Fiber Laser Cutting of AISI-304 Stainless Steel: An Experimental Study of the Influence of Process Parameters on Kerf Width and Cutting Edge Quality

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Abstract

Cutting with a laser beam is one of the more modern and precise cutting processes, and the cutting speed and precision are also very high. Inappropriate determination of cutting parameters during the laser cutting process is one of the most significant problems that can arise. This parameter mismatch results in a loss of cut surface quality that is difficult to recover. This decrease in quality is usually caused by problems with the appearance of dross and variations in the width of the surface kerf gap. This study aims to investigate the effect of laser cutting parameters such as cutting speed and nozzle diameter on cutting kerf gaps and cutting surface quality on AISI-304 stainless steel. Nine different sets of experiments were carried out according to a full factorial design of 3^2, two factors, and three levels each. By utilizing the analysis of variance and the substantial contribution of each parameter, the impact of processing factors on kerf width and surface quality is investigated. Based on the findings and results obtained, the cutting speed is the component that has the greatest impact both on the variation of the cutting kerf and the surface quality. Meanwhile, the diameter of the nozzle also plays an important role in determining how the gas flow changes in the process of forming the kerf gaps, which in turn determines the extent to which the laser cutting surface will appear drossy and form striations due to the molten metal flowing on its cutting surface.

Abstrak

Memotong dengan sinar laser adalah salah satu proses pemotongan yang lebih modern dan presisi, serta kecepatan dan presisi pemotongannya juga sangat tinggi. Penentuan parameter pemotongan yang tidak sesuai selama proses pemotongan laser adalah salah satu masalah paling signifikan yang dapat muncul. Ketidaksesuaian parameter ini mengakibatkan hilangnya kualitas permukaan potong yang sulit dipulihkan. Penurunan kualitas ini biasanya disebabkan oleh masalah munculnya sampah logam cair melekat (dross) dan variasi lebar celah garitan permukaan. Penelitian ini bertujuan mengkaji pengaruh parameter pemotongan laser seperti kecepatan potong dan diameter nozel mesin pemotongan fiber laser terhadap celah garitan potong dan kualitas permukaan potong pada pemotongan baja tahan karat AISI-304. Sembilan set eksperimen berbeda dilakukan sesuai dengan desain faktorial penuh 3^2*, dua faktor dan masing-masing pada tiga level. Dengan memanfaatkan analisis varians dan kontribusi substansial dari masing-masing parameter, dampak faktor pemrosesan pada lebar celah garitan dan kualitas permukaan diinvestigasi. Berdasarkan temuan dan hasil yang didapat, bahwa kecepatan potong adalah komponen yang memiliki dampak terbesar baik pada variasi garitan pemotongan maupun kualitas permukaan. Sementara, diameter nozel juga memainkan peran penting dalam menentukan bagaimana aliran gas berubah dalam proses pembentukan celah garitan, yang pada gilirannya menentukan sejauh mana permukaan pemotongan laser akan muncul sampah logam melekat (dross) dan membentuk lurik-lurik (striation) akibat logam cair mengalir di permukaan pemotongan.*

Keywords: Laser cutting; cutting edge quality; stainless steel 304, laser cutting parameters.

1. Introduction

Laser cutting techniques involve concentrating the radiation at a point, known as the "point of maximum energy," to raise the temperature to a level suitable for cutting various materials. In a laser generator, there are components necessary for the process to exist, such as an active medium (atoms or molecules), which is placed between two mirrors, and an excitation source from which this laser beam is formed. This occurs when an excitation source causes atoms or molecules in the active medium to become excited (photon emission). When an electron is placed in an orbit with a lower energy level, the active medium is stimulated by the excitation source, which then triggers a photon incident. This makes electrons give off photons when they drop to a lower energy level [1].

Two types of laser cutting technique devices, namely fiber lasers and CO_2 lasers are currently the most widely used in the industry. CO_2 lasers are part of the laser form of gas; The main distinguishing features are the 1.6 μm wavelength, active media composition, and gas mixture [2]. Using a series of mirrors, the laser beam is aimed at the specimen material to be cut or melted. However, fiber lasers are solid-state lasers that offer significant advantages over traditional laser cutting methods in several important respects, including precision, quality of the cutting surface, speed, and cost [3].

The advantages of laser cutting include the ability to process a wide variety of geometries, the ability to cut a wide variety of metals (aluminum, copper, steel and also superalloys) and non-metals (thermoplastics, rubber materials, polymer composites and woods), relatively high cutting speeds, and low cost [4]. However, the success and quality of laser cutting results are highly dependent on the type of material being cut and the suitability of cutting parameters such as speed, gas type and pressure, and also the diameter of the laser beam. In addition, the heat-affected zone (HAZ) of the plate can also cause thermal damage to the edges.

Stainless steel is one of the materials that has been the focus of various investigations about the laser cutting process. This type of steel is a versatile material that finds usage in a wide variety of industries and applications, such as nuclear industry, food industry, chemical business, textile industry, and medical industry. This material's microstructure is made up of ferrite and austenite, and the combination of these two phases is what enables this material to have the beneficial qualities of both phases. The presence of ferrite contributes to an increase in the tensile strength, and the material demonstrates an exceptional resistance to cracking even when subjected to high levels of stress. In addition, the presence of austenite enhances the resistance of this material to both impact and corrosion.

Li [5] investigated the influence that process parameters including cutting speed, focal length, and laser power had on the temperature near the cutting kerf as well as the surface roughness of a material made of duplex 2205 stainless steel. He found that a laser power that was too high would reduce the surface roughness by approximately 45%. Jarosz et al. [6] investigated the impact of cutting speed on the heat-affected zone (HAZ) and surface roughness of AISI-316L stainless steel during laser cutting. The greatest cutting speed examined (16.5 mm/s) produced a cut surface with acceptable roughness and few heat-affected zones. In accordance with Amaral et al. [7], the lower radiation power of the laser beam combined with a faster cutting speed results in a superior cutting surface quality compared to stainless steel 316L and cold-rolled steel St12.

Type 304 duplex stainless steel material has also been reported in a study conducted by Buj-Corral et al [8], who investigated the correlation of process parameters such as pulse frequency, pulse width, and velocity, to surface roughness, dimensional accuracy, and burr thickness for 0.8 mm thin plate. Jadhav and Kumar [9] also investigated the effect of process parameters, namely laser processing power, cutting speed, and gas pressure, on the surface roughness of AISI 304 material. They stated that gas power and pressure were factors that affected the surface roughness. However, the gas pressure is closely related to the laser machine nozzle, which will affect the pressure applied to the cutting zone so that the material is perfectly cut. However, it is still rare to study the effect of the nozzle on the surface quality of laser-cut products. Therefore, the purpose of this study was to investigate the effect of laser cutting parameters, such as cutting speed and nozzle diameter, on the cutting kerf width and the quality of the cutting surface on AISI-304 stainless steel.

2. Material and Method

A commercial fiber laser cutting machine with a maximum output power of 1000 W, model (GWEIKE LF3015E), was utilized for the experimental test of laser cutting. This experiment made use of a cutting head of the Raytools type for its cutting operations. At an average pressure of roughly 10 bars, nitrogen gas is flows through a co-axial conical nozzle in a continuous circulation. The sample that was used was a plate of AISI 304 duplex stainless steel. The sample used was AISI 304 duplex stainless steel with dimensions of 200 x 150 mm and a thickness of 3 mm. The chemical composition and material properties are described in Table 1.

Table 1. Chemical composition and mechanical properties of AISI 304

Grade		C	Mn	Si	P	S	Cr	Ni
304	Min.	-	-		-	-	17.5	8.0
	Max.	0.07	2.0	0.75	0.45	0.030	19.5	10.5
Density 7900 (kg/m^3) Specific Heat 502 (J/kg.K) Thermal Conductivity 16.2 (W/m.K) Tensile Strength 515 (MPa) Young's modulus 193 (GPa)								

In this study the nozzle used for cutting was a conical type subsonic nozzle with variations in diameter of 1.5 mm, 1.5 mm and 2.0 mm as shown in Fig. 1.

Cutting speed (*v*) is the movement of the cutting head to the workpiece which is set before the cutting process is carried out with variations of 2 m/min, 3 m/min and 4 m/min. By using a full factorial of 3^2, where the parameters that become factors are cutting speed and nozzle diameter with each of the three levels of variation. Table 2 illustrates the low, medium and high level factors of each parameter.

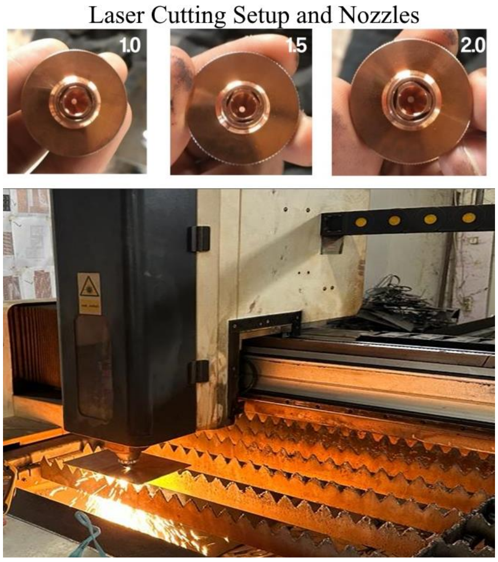

Fig. 1. Experimental setup and variation of nozzle diameter.

Table 2. Factor levels of process parameters.

Factors	Level		
	Low	Medium	High
Cutting speed (m/min)	2	3	4
Nozzle diameter (mm)	1.0	1.5	2.0
Power (W) and Gas Pressure (Bar)	Constan at 1000 W and10 Bar		

In the laser cutting test, there are a total of nine trial sets carried out, each of which is determined by a different combination of cutting parameters. As can be seen in Fig. 2, the procedure of cutting each different parameter variation consists of three repeats.

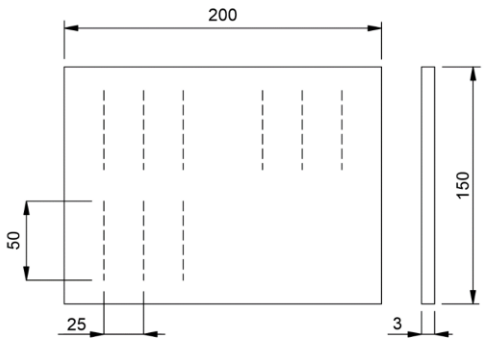

Fig. 2. Dimension of sample and cutting position.

The Digital X-1600 microscope was used to measure and analyze the outcomes of the laser cut in the form of kerf conditions and macroscopic images of the surface section of the laser cut. These results were viewed and measured after the laser cut. The procedure of measuring kerf width consists of taking measurements at 39 different sites spaced every 3 mm along each cutting result for every possible combination of cutting speed and nozzle diameter. The measurement equipment is also utilized in the process of observing the surface quality conditions.

3. Results and Discussion

3.1. Effect of cutting speed and nozzle diameter on the kerf width

A series of experiments were carried out in accordance with the experimental design in order to study the factors that influence the level of quality achieved during the laser cutting process. Table 3 illustrates the influence that each cutting parameter has on the typical kerf width that is generated. With a nozzle diameter of 2 mm and a cutting speed of 4 m/min, it was discovered that a kerf width had been generated, which was then covered up by the non-expelled molten metal. What this signifies is that a 3 mm thick sample was not successfully cut using the specified cutting parameters.

Table 3. Data lebar celah rata-rata pemotongan laser

Nozzle Diameter (mm)	Average kerf width (μm)		
	v = 2 m/min	*v* = 3 m/min	*v* = 4 m/min
1.0	368.46	326.92	301.54
1.5	367.18	338.97	315.38
2.0	392.31	359.49	uncut

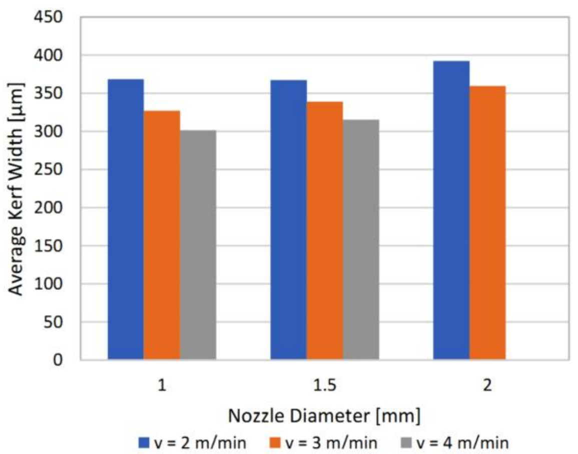

Fig. 3. Influence of nozzle diameter and cutting speed of cutting kerf width.

It is clear from looking at Fig. 3 that the parameter representing the nozzle diameter has a much smaller impact on the formation of the kerf width that results from laser cutting than does the effect of cutting speed. The cutting kerf width will be reduced in range 14% – 18% when the cutting speed is increased, whereas the cutting kerf width will be increased only in range 6% - 9% when the nozzle diameter is increased. So far, because there is no cutting gap formed, a nozzle with a diameter of 2 mm and a cutting speed of 4 m/min cannot be utilized as a comparison. Fig. 4 displays the results of the kerf gap formed in one of the combinations of cutting sets with a cutting speed of 4 m/min and a nozzle diameter of 1 mm.

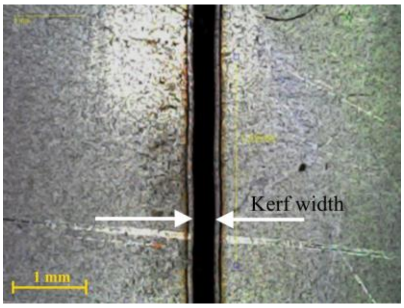

Fig. 4. Top view of laser cutting results at a cutting speed of 4 m/min and a nozzle diameter of 1 mm.

3.2. *Effect of cutting speed and nozzle diameter on the cutting edge quality*

Fig. 5 depicts the quality of the cutting edge of the sample when a nozzle with a diameter of 1 mm was used and the cutting speed was varied. It is impossible to ignore the fact that cutting speed has a significant impact on surface quality. When the cutting speed is low, the topography of the cutting edge is smoother, but when the speed is increased, coarse striation patterns and thick dross attachments build on the cutting surface. This can be seen clearly when the cutting edge is observed in its entirety.

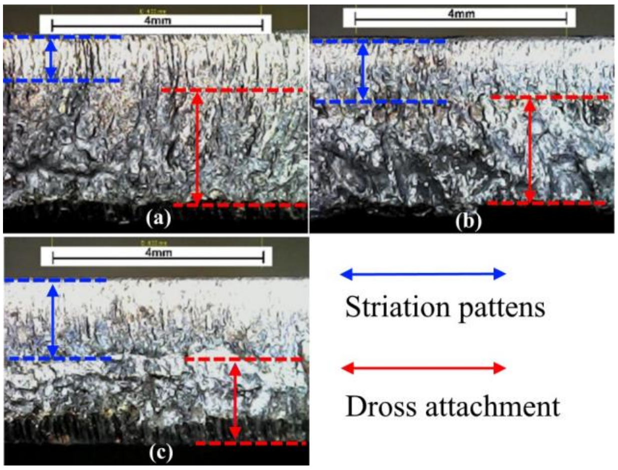

Fig. 5. Morphology of the cut surface with a nozzle diameter of 1 mm and cutting speed: (a) v = 2 m/min; (b) v = 3 m/min; v = 4 m/min;

In particular, the quality of the sample cutting tip with a nozzle diameter of 1.5 mm is displayed in Fig. 6. It is evident that the formation of smooth and even striations begins at a thickness that is approximately 35% of the total plate thickness. But, when the cutting speed is increased, a substantial amount of dross appears to dominate the surface. As can be seen in Fig. 7, in comparison to the use of a nozzle with a diameter of 2 mm, low and medium cutting speeds (2 and 3 m/min) provide a smooth and even striation along the cutting region.

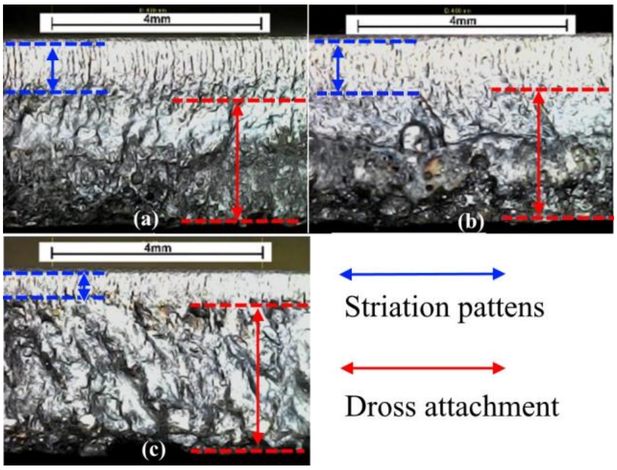

Fig. 6. Morphology of the cut surface with a nozzle diameter of 1.5 mm and cutting speed: (a) v = 2 m/min; (b) v = 3 m/min; v = 4 m/min;

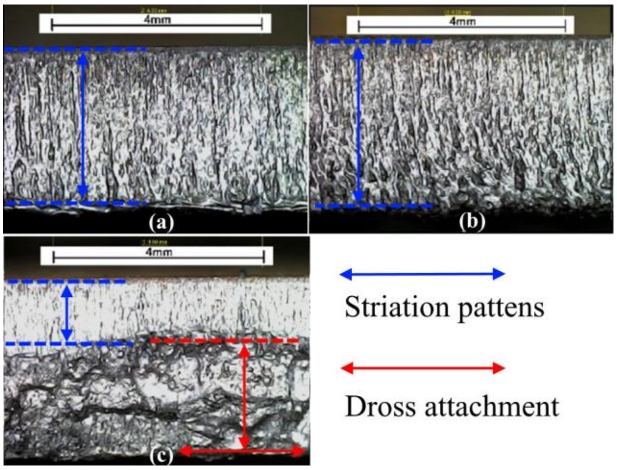

Fig. 7. Morphology of the cut surface with a nozzle diameter of 2.0 mm and cutting speed: (a) v = 2 m/min; (b) v = 3 m/min; v = 4 m/min;

The surface quality that causes striation is smooth and uniform at a low speed of 2 m/min with a big nozzle diameter. This conclusion is based on the three different modifications to the diameter of the nozzle. In addition to this, the dross that is produced in the cutting process is consistently located at the very bottom of the plate. This indicates that the pressure and kerf gap spaces are too narrow, which will make it difficult for the molten metal to flow out completely in the cutting zone, causing it to stick and become trapped at the bottom edge of the plate. This is because the pressure is making it difficult for the metal to flow out completely in the cutting zone. This finding is consistent with the findings of prior research, which discovered that dross always emerges because metal melts slowly out of the cut zone and then solidifies to create thick dross [5, 10, 11]. This finding is consistent with the findings of previous research.

Both the cutting speed and the diameter of the nozzle have a significant impact on the quality of the cut achieved in stainless steel plate cutting. If the speed of cutting is too high, the material will not be cut, spatter will occur, and dross will appear on the bottom surface and stick to it if it is allowed to accumulate. A nozzle that is too small also causes a gap that is too narrow; as a result, liquid dross is unable to escape freely, and it becomes trapped at the bottom of the cutting plate section. When cutting AISI-304 with a thickness of 3 millimeters using a combination of a cutting speed of 2 meters per minute and a nozzle diameter of 2 millimeters, the best surface was obtained. By carefully selecting the optimal cutting speed, one can achieve a high level of surface quality.

4. Conclusion

In this present study, the effect of fiber laser cutting parameters on kerf width and surface quality of a 3 mm thick AISI-304 stainless steel plate was investigated. Cutting speed and nozzle diameter on the laser head are considered process parameters. The cutting speed directly affects the striation pattern and dross attachment shape on the cutting edge surface. When cutting speed is raised, the kerf width is reduced by 14–18%, but an increase in nozzle diameter has a much less effect, increasing the kerf width by only 6–9%. The large nozzle diameter will produce a sufficient kerf width for the process of removing molten metal material during the process. The increase in cutting speed prevents the flow of molten metal from flowing out of the kerf gap, causing dross to form, which degrades the surface quality. However, a high nozzle diameter will produce a homogeneous and good surface and striation pattern. It was found that laser cutting had suitable parameters, and the best for cutting AISI-304 stainless steel with a plate thickness of 3 mm was a combination of a cutting speed of 2 m/min and a nozzle diameter of 2 mm.

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