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Investigation of the Effects of the Different Laser Powers on the Steel Surface

Timur CANEL [1*]

[1] Kocaeli University, Faculty of arts and Science, Physics Department, Umuttepe-İzmit-Kocaeli-Türkiye

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Laser machining,
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Laser Ablation.

Abstract: In this study, grooves were created on a 3 mm thick steel plate by using a carbon dioxide laser at different laser powers at a constant speed. High-resolution images of the laser-processed surfaces were taken with a high-resolution stereo microscope. The molten zone and heat-affected zone widths of the troughs were measured using the images. To reduce the error rate, measurements were made from 5 different regions on the obtained grooves. Finally, the changes in the molten zone and heat-affected zone widths against the applied laser power were examined graphically. As a result, it has been observed that the widths were increasing by laser power with slowing down. Heat Affected Zone and Molten zone widths have changed at the same rate. As the energy transferred to the material surface increases, both the Heat Affected Zone and the molten zone width has increased. The applied laser power has been studied from 40 W to 115 W. Heat Affected Zone Size increased almost linearly when laser power was increased from 40 W to 80 W. It has been observed that the HAZ size increase was less for higher power values.

Çelik Malzeme Yüzeyinde Farklı Lazer Güçlerinin Etkisinin İncelenmesi

Anahtar Kelimeler:
Lazer işleme,
Çelik,
CO2 Lazer,
Yüzey Tekstüre Etme,
Lazer Aşındırma

Özet: Bu çalışmada, 3 mm kalınlığındaki bir çelik levha üzerinde farklı lazer güçlerinde ve sabit hızda karbondioksit lazer kullanılarak oluklar oluşturulmuştur. Yüzeyler lazer ile işlendikten sonra yüksek çözünürlüklü mikroskop ile yüzeylerin görüntüleri alınmıştır. Olukların erimiş bölge ve ısıdan etkilenen bölge genişlikleri, görüntüler kullanılarak ölçülmüştür. Hata oranını azaltmak için elde edilen oluklar üzerinde 5 farklı bölgeden ölçüm yapılmıştır. Son olarak erimiş bölge ve ısıdan etkilenen bölge genişliklerinin uygulanan lazer gücüne karşı değişimi grafiksel olarak incelenmiştir. Genel olarak lazer gücü ile genişliklerin yavaşlayarak arttığı gözlemlenmiştir. Isıdan Etkilenen Bölge ve Erimiş Bölge genişlikleri aynı oranda değişmiştir. Malzeme yüzeyine aktarılan enerji arttıkça hem Isıdan Etkilenen Bölge hem de eriyik bölge genişliği artmıştır. Uygulanan lazer gücü 40 W ila 115 W arasında incelenmiştir. Lazer gücü 40 W'tan 80 W'a çıkarıldığında Isıdan Etkilenen Bölge Boyutu neredeyse doğrusal olarak artmıştır. Daha yüksek güç değerleri için HAZ boyut artışının daha az olduğu gözlemlenmiştir.

**İlgiliyazar:* tcanel@kocaeli.edu.tr
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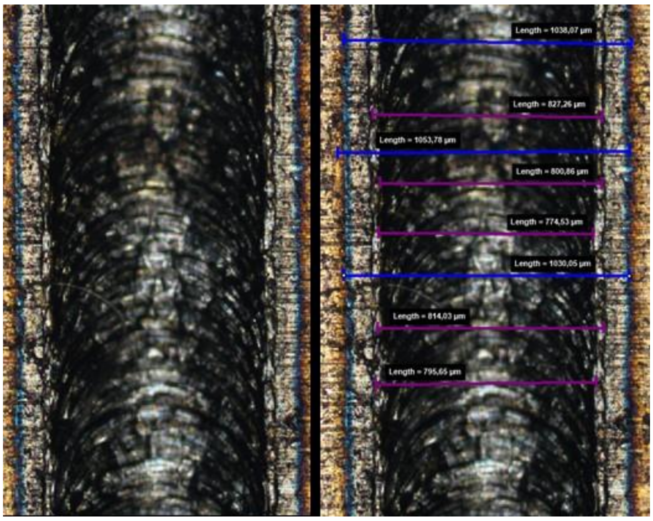
GRAPHİCAL ABSTRACT



1. INTRODUCTION

Steel, which is used in many areas in the industry, is an alloy consisting of iron (Fe) and around 1% carbon (C) composition. Depending on the usage requirements, different elements such as magnesium, chromium, vanadium and tungsten can also be used in the steel alloy (Adams, 1983). The elements added to the alloy change the microstructure of the steel and contribute to the property of the steel according to usage requirements (Musfirah and Jaharah, 2012). Components in different proportions added to the alloy provide different additives to the steel. (improvement, normalization, etc.). (Narsimharaju et al., 2022). Manganese (Mn), Phosphorus (P), Sulfur (S) and Silicon (Si) are elements originating from the raw material during production and are found in certain proportions within the steel (Gardner, 2005). Other elements (Cr, Ni etc.) are added to the steel structure in desired amounts in the form of ferroalloys. Steel is produced in two ways by recycling from iron ore or scrap. After the liquid steel is produced, it is shaped as ingots by casting or as billet or blooms by continuous casting (Choudhary and Ganguly).

Specialized Steels are unalloyed, low-alloyed and alloyed steels and differ from mass-produced steels at some points (Ceau et al., 2010). The basic properties of steel can be summarized as follows; almost all types of steel are sensitive to heat (Tabernero et al., 2020). In addition to the chemical composition, as a result of the heat treatments applied, the desired hardness, mechanical and physical properties, electrical properties, corrosion and high-temperature resistance properties can be fully achieved (Aboulkhair et al., 2016)

Steels have resistant to impact and deformation and must be heated to a certain temperature to shape them (Rogers., 1979). They can be easily shaped by methods suitable for this temperature (rolling, pressing, forging). In addition, steels can be cold formed using methods such as rolling and pressing in accordance with the chemical composition and internal structure (Morozov et al., 2007). It can be brought to the desired shape and surface smoothness by processing on-chip remover benches. Steels can be welded. Most of the steels are suitable for metal coating, enameling, painting and coating with plastic materials by various methods.

To prevent excessive wear of the machine equipment used in contact in the industry, they must be compatible with each other in composition (Tung and McMillan., 2004). In addition, having the same wear rates of the machine equipment are also desirable because, at the same time, the replacement and repair times of the wearing parts are the same. This is achieved by using parts that are compatible with each other. (Zarei et al., 2009). This also saves time. It is possible to reduce the amount of wear on machine parts by hardening the material surface or by controlling the friction coefficients of the surfaces. In some cases, instead of hardening the entire machine part, only the contacting surfaces can be hardened to reduce costs. As a result of the surface hardening process, with the increase in the resistance of the part to wear, the volume expansion is minimized, the danger of warping of the part is reduced and an increase in the failure strength of the part is observed. Because an increase in volume is observed in the layer on the hardened surface of the part and it pulls the surface towards the interior of the part and compressive stresses occur on the surface (Altenberger, 1999); When the part is forced to bend or pull periodically during operation, the average stress intensity on the surface will decrease as a result of these pressure stresses, so the part becomes resistant to fatigue. The aim of this study is to investigate the effect of applied laser power on Heat Affect Zone Size on the steel surface.

2. MATERIAL AND METHOD

First of all, excessive structural defects on the surfaces of the 3 mm thick steel plates were removed. Then, the surfaces were cleaned with chloroform. With the CO_2 laser with a laser spot diameter of 220 µm, beams of different strengths were used and thus grooves were formed. The scanning speed of the laser with a maximum power of 130 W was kept constant at 10 mm/s. After creating grooves on the surface with the laser, the surfaces were examined without chemical or mechanical treatment. The heat Affected Zone on the surface of the material was studied by observing the high-resolution microscope images. In this study, only the thermal effects on the surface were examined. Effects in deeper areas below the surface have not been studied. Plate surfaces were visualized with a high-resolution optical microscope and the widths of the melted zone and the Heat Affected zone were measured on the images. To reduce the error rate, measurements were made from five different places on the groove and the average of these five measurements was taken.

3. RESULTS AND DISCUSSIONS

In Figure 1a, an optical microscope image of the steel surface scanned with a 40-Watt laser beam at a speed of 10 mm/s has been given. As can be seen in the figure, the measurements were taken from five different parts of the groove. The mean widths of the molten zone and the heat affected zone were calculated as 127.7 µm and 169.22 µm, respectively. The diameter of the laser beam used is 220 µm.

The width of the heat-affected zone is 127.7 µm, indicating that the energy distribution in the laser beam is not homogeneous. Towards the edges of the laser spot, which is considered circular, the energy of the beam decreases in the radial direction (Shi et. Al., 2021). Since the energy distribution of the beam of the laser used is Gaussian, the width of the molten region and Heat Affected Zone have been smaller than the laser spot size since the energy decreases rapidly as it moves away from the center of the spot (Taberno et. Al., 2012).

As seen in Figure 1b, when Laser Power was adjusted to 55 Watt, both molten zone width and Heat Affected Zone width increased and both widths have become larger than the spot size. At energies higher than this energy value, molten zone boundaries and Heat Affected Zone boundaries can be observed more clearly.

Since the laser beam power has now reached sufficient energy for both molten zone formation and heat-affected zone formation when the laser beam power was set to 70 watts, as seen in Figure 1c that the groove width formed homogeneously. Figure 1c also shows overlapping spot lines, referred to as the "semi-circular (C-shape or weave Bead)", inside the groove (Ganini et. Al., 2007).

Optical microscope images of the surfaces obtained with 80, 95 and 115 Watt laser beams are also seen in Figures 1d, e and f respectively. As can be seen from these figures, the molten zone and heat-affected zone widths also increased when the laser beam power increased.

The measured molten zone and heat-affected zone widths for all laser powers used have been given in Table 1 and Table 2, respectively.

The size of the Molten and Heat Affected Zone changed according to the applied laser beam power from 40 Watt to 115 W were presented in the graph in Figure 2.

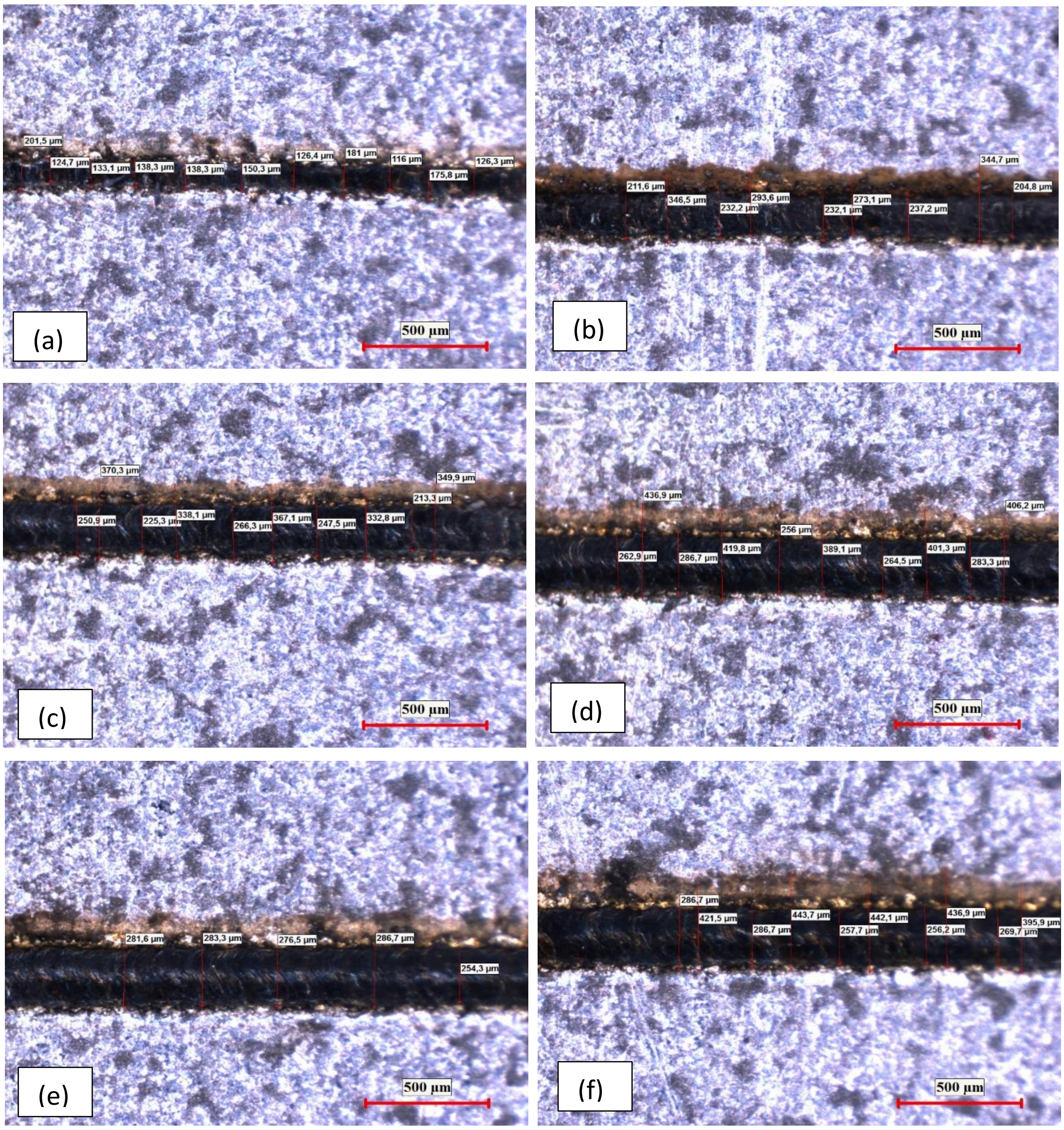


Figure 1. The optical microscope images of the steel surface that were scanned with (a) 40-Watts, (b) 55-Watts, (c) 70-Watts, (d) 80-Watts, (e) 95-Watt laser beam, (e) 95-Watt laser beam.

Table 1. Width of the molten region.

	Measurements					
Power (Watt)	1st	2nd	3th	4th	5th	Average (µm)
40	124.7	133.1	138.3	126.4	116.0	127.70
55	216.6	232.2	232.1	237.2	204.8	224.58
70	250.9	225.3	266.3	247.5	213.3	240.66
80	262.9	286.7	256.0	264.5	283.3	270.68
95	286.7	286.4	257.7	256.2	269.7	271.34
115	281.6	283.3	276.5	286.7	254.3	276.48

Table 2. Width of Heat Affected Zone.

	Measurements					
Power (Watt)	1st	2nd	3th	4th	5th	Average (µm)
40	201.5	150.5	181.0	175.0	138.3	169.22
55	346.5	293.6	273.1	344.7	315.1	314.60
70	370.3	338.1	367.1	332.8	349.9	351.64
80	436.9	419.8	389.1	401.3	406.2	410.66
95	421.5	443.7	442.1	436.9	395.9	428.02
115	436.2	438.1	432.6	440.5	437.9	437.06

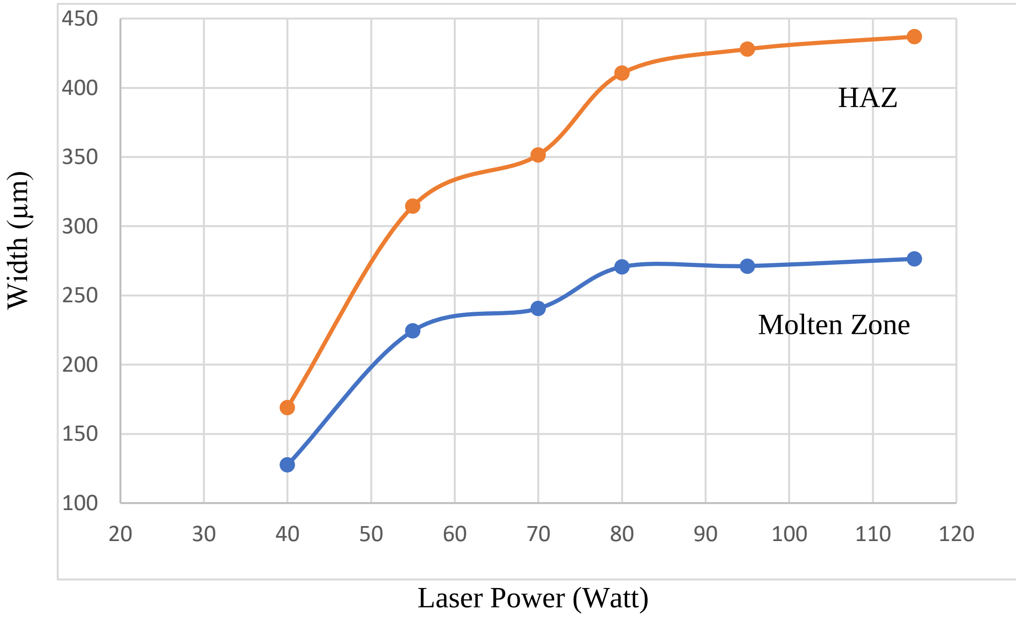


Figure 2. The size of the Molten and Heat Affected Zone changed according to the applied laser beam power from 40 Watt to 115 W

4. CONCLUSION

When the change in the molten zone and Heat Affected Zone width are analyzed as a whole, it is seen that as the applied laser power increases, the rate of increase in the width of the groove decreases. The applied laser power has been studied from 40 W to 115 W. Heat Affected Zone Size increased almost linearly when laser power was increased from 40 W to 80 W. For higher power values, the HAZ size increase is very small. Especially after 80 W, although the width of the Heat Affected zone increased slightly, the molten zone width didn't increase at all

One of the reasons for this may be that when the melt pool reaches a certain amount, the heat is trapped and the heat flow towards the edges slows down.

Another reason may be that the coefficients assumed as constant, such as the heat transfer coefficient of the material, change with temperature and the heat transfer decreases.

Similarly, another reason may be that the melt pool reaches a certain amount or that the physical constants of the material change with heat, so that the heat transfer decreases in the lateral directions and the increased heat spreads downstream and the cavity depth increases accordingly.

The thermophysical properties of materials change with temperature. This change in the thermophysical properties is prominently observed when the laser power is 80 watts or more. Since the heat loss mechanism on the surface is different from the heat loss mechanism inside the material, the results of this study only cover the surface properties. A comprehensive database for laser-machined steel can be created if the cross-section of the material is examined and the results are compared with the results presented in this article.

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