The Analysis of Fiber and CO_2 Laser Cutting Accuracy

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Abstract The aim of the conducted research was to compare the functional properties and the cutting accuracy of items produced using Fiber lasers in comparison with CO_2 lasers. The object of 6 mm thick sheet plates made of S235JR steel cut with the two different laser types were analyzed. The tests covered dimensional accuracy (in accordance with the PN EN 22768-fH standard) and the surface after cutting (in accordance with the PN-EN ISO 9013: 2017-04). The results of the analysis have demonstrated that for the same welding linear energy, more accurate cutting surface is obtained using Fiber laser cutting.

1 Introduction

The laser technology was applied for the first time for cutting of steel sheets using CO_2 laser. It took place in 1967 [1]. Thanks to advancements in the design of laser devices the laser cutting technology has become one of the basic technologies of cutting engineering materials [2]. CO_2 lasers have been used for a long time for laser cutting, but recently Fiber lasers have become more and more popular [3-4].

List of basic parameters of CO_2 and Fiber lasers is shown in the Table 1. Fiber lasers are characterized by significantly lower BPP (Beam Parameter Product). The most favorable BPP value for Fiber lasers is achieved for the power of up to about 3-4 kW. Above this value of power BPP starts to increase (i.e. the beam quality decreases). However, for cutting with a power of about 1 kW, the BPP is characterized by about 50% better value for Fiber lasers as compared to CO_2 lasers.

Fiber lasers emit about 10 times shorter wavelengths than CO_2 lasers. Shorter wavelength improves the laser beam absorption coefficient. Thanks to the lower BPP and shorter wavelengths, cutting with Fiber lasers can be faster and more accurate [2]. As a result of the increase in the laser beam absorption, through the use of a laser that emits a shorter wavelength laser beam, the scope of cut materials is also broadened by e.g. copper, nickel and its alloys, as well as composite materials such as Kevlar coated sheet metal [2].

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Fiber lasers do not require such frequent servicing. From the list presented in Table 1 it follows that Fiber lasers can operate without the need for servicing 5 times longer. This solution reduces machine downtime as well as lowers service costs.

The downside of Fiber lasers is their higher purchase cost, which can be more than twice as high as for CO_2 type lasers. However, thanks to high energy efficiency (about 30%), high quality of the beam when cutting with power of up to 4 kW and other advantages of the aforementioned Fiber lasers, the demand for them on the market and the interest in their use is growing.

The aforementioned advantages of Fiber lasers as compared to CO_2 lasers result also in the possibility to obtain better quality of the cut surface. It should be borne in mind that better surface quality obtained after laser cutting can contribute to the elimination of the need for additional machining. The quality of the surface is also of great importance for the surface preparation for various types of connections, for example adhesive ones [5-6] as well as for preparation of various types of specimens, e.g. for destructive tests [7].

Table 1. Comparison of basic physical properties and technical parameters of CO_2 and Fiber lasers [2]

Laser type	**Laser source**	**Length of emitted wave, µm**	**Beam transfer**	**Laser mobility**	**Output power, kW**	**Energy efficiency, %**
CO_2	gas mixture	10.6	mirrors, lenses	low	up to 50	5-8
Fiber	admixtured fiber	1.07	fiber, lenses	high	up to 50	20-30
Laser type	**The BPP for laser power of 1.0 kW, mm/mrad**	**The BPP at max. laser power, mm/mrad**	**Required frequency of periodic inspections of the equipment, in h**	**Approximate cost of the laser per 1.0 kW of power, 1000 USD**	**Surface area occupied by the device**	**Typical diameter of transporting fiber, µm**
CO_2	3.7	3.7	2 000	60	very high	-
Fiber	1.8	12	10 000	130-150	low	100-200

Studies available in the professional literature concerning tests on surfaces obtained using various types of lasers demonstrate that the accuracy of the cut depends mainly on the roughness. In the study [8] on the surface quality after cutting with Nd-YAG laser, it was shown that the surface roughness increases with the increase of the cutting speed. It depends also on the frequency of the pulse as well as on its length. In other studies [9] authors observed that the surface roughness after cutting with Slab type CO_2 gas lasers was sometimes increasing and sometimes was falling with the increase of the cutting power. Other researchers [10] determined optimal cutting parameters without roughness measurement. However, the standard [11] clearly states that the mean height of the profile Rz5 and the value of the perpendicularity tolerance of the surface after cutting „u" are used to qualify the cutting accuracy.

The authors of this paper compared the functional properties and the accuracy of cutting using Fiber lasers in comparison with CO_2 lasers. Surfaces of 6 mm thick sheet metal plates made of S235JR steel were analyzed after cutting. The tests included the analysis of the manufacturing accuracy in terms of dimensional tolerance (based on the PN EN 22768-fH standard) and surface quality after cutting (based on PN-EN ISO 9013: 2017-04).

2 Research object

In order to conduct a comparative analysis, Figure 1 was prepared, on the basis of which two items were cut from S235JR steel. One was cut with CO_2 laser and the other with Fiber laser. The cutting parameters (Table 2) were selected so that the linear energy in both cases was 55.4 kJ/m. Figure 2 shows photos of the item produced. The item is 6 mm thick.

Table 2. Cutting parameters used for cutting accuracy tests.

	Power, kW	Focus, mm	Pressure, bar	Cutting speed, m/s
CO_2	2.0	Auto	0.8	0.03667
Fiber	2.0	- 1.6	0.6	0.03667

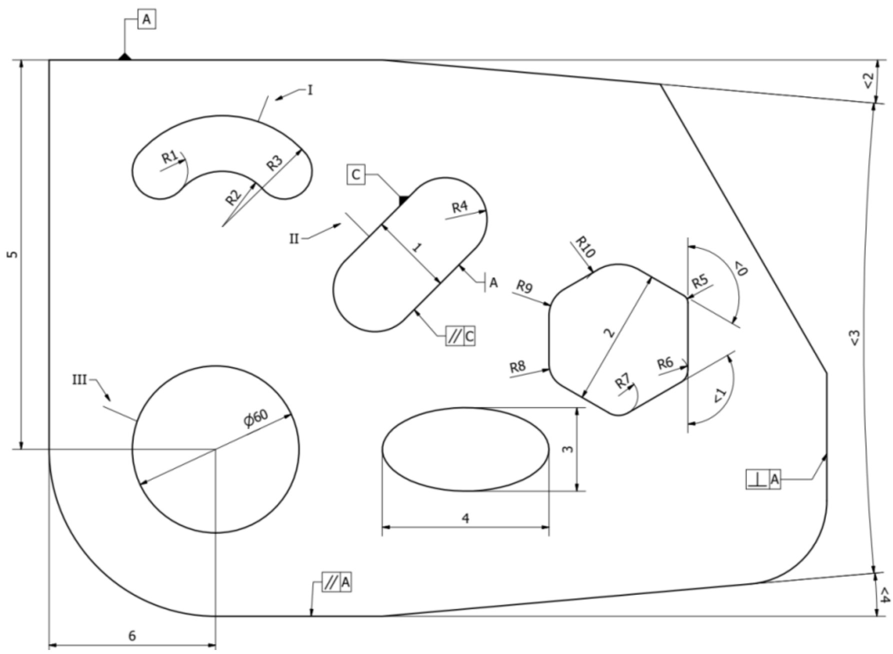

Fig. 1. Detailed drawing of the item

3 Results and discussion

3.1 Measurement of main dimensions after cutting operation

The main geometrical dimensions indicated in Figure 1 were analyzed. Measured radii were marked with R1 to R10 symbols, the lengths with 1 to 6 numbers, angles with <1 to <4 symbols and one diameter was marked as ø60. The tolerance of perpendicularity and parallelism with regard to A and C bases indicated in Figure 1 was also measured. The tests were carried out using Quick Scope CNC machine tools of QS and CRYSTA-APEX S series manufactured by Mitutoyo. Nominal dimensions and actual dimensions of items cut with CO_2 and Fiber laser are listed in Table 3. This table also includes the difference between the nominal dimension N and the actual dimension R and the dimensional tolerances determined in accordance with PN EN 22768-fH standard. The dimensions obtained were compared with the most accurate class provided in the PN EN 22768 series standards [12-13].

Table 3. Nominal and actual dimensions of measured parameters.

Item	Symbol in the drawing	Nominal dimension N	Actual value - R		Difference = N - R		Tolerance
			CO_2	Fiber	CO_2	Fiber	PN EN 22768-fH
1	R1	10M	10.135 mm	10.061 mm	***-0.135***	-0.061	± 0.100 mm
2	R2	20 mm	19.937 mm	20.076 mm	0.063	-0.076	± 0.100 mm
3	R3	40 mm	40.129 mm	39.964 mm	-0.129	0.036	± 0.150 mm
4	R4	15 mm	15.134 mm	15.075 mm	***-0.134***	-0.075	± 0.100 mm
5	R5	3 mm	3.280 mm	2.936 mm	***-0.280***	***0.064***	± 0.050 mm
6	R6	5 mm	5.046 mm	5.017 mm	-0.046	-0.017	± 0.050 mm
7	R7	7 mm	7.242 mm	7.005 mm	***-0.242***	-0.005	± 0.100 mm
8	R8	9 mm	9.122 mm	9.033 mm	***-0.122***	-0.033	± 0.100 mm
9	R9	11 mm	11.109 mm	11.033 mm	***-0.109***	-0.033	± 0.100 mm
10	R10	15 mm	15.270 mm	15.168 mm	***-0.270***	***-0.168***	± 0.100 mm
11	1	30 mm	30.145 mm	30.044 mm	***-0.145***	-0.044	± 0.100 mm
12	2	50 mm	50.030 mm	49.961 mm	-0.030	0.039	± 0.150 mm
13	3	30 mm	30.177 mm	30.157 mm	***-0.177***	***-0.157***	± 0.100 mm
14	4	60 mm	60.201 mm	60.182 mm	***-0.201***	-0.182	± 0.150 mm
15	5	140 mm	139.893 mm	139.962 mm	0.107	0.038	± 0.200 mm
16	6	60 mm	60.024 mm	59.988 mm	-0.024	0.012	± 0.150 mm
17	<0	120°	119°56’09”	119°58’39”	0.064°	0.022°	± 0.500°
18	<1	120°	120°01’52”	120°00’36”	-0.031°	-0.010°	± 0.500°
19	<2	5°	4°57’03”	4°59’02”	0.049°	0.016°	± 0.333°
20	<3	10°	9°59’11”	9°57’08”	0.014°	0.048°	± 0.333°
21	<4	5°	5°01’18”	4°59’18”	-0.022°	0.012°	± 0.333°
22	Ø60	60 mm	60.063 mm	60.074	-0.063	-0.074	± 0.150 mm
23	A	-	***0.403 mm***	***0.443 mm***	-	-	0.200 mm
24	// A	-	0.016 mm	0.015 mm	-	-	0.200 mm
25	// C	-	0.089 mm	0.023 mm	-	-	0.200 mm

The tests show that for 25 measurements taken for the object cut with the CO_2 laser, 11 of them do not fall within the range of the selected tolerance specified in the standards [12,13]. However, in the case of an object cut with the Fiber laser, only 5 measurement results are outside the tolerance. It is clearly observed that deviations from the nominal dimension for the object being cut with the Fiber laser are lower than in the case of those cut with CO_2 laser.

3.2 Measurement of surface accuracy after cutting operation

The cut surface accuracy was tested on the basis of standard [11] titled: Thermal cutting - Classification of thermal cuts - Geometrical product specification and quality tolerances. The following parameters were tested: drag - n, perpendicularity tolerance - u, mean height of the profile – Rz5 and additionally arithmetic mean deviation of the assessed profile - Ra. The tests were carried out using Mahr MarSurf GD 120 testing machine.

The "u" and "n" parameters were measured three times on the surface designated in Figure 1 as the base A. The roughness measurements were made at the height of 1/3a viewed from the upper surface of the sheet plate (in accordance with [11]) and, as a comparison, at a height of 2/3a (where : a - thickness of the cut sheet plate). The measurements were carried out three times on the surface A and three times on the surface for which the parallelism tolerance was determined (Fig. 1). Table 4 presents the results of mean values of the measurements carried out. A graphical illustration of the Rz5 roughness measurement results is shown in Figure 2.

Table 4. Measurement results for u, n, Rz5 and Ra parameters

CO_2				**Fiber**			
n, µm		**u, µm**		**n, µm**		**u, µm**	
0.084		0.052		0.077		0.051	
Base A surface - 1/3a		**Surface II to A - 1/3a**		**Base A surface - 1/3a**		**Surface II to A - 1/3a**	
Rz5, µm	Ra, µm	Rz5, µm	Ra, µm	Rz5, µm	Ra, µm	Rz5, µm	Ra, µm
4.1981	0.7591	8.5201	1.4010	5.0380	0.9566	7.7669	1.5299
Base A surface - 2/3a		**Surface II to A - 2/3a**		**Base A surface - 2/3a**		**Surface II to A - 2/3a**	
Rz5, µm	Ra, µm	Rz5, µm	Ra, µm	Rz5, µm	Ra, µm	Rz5, µm	Ra, µm
128.8031	23.8343	33.3495	6.3180	6.2384	1.2569	4.3192	0.6956

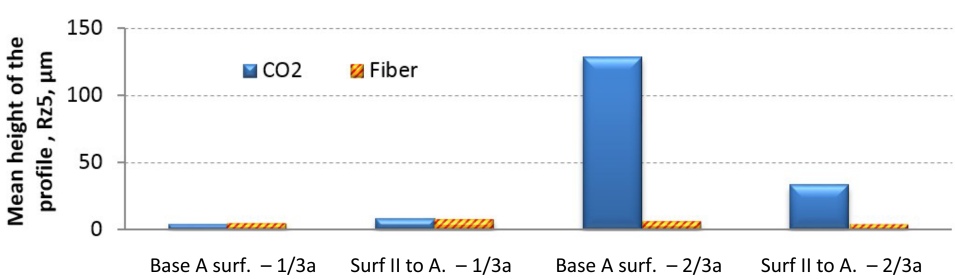

Fig. 2. A graphical illustration of the Rz5 roughness measurement results

Considering the comparison between the value of the drag distances "n" for the CO_2 and Fiber laser, it should be noted that the surface obtained after the Fiber laser cutting is characterized by smaller deviation. The perpendicularity tolerance "u" of surfaces obtained with CO_2 and Fiber laser cutting is comparable. Significant differences are observable for Rz5 values measured at a height of 2/3a. For example, the Rz5 value of the base surface A measured at that height is 95% higher for a surface obtained using CO_2 laser than for a surface obtained using Fiber laser. Noteworthy is also the fact that the surface roughness obtained with the Fiber laser is more repeatable than obtained using the CO_2 laser.

Better results of deviations from the nominal dimension and accuracy the cut surfaces were obtained after Fiber laser cutting. This is due to the fact that Fiber lasers are characterized by the higher energy density as a result of a better beam quality. Furthermore the Fiber lasers have a higher value of absorptivity when compared with CO_2 laser, and thus is able to reach higher accuracy of the cut surfaces.

4 Conclusions

When comparing functional properties, frequency of servicing, efficiency of CO_2 and Fiber lasers, it should be concluded that Fiber lasers are a good solution for cutting. The sole disadvantage of Fiber lasers can only be their purchase price.

The conclusions refer only to the tests carried out with specific cutting parameters. It was assumed for the tests that the value of linear energy during cutting with both types of lasers would amount to 55.4 kJ/m. With such assumptions, the comparison of the accuracy of the surface after cutting with CO_2 laser and Fiber laser shows that significantly higher dimensional accuracy was obtained for Fiber laser. Surfaces cut with Fiber laser were also characterized by better roughness and high repeatability of roughness results over the entire cutting height.

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