can be machined by mechanical and thermal methods such as Vibro Rolling, Reactive ion etching, Abrasive jet machining and Lithography and Lithography and anisotropic etching. However, almost all of these applications have disadvantages. Lasers are frequently preferred in material processing due to reasons such as compactness, no need for extra mechanical materials, no material wear and being applicable to many materials. Today, the most successful method used to texturize surfaces in engineering applications is laser surface texturing (Etsiton 2005). Especially in micro-scale surface

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treatments, lasers can perform high precision and repeatable operations without contacting the material and without encountering the disadvantages of other methods.

Laser selection is made according to the type of material to be processed in laser material processing. The most important parameter in the selection here is the wavelength and intensity of the laser beam. When the laser beam is sent to the material such as steel, the material first heats up, then structural deterioration begins and melts (~1450 °) and evaporates (~3000 °) respectively. Structural deterioration changes from discoloration to softening. Then melting begins. In laser material processing, there are many parameters such as laser energy, frequency, wavelength, intensity, scanning speed, ambient gases, and these parameters affect the final product differently in different processes and different materials.

Dual-phase steels are produced from high-strength low-alloy steels by special processes (Demir 2014). There are martensite phases in the main structure, the main structure of which is soft ferrite. Its content and method of obtaining have been developed according to the intended use. Dual-phase steels have many superior properties according to the steel from which they are obtained. Dual-phase steels are used by many automobile manufacturers in different parts of automobiles. Phases such as martensite and ferrite in dual-phase steel also affect the thermophysical properties of the material. For this reason, examining the effects of laser parameters on the product is the subject of many studies in order to understand the laser-material interaction well.

In this study, micro-scale grooves were created on dual-phase steel material. The width of the formed grooves and the permeability of the heat affected zone were measured. The heat-affected zone (HAZ) is an area of bulk metal that undergoes changes in material properties as a result of exposure to high temperatures. These changes in material property are often the result of thermal effects such as welding, high-temperature cutting, or surface treatment. The HAZ is the area between the molten or ablated portion and the base (unaffected), base metal. In many cases, it is desirable to have this heat-affected zone minimal. Because it is difficult to predict in advance what changes will occur in the microstructure of this region. The intensity and size of the HAZ field can vary depending on the properties of the materials, the concentration and intensity of the heat, and the heat source and process used.

The various HAZ are created by different temperatures in the base metal away from the heat source. This should not be confused with a series of visible colored bands caused by surface oxidation near a weld in stainless steel. The 'temperature colors' represent temperatures much lower than those that make up the heat-affected zone and extend somewhat beyond the actual heat-affected zone. These different colors, also known as heat tints, provide an approximate indication of the temperature reached by the metal. Depending on the type of stainless steel being heated outdoors, the tint colors and associated temperatures are as follows:

Light yellow 290 °C
Straw yellow 340 °C
Yellow Sarı 370 °C
Brown 390 °C
Purple brown 420 °C
Dark purple 450 °C
Blue 540 °C
Dark Blues 600 °C

Heat tint colors depend on the material's resistance to oxidation, metals with higher steel chromium content show less intense coloring as they are more resistant to oxidation. The use of shielding gas and electrode coatings can also reduce heat tone as they partially protect the metal from oxidation. Conversely, rougher surfaces oxidize faster, resulting in darker colors. Also, paint, oil, rust and even fingerprints can change the tone of the heat, although they do not affect the coverage of the HAZ.

2. *Materials and Methods*

In this study, 2 mm thick dual-phase steel plates used in the automobile industry were used. Before the laser was sent on the material, the plates were cleaned with chloroform to eliminate possible accumulated contamination on the material.

The CO_2 laser with a wavelength of 10.6 μm (10600 nm) was used in the air environment in the corrugation process on the steel plates. The grooves were obtained with a constant power of 30 W. The frequency of the laser was set to 50 kHz during the process. The laser scanning speeds were changed from 5 to 10, 15, 20, 25 and 30 mm/s and the effects of laser scanning speed on the shape and structure of the groove were investigated. Air with 0.3 MPa pressure was sprayed to remove the possible vapor that will occur on the material from the material surface. Leica stereo microscope was used to take detailed images of samples.

3. *Results*

The geometries and structures of the grooves obtained by increasing the scanning speed of the laser were examined in detail with an optical microscope. The images and measurements of the laser-grooved surfaces are given in Figure 1. When the groove created by laser on the dual-phase steel material is examined, the molten zone in the middle of the plate and the heat-affected zone towards the outside of the molten zone are seen. The heat-affected zone shows that melting has not started, but there are deteriorations in the base material. These deteriorations can be observed with differences such as roughness or color changes on the material caused by the softening and re-hardening of the material surface. In this study, the color change region within the boundaries of the heat-affected region was taken into account. In more detail, the purple-brown heat tone line, which appears at 420 °C in color change, has been taken into account. The geometries of the grooves obtained on the material were made on the obtained optical microscope images.

Measurements were repeated five times for each scan rate and the average of the measurements was taken. The figures show a molten and/or evaporated zone (indicated by yellow arrows) and a heat-affected zone (indicated by blue arrows) in the middle of the trough. The mean of the five measurements is given in Table 1. The graph showing the effect of the scanning speed of the laser beam on the geometry and structure of the groove obtained on the material according to the data in the table is given in Figure 2.

Table 1. Graph showing the effect of the scanning speed of the laser beam on the geometry and structure of the groove obtained on the material. (A) Average width of molten and/or evaporated zone, (B) Average width of violet brown Heat tint.

Speed (mm/s)	**(A) (μm)**	**(B) (μm)**
5	220	336
10	184	301
15	155	260
20	155	240
25	151	220
30	149	226

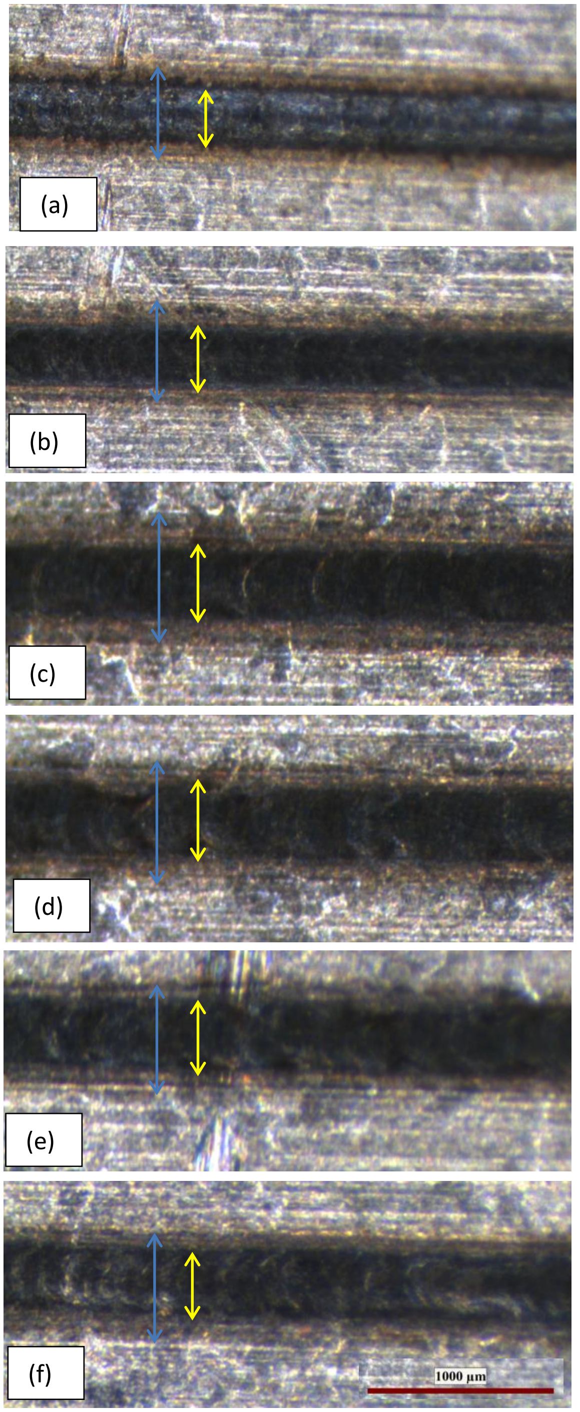

Figure 1. Optical microscope images and measurements of the grooves created with the CO_2 laser on dual-phase steel material with different scanning speeds. Scan speeds, (a) 5 mm/s , (b) 10 mm/s, (c) 15 mm/s, (d) 20 mm/s, (e) 25 mm/s, (f) 30 mm/s,

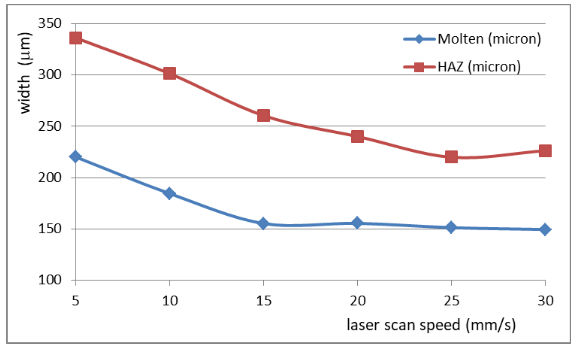

Figure 2. As can be seen from the change graph, the width of the molten region decreased linearly up to a scanning speed of 15 mm/s. At values above 15 mm/s, the width of the molten zone remained almost constant. The Violet-Brown heat tone line studied in this study decreased almost linearly up to a scan speed of 25 mm/s. After this value, the heat tone line remained almost constant as in the molten region.

Velocity-width changes obtained from measurements made on optical microscope images are given in Figure 2. The effect of the molten region of the groove and the width of the Violet-Brown heat tone line depending on the laser scanning speed.

4. *Discussion*

In this process with low heat input, the material cooled faster and resulted in a smaller HAZ, while high heat input had a slower cooling rate and resulted in a larger HAZ in the same material. Also, the size of the HAZ increased as the speed of the transaction decreased. The diameter and intensity of the laser beam is another factor that plays into the size of the HAZ as it affects the heat sink, and a larger heat sink material usually leads to faster cooling.
The reason why the width of the molten and/or vaporized region is observed in a narrower area than the laser spot width is that the distribution of the energy sent by the laser beam within the spot is not homogeneous but has a Gaussian distribution.
ince the division is troubled in rings except for fields,

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