The Effect of Focal Distance and Type of Auxiliary Gas on Cut Width in CO_2 Laser Cutting of Stainless and Mild Steel Sheets

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Abstract: Lens focal distance and auxiliary gas type utilized in CO_2 laser cutting are two important parameters affecting process measures such as cuts width and quality at desired cutting speeds. This research work focuses on cuts width and quality in CO_2 laser cutting with a power of 4000W on two types of steel sheets at different focal distance values and using different types of auxiliary gas. The effect of focal distances of 5” and 7.5” as well as utilizing oxygen and nitrogen as auxiliary gas on cut width and quality in 304L stainless steel and St37 steel sheets were investigated. The size of cut widths was measured using an optical microscopy. The results demonstrate that cuts performed at the focal distance of 7.5” are wider than those created at the focal distance of 5”. It is also observed that with increased workpiece thickness, the use of focal distance of 7.5” is more feasible because cuts are faster; need lower laser power, and use less amount of auxiliary gas. When using oxygen as auxiliary gas, the main factor affecting the cutting efficiency is the oxidation reaction, whereby oxidation energy is added to laser power which results to an increased energy level in the cutting region. This means that using oxygen as auxiliary gas makes it possible to cut thicker sheets at higher cutting speeds as compared to that of nitrogen. However, when using oxygen as auxiliary gas, the quality of cuts appears to be lower and their width larger as compared to cuts performed by nitrogen auxiliary gas.

Keywords: CO_2 Laser Cutting, 304L Stainless Steel, St37 Mild Steel, Auxiliary Gas, Cut Width

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1 INTRODUCTION

Traditional cutting techniques have been in use for generations but with advances in technology, novel metal cutting techniques such as laser, plasma and water jet cutting were introduced to different industries such as automotive, aerospace, biomedical, electronics, etc. Laser cutting is a process whereby a laser beam is used for cutting various objects through focusing a powerful laser beam on the desired location of the workpiece. The location affected by the laser beam is melted and subsequently molten material is removed due to the pressure of utilized auxiliary gas, thereby creating a clean cut on the workpiece material.

Laser, which is an abbreviation of "Light Amplification by Stimulated Emission of Radiation", in its simplest form, is made from two mirrors parallel with each other to create a light oscillator. Laser emission takes place by excitation of the active medium also known as laser medium between the two parallel mirrors. There are various types of laser including gas laser, chemical laser, radioactive laser, solid-state laser, fiber laser, and diode laser. However, only two types of laser namely gas laser and solid-state laser currently have industrial use. These industrial lasers are also divided into several categories, the most common one being CO_2 gas laser used for cutting and engraving of various metals, plexiglass, glass and other materials [1]. Dimensional accuracy, cut width (kerf), and cut quality are among important process measures in CO_2 laser cutting. Thus, the study of the effect of various process parameters on above process measures is crucial for both academic researchers and industrial users in order to enhance the efficiency and quality of CO_2 laser cutting process.

Librera et al. investigated the quality of cut surface in CO_2 and fiber laser cutting on stainless steel workpieces [2]. Tahir et al. investigated the cut quality of 22MnB5 hard steel based on the size of the heat affected zone (HAZ). They used Behnken experimental design to optimize the process parameters [3]. In another study, Chen et al. [4] investigated the forward cutting-edge temperature and cut quality of Al-Cu alloy using fiber laser while Anicicet al. [5] investigated the effects of various parameters on the size of HAZ and proposed a method for predicting this measure. They investigated the HAZ in different cutting techniques and compared the results with numerical predictions from genetic and neural network algorithm. In another work, Adalarasanet al. investigated the optimization of laser cutting parameters for Al6061/SiCp/Al2O3 composite alloy sheets. They used the Taguchi method and conducted a number of experiments to optimize process parameters including laser power, pulse frequency, cutting speed and auxiliary gas pressure [6]. In another empirical study, Long et al. investigated temperature changes in the cutting process of thin steel sheets using fiber lasers [7]. Petkovićet al. [8] investigated the parameters affecting the size of HAZ in laser cutting. They investigated three main parameters including laser power, cutting speed and auxiliary gas pressure. Choubeyet al. [9] conducted a research on Nd:YAG laser cutting of stainless steel sheets in dry air and underwater conditions. The objective of the study was to optimize the laser cutting process of stainless steel sheets with a thickness range of 4 to 20mm. Scintilla et al. [10] investigated the cutting of Ti6Al4V sheets using fiber laser for butt welding. Li et al. investigated scratchless laser cutting and evaluated the presence of parallel lines on the surface which is one of the important quality factors in steel sheets [11]. Petring et al. investigated the flow of molten metal in the cutting of a 10mm 304L stainless steel sheet using Fiber laser and nitrogen auxiliary gas [12]. They also investigated the effect of laser type and laser power on cutting efficiency of mild steel and stainless steel sheets [13]. Powell et al. studied the effect of alloy elements on laser cutting using oxygen auxiliary gas. They focused on investigating the effects of carbon, manganese and silicon [14]. In another work, Vaziri et al. investigated the effect of Nd:YAG laser parameters on cut quality of 316-stainless steel sheets [15]. Kaplan et al. compared the cost, cutting speed, cutting quality, the possible range of materials, and cutting efficiency using fiber and CO_2 lasers [16]. In another study, Powell et al. investigated the cutting of thin steel sheets using fiber laser and oxygen auxiliary gas [17]. Yilbaset al. investigated the effect of cutting parameters on cut width for laser cutting of mild steel sheets [18]. Vladimir et al. proposed an optimization model for cutting speed and auxiliary gas pressure [19]. Chen et al. investigated the effect of the auxiliary jet on surface quality in laser cutting [20]. Powell et al. investigated the convection heat loss in laser cutting by CO_2 laser [21].

It can be concluded from the review of existing literature that no research work has been reported on the effect of focal distance and the type of auxiliary gas on cut width of 304L stainless steel and St37 mild steel sheets using CO_2 laser. Therefore, the current study aims to investigate the effects of focal distance as well as nitrogen and oxygen auxiliary gas types on cut width in CO_2 laser cutting of above-mentioned steels with a power of 4000W.

2 MATERIALS AND METHODS

2.1. Materials

The materials used in this study include mild steel and stainless steel sheets which are divided into three categories. Group A includes 304L stainless steel sheets which are the low-carbon variant of 304 steel sheets, having carbon content lower than 0.03%. These sheets were used with a thickness of 1, 2, 3 and 4mm with dimensions equal to that of an A4 paper. Cutting of these sheets was performed using nitrogen auxiliary gas with a pressure of 16bar. Group B includes St37 mild steel sheets with a yield strength of 3700 Kg/cm2 and with the same dimensions as stainless steel sheets. Cutting was carried out using nitrogen auxiliary gas with a pressure of 16bar. Group C includes St37 mild steel sheets with similar characteristics to group B with the only difference being that oxygen auxiliary gas with a pressure of 5bar was used for the laser cutting. Experimental conditions used for cutting of steel sheets are presented in "Table 1".

Table 1 Experimental conditions for laser cutting tests

Group	Sheet material	Auxiliary gas	Auxiliary gas pressure (bar)	Sheet Thickness (mm)
A	304L stainless steel	Nitrogen	16bar	1, 2, 3, 4
B	Mild steel St37	Nitrogen	16bar	1, 2, 3, 4
C	Mild steel St37	Oxygen	5bar	1, 2, 3, 4

2.2. Laser Cutting System

The laser used in experiments is a CO_2 laser with a power of 4000W. Two lenses with a focal distance of 127mm and 190mm were employed. Before the start of experiments, it was made sure that the laser beam is focused on the sheet surface. The nozzle diameter of the laser was equal to 1.5mm and kept constant in all experiments. The distance between the nozzle and sheet surface was equal to 1mm.

2.3. Experiments

Each sample was cut 18 times: 9 times with 5" lens on one side of steel sheets and 9 times with 7.5" lens on the other side. Power values of 1000, 2000 and 3000W were applied for cuts on each side, with the first three cuts using 1000W, second set using 2000W and third set using 3000W. It should be mentioned that while the speed applied in each cut was different but the cutting speeds for both 5" and 7.5" lenses were nearly the same for each sheet thickness. After laser cutting experiments were carried out, the width of each cut was observed with an optical microscope with a magnification of 700X.

3 RESULTS AND DISCUSSION

According to instructions by the supplier of utilized laser cutting system, 5" lens is usually used for sheets with thickness up to 3.1mm and higher thicknesses are not defined for the machine. However, in this study, due to necessity and after various safety and technical considerations, machine parameters were changed and sheets with a thickness of 4mm were cut. As shown in "Fig. 1", cuts made on the sheets with a thickness of 4mm using 5" lens have low quality with numerous grooves.

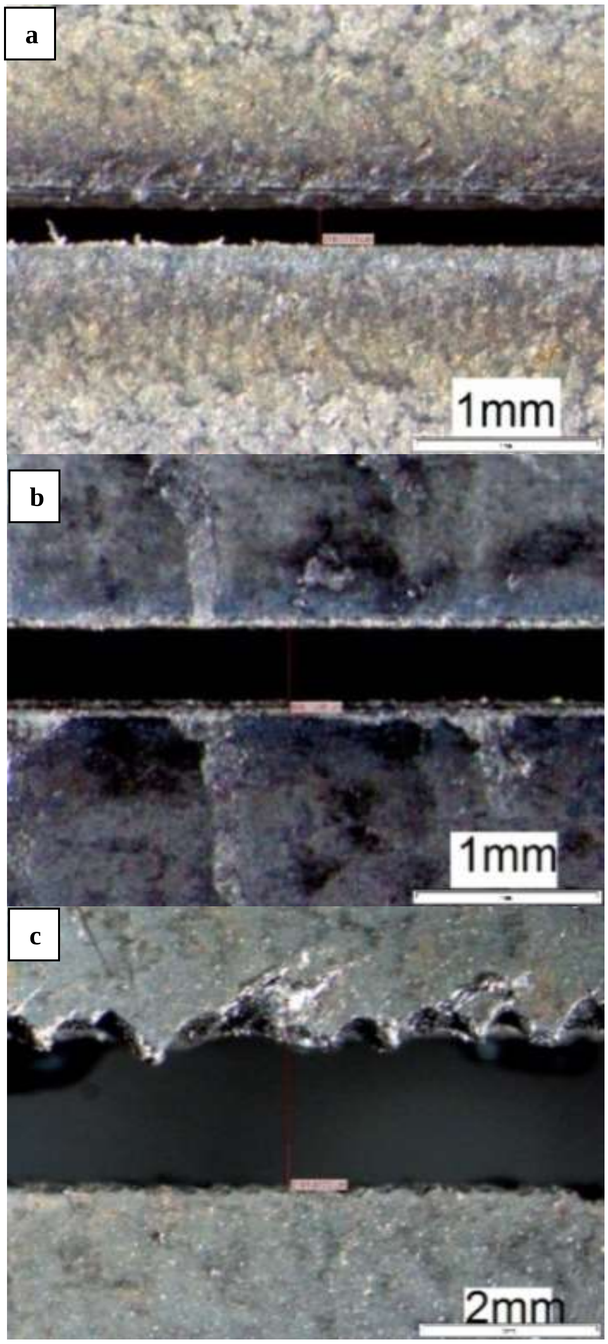

Fig. 1 Cut surface on 4mm sheets using 5" lens: (a): St37 sheet, 2000W, 3000mm/min,O_2 auxiliary gas, (b): St37 sheet, 2000W, 700mm/min, N_2 auxiliary gas and (c): 304L stainless sheet, 1000W, 100mm/min, N_2auxiliary gas.

For cuts with oxygen auxiliary gas, one important factor is the oxidation reaction where the heat of oxidation reaction is added to the laser power and leads to higher powers [21]. This condition results in larger cut widths. Therefore, it is necessary to use lower powers and higher cutting speeds, the results of which are shown in “Fig. 2”.

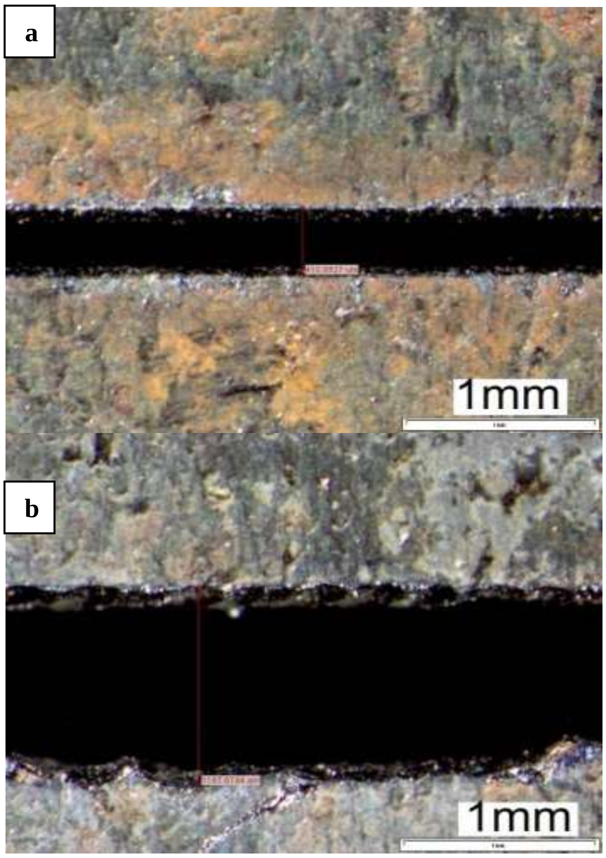

Fig. 2 Cut width on St37 mild steel sheets with the laser power of 2000W, 5” lens, and O_2 auxiliary gas at different cutting speeds: (a): 900mm/min, cut width of 1197microns; and (b):1500mm/min, cut width of 410microns.

Cuts do not normally start at free edges and it is necessary to drill a hole through the sheet as the starting point of the cut. This can be easily done by holding the laser beam at the starting point so that the beam drills through the entire thickness of the sheet. Afterwards, the laser beam starts movement and cuts the rest of the sheet [22]. As depicted in “Fig. 3”, the diameter of the starting hole is significantly higher than the cut width.

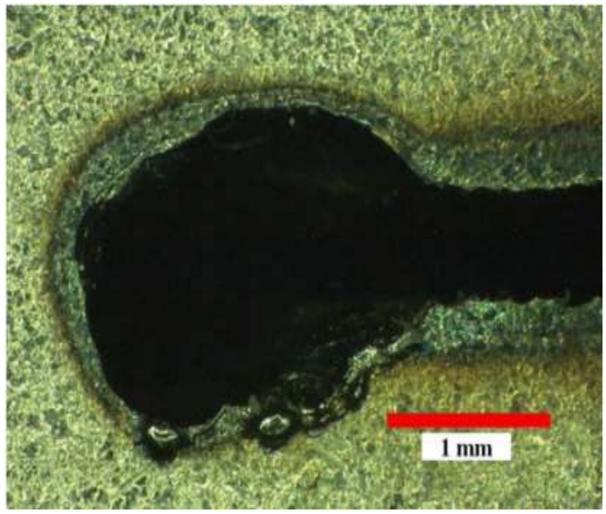

Fig. 3 The starting point of the cut on St37 mild steel sheet with a thickness of 2mm, power of 1000W and oxygen auxiliary gas with a pressure of 2bar [22].

Various studies investigated the parameters affecting laser drilling. The closest process to the holes created at the start of the cut is laser drilling in metal sheets with various thicknesses using Nd:YAG laser with millisecond pulse length and pulse energy of several joules. The fact that auxiliary gas pressure affects the size and shape of the hole due to facilitating the removal of molten metal and reducing the time necessary for drilling is generally accepted. Laser drilling also often uses oxygen auxiliary gas due to the heat of oxidation reaction added to laser power and facilitates the drilling process [22].

Using oxygen auxiliary gas leads to larger starting holes compared to nitrogen auxiliary gas. Figure 3 clearly shows this phenomenon. An increase in laser power, focal distance and gas pressure parameters also affect significantly the initial hole. Figure 4 shows two cases with similar laser parameters with the only difference being the auxiliary gas. It is clear from the figure that the cut performed by oxygen auxiliary gas has a larger starting hole.

Figure 5 shows the front and backside of one of the St37 mild steel sheets cut using nitrogen auxiliary gas. Surface depicted in “Fig. 4a” is the surface directly affected by the laser while surface presented in “Fig. 4b” is the backside of the sheet. The results show that 5” lens is not suitable for thicknesses higher than 3.1mm and the cut surface has low edge quality.

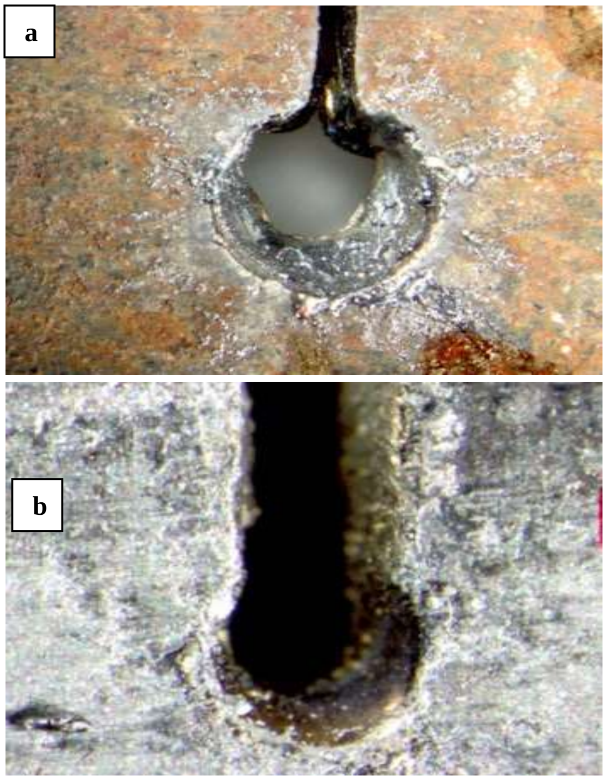

Fig. 4 The initial hole for: (a): oxygen auxiliary gas and (b): nitrogen auxiliary gas.

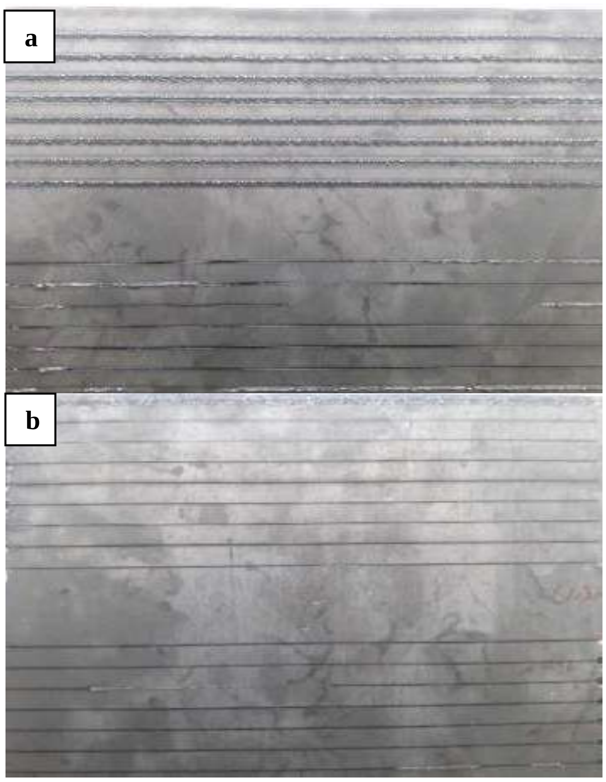

Fig. 5 St37 mild steel sample with a thickness of 4mm. Cuts on the upper part are made with 5” lens while the ones on the lower part are made with 7.5” lens: (a): front side of the sheet and (b): backside of the sheet.

Oxygen and nitrogen auxiliary gases were employed for cutting St37 mild steel sheets. Figure 6 shows the average cut width of St37 mild steel sheets for 5” and 7.5” lenses. It is illustrated in that when using nitrogen as auxiliary gas, the width of cuts performed by 7.5” lens was larger than that of 5” lens. This is due to the larger focal point of 7.5” lens. In contrast, using oxygen gas, the width of cuts made by 5” lens was higher as compared to that of 7.5”. It could be ascribed to applying 5” lens for 4mm sheets, as most of the width measurements were obtained from sheets with 4mm thickness.

Figure 7 shows the average cut width of 304L stainless steel sheets for 5” and 7.5” lenses. As depicted, the average width of cuts made using 7.5” lens is larger as compared to that of 5” lens which is due to the larger focal point of 7.5” lens. The divergence angle of the laser beam in 5” lens is also higher than that of 7.5” lens. In the selected range of parameters, the interaction between diameter and divergence angle of the beam at the presence of auxiliary gas has resulted in significant changes in cut width as shown in “Figs. 6-7”

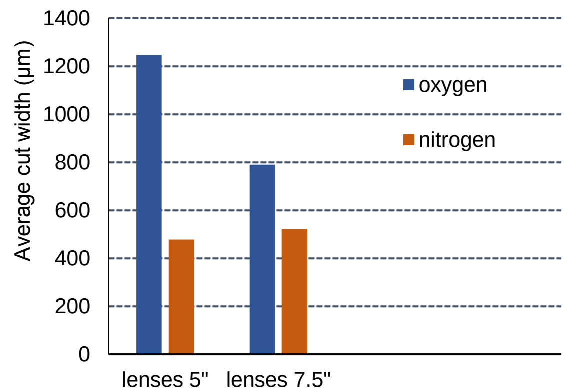

Fig. 6 Average cut width of the upper surface using 5” and 7.5” lenses on St37 steel sheets.

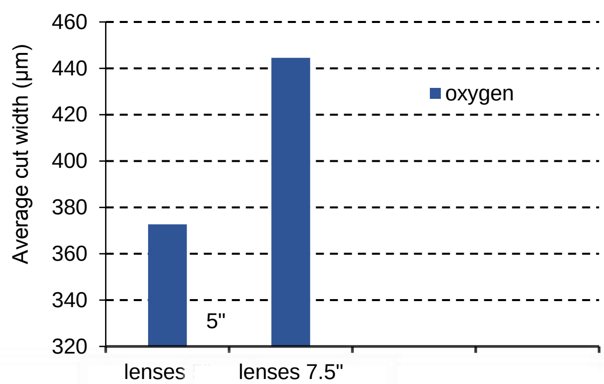

Fig. 7 Average cut width of the upper surface using 5” and 7.5” lenses on 304L stainless steel sheets.

4 CONCLUSION

- In both stainless and mild steel sheets, using nitrogen auxiliary gas and applying the cutting speed ranges used in this study, the width of cuts performed by using 7.5” lens was larger as compared to that of 5” lens which is due to the larger focal diameter of 7.5” lens.
- In the range of selected parameters and using oxygen auxiliary gas, the width of cuts using 5” lens is larger than that of 7.5” lens which is due to the difference in divergence angles of these two lenses.
- With increased sheets thickness, using 7.5” lens is more feasible because the lens can perform cutting with higher speeds at lower laser power and auxiliary gas pressure.
- The most important factor in cutting with oxygen auxiliary gas is the oxidation reaction. The heat produced by the oxidation reaction is added to the heat produced by the laser beam and therefore, the total power applied to the cutting zone increases. As a result, oxygen auxiliary gas makes it possible to cut thicker sheets at a higher speed. However, the cut quality is lower when using oxygen auxiliary gas as compared to that of nitrogen gas.
- When cutting with oxygen auxiliary gas at low speeds, cut width is larger and cut quality is low. This could be attributed to the imbalance between energy and speed in the cutting zone. The results show that the increase of cutting speed up to a certain level, improves the cut quality and reduces the cut width.
- When applying certain values for laser power and sheet thickness in laser cutting experiments, cut widths from largest to smallest are obtained in the cutting of mild steel sheets with oxygen auxiliary gas, mild steel with nitrogen auxiliary gas and 304L stainless steel sheets with nitrogen auxiliary gas.
- Generally, the diameter of the initial hole when using oxygen auxiliary gas is larger than when using nitrogen auxiliary gas.

REFERENCES

[1] Oroumand, Z., Laser and its Applications, DaneshParvar Pub, 2006, pp. 1.

[2] Librera, E., Riva, G., Safarzadeh, H., and Previtali, B., On the Use of Areal Roughness Parameters to Assess Surface Quality in Laser Cutting of Stainless Steel with CO_2 and Fiber Sources, Procedia CIRP, Vol. 33, No. 1, 2015, pp. 532-537.

[3] Tahir, A. F., Aqida, S. N., An Investigation of Laser Cutting Quality of 22MnB5 Ultra High Strength Steel Using Response Surface Methodology, Optics& Laser Technology, Vol. 92, No. 1, 2017, pp. 142-149.

[4] Chen, C., Gao, M., and Zeng, X., Relationship Between Temperature at Cut Front Edge and Kerf Quality in Fiber Laser Cutting of Al–Cu Aluminum Alloy, International Journal of Machine Tools and Manufacture, Vol. 109, 2016, pp. 58-64.

[5] Anicic, O., Jović, S., Skrijelj, H., and Nedić, B., Prediction of Laser Cutting Heat Affected Zone by Extreme Learning Machine, Optics and Lasers in Engineering, Vol. 88, 2017, pp. 1-4.

[6] Adalarasan, R., Santhanakumar, M., and Rajmohan, M., Optimization of Laser Cutting Parameters for Al6061/SiCp/Al2O3 Composite Using Grey Based Response Surface Methodology (GRSM), Measurement, Vol. 73, 2015, pp. 596-606.

[7] Long, N. P., Matsunaga, Y., Hanari, T., Yamada, T., and Muramatsu, T., Experimental Investigation of Transient Temperature Characteristic in High Power Fiber Laser Cutting of a Thick Steel Plate, Optics & Laser Technology, Vol. 84, 2016, pp. 134-43.

[8] Petković, D., Nikolić, V., Milovančević, M., and Lazov, L., Estimation of the Most Influential Factors on the Laser Cutting Process Heat Affected Zone (HAZ) by Adaptive Neuro-Fuzzy Technique, Infrared Physics & Technology, Vol. 77, 2016, pp. 12-5.

[9] Choubey, A., Jain, R. K., Ali, S., Singh, R., Vishwakarma, S. C., Agrawal, D. K., Arya, R., Kaul, R., Upadhyaya, B. N., and Oak, S. M., Studies on Pulsed Nd: YAG Laser Cutting of Thick Stainless Steel in Dry Air and Under Water Environment for Dismantling Applications, Optics & Laser Technology, Vol. 71, 2015, pp. 6-15.

[10] Scintilla, L. D., Palumbo, G., Sorgente, D., and Tricarico, L., Fiber Laser Cutting of Ti6Al4V Sheets for Subsequent Welding Operations: Effect of Cutting Parameters on Butt Joints Mechanical Properties and Strain Behaviour, Materials & Design, Vol. 47, 2013, pp. 300-308.

[11] Li, L., Sobih, M., and Crouse, P. L., Striation-Free Laser Cutting of Mild Steel Sheets, CIRP Annals-Manufacturing Technology, Vol. 56, No. 1, 2007, pp. 193-196.

[12] Pocorni, J., Petring, D., Powell, J., Eckard, D. and Alexander, K., Measuring the Melt Flow on the Laser Cut Front, Nordic Laser Materials Processing Conference, Vol.15, 2015, pp. 25-27.

[13] Pocorni, J., Petring, D., Powell, J., Deichsel, E. and Kaplan, A., The Effect of Laser Type and Power on the Efficiency of Industrial Cutting of Mild and Stainless Steels, Journal of Manufacturing Science and Engineering, Vol.138, 2015, pp. 1-6.

[14] Ivarsona, A., Powell, J., and Siltanen, J., Influence of Alloying Elements on the Laser Cutting Process, Nordic Laser Materials Processing Conference, Vol. 15, 2015, pp. 84-88.

[15] Vaziri, M., Soulati, A., and Bani Mostafa Arab, N., Effects of YAG Laser Cutting Parameters on Cut Quality of 316 Stainless Steel Sheets, J. Modares Mechanical Engineering, Vol. 15, No. 13, 2015, pp. 426-430.

[16] Powell, J., Kaplan, A., A Comparison of Fiber Laser and CO_2 Laser Cutting, Macro Materials Processing, Vol. 69, 2013, pp. 23-27.

[17] Powell, J., Kaplan, A., Mashikhi Al, S. O., and Voise, K. T. Y., Fibre Laser Cutting of Thin Section Mild Steel: An Explanation of the 'Striation Free' Effect", Optics and Lasers in Engineering, Vol. 49, No. 8, 2011, pp. 1069–1075.

[18] Yilbas, B. S., Karatas, C., Uslan, I., Keles, O., Usta, Y., Yilbas, Z., and Ahsan, M., Wedge Cutting of Mild Steel by CO_2 Laser and Cut-Quality Assessment in Relation to Normal Cutting, Optics and Lasers in Engineering, Vol. 46, No. 10, 2008, pp. 777-784.

[19] Vladimir, A., Karasev, E., Influence of Basic Parameters of Metal Cutting with a Gas Laser on Process Energy Efficiency, XV International Symposium on Gas Flow, Vol. 5777, 2005, pp. 864-873.

[20] Chen, K., Yao, Y. L., and Modi, V., Gas Dynamic Effects on Laser Cutting Quality, Journal of Manufacturing Processes, Vol. 3, No.1, 2001, pp. 38-49.

[21] Ivarson, A., Powell, J., Kamalu, J., and Magnusson, C., The Oxidation Dynamics of Laser Cutting of Mild Steel and the Generation of Striations on the Cut Edge, Journal of Materials Processing Technology, Vol. 40, No. 3-4, 2000, pp. 359-374.

[22] Hashemzadeh, M., Powell, J., and Voisey, K. T., Fibre Laser Piercing of Mild Steel–The Effects of Power Intensity, Gas type and Pressure, Optics and Lasers in Engineering, Vol. 55, 2014, pp. 143-149.