# Parametric Investigation and Optimization of $Co_2$ Laser Cutting process used for Cutting Hardox-400 materials

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**Abstract**: A laser uses amplified & stimulated radiation of light. Laser machine is a device which is used to generate & amplifies light. Laser stands for Light Amplification by Stimulated Emission of Radiation. Laser machine is an electrical-optical device that produces coherent radiation. Simply put, a laser is a device that creates and amplifies a narrow, intense beam of coherent light. This paper reviews some of the experimental investigates different process parameter like cutting speed, laser power, gas pressure, pulse frequency on hardox 400 material. Then the CO2 laser cutting experiment was made by using 8 mm thickness hardox 400 material. In this experiment work it is focused to establish relation of different process parameter on cut quality, which is decided by the surface roughness, kerf width, and perpendicularity.

**Keywords**: Hardox-400, CO2 laser cutting, cutting quality,

## 1. INTRODUCTION

Laser, which stands for Light Amplification by Stimulated Emission of Radiation, is an electrical-optical device that produces coherent radiation. Simply put, a laser is a device that creates and amplifies a narrow, intense beam of coherent light. Now days, laser is widely applied in today's industry. A laser comprises three principal components, namely, the lasing medium, means of exciting the lasing medium into its amplifying state (lasing energy source), and optical delivery/feedback system. Additional provisions of cooling the mirrors, guiding the beam and manipulating the target are also important. Lasers are widely used in industry for cutting and boring metals and other materials, in medicine for surgery, and in communications, scientific research, and holography. They are an integral part of such familiar devices as bar code scanners used in supermarkets, scanners, laser printers, and compact disk players [6].

Laser cutting is a process in which the material is heated to its melting or vaporization temperature. Heating is achieved by concentrating the energy in a very small spot. This allows the cutting of almost all types of materials with thickness of up to 20 mm in the case of steel sheets without the need for very high levels of energy . There are different laser generators depending on the type of the laser-active material they use. Each type of laser creates a laser beam at a given wavelength. The CO2 generators are the most used for steel cutting with a wavelength 10.6 mm, whilst the Nd: YAG lasers generate a beam with a wavelength of 1.06 mm. In general, the Nd: YAG lasers wavelength is better absorbed by most of materials (copper, aluminum, precious metals,). Steel, however, has acceptable absorption levels for the beam generated by CO2. This, added to the fact that these CO2 generators are more powerful and cheaper, explains why their use in industry is much more widespread. Once the beam has been generated, a lens system focuses the beam on a point with diameters of around 0.2 mm. The focusing of the beam allows for high energy densities to be reached, a typical value is about 1.4 _ 1010 W/m2. The high power density concentrated on the spot vaporizes almost all types of material (as long as there is a certain amount of beam absorption) [3].

## 2. EXPERIMENTAL PROCEDURE AND OPERATION PARAMETER

### 2.1 Material:

The base material used in this study was hardox-400 sheet 6 mm thick, whose chemical composition and mechanical properties are listed in Table 1. This hardox-400.

**Table 1. Chemical composition of hardox-500 Material**

| C | Si | Mn | P | Cr | Mo | B |
|---|---|---|---|---|---|---|
| 0.13 | 0.53 | 1.24 | 0.002 | 0.65 | 0.019 | 0.002 |

### 2.2 Taguchi methodology based experiments:

These experiments were performed with a 3.5 kW CO2 (omada),To prevent the instability and damage caused by back reflections, the cavity is isolated by using a beam bender mirror with a multilayer coating that absorbs the back reflected laser beam. The laser beam was focused using a 127mm focal length lens except for the tests conducted to detect the influence of this parameter. For this purpose, lenses with 127 and 190.5mm were used. Tests were conducted in continuous wave (CW) and in pulsed mode. In CW mode, when the laser source delivers a constant power, the experiments were performed varying one factor at a time. The ranges of cutting parameter are summarized in Table 2.

A commercial cutting head incorporating a conical converging coaxial nozzle with a 1.5 mm exit diameter was employed to supply the assist gas in a coaxial manner with the laser beam. In the tests conducted to reveal the influence of the nozzle exit on the quality of the cuts, nozzles with an exit diameter of 0 1.5 mm were also used. The distance from the lower part of the nozzle to the plate (also known as stand-off distance) was fixed at 1.5mm except for the tests conducted to reveal the influence of this parameter. Compressed air, nitrogen and oxygen at various pressures were used as assist gases.

**Table 2. Control factors and theirs level use in experiment**

| Symbol | Factor | Unit | Level-1 | Level-2 | Level-3 |
|---|---|---|---|---|---|
| A | Power | watt | 1300 | 1500 | 1700 |
| B | Gas pressure | Bar | 0.5 | 0.6 | 0.7 |
| C | Cutting speed | Mm/ min | 300 | 500 | 700 |
| D | Pulse frequency | Hz | 20 | 25 | 30 |

An experimental performance is carried out which analysis of co2 laser cutting process for hardox – 400 Sheet. It shows that by proper control of the cutting parameter, good quality cuts are possible at high cutting rates. Some characteristics such as the surface roughness, kerf width, and perpendicularity as output parameters also discussed.

### *2.2.1 Surface Roughness Measurement*

The surface roughness for all trial runs is measured with profilometer named as sj-201. After the measuring number of samples through surface roughness tester (SJ -201) In which we have measured L1, L2, L3 sample lengths and considered their average value in terms of length in mm. in figure we have described measuring surface roughness of the sample and in table shown results of surface roughness test according to experiment.

Figure 2 Measuring surface roughness of the sample

**Table 3. Plan of experiments**

| Trial no. | A Power (W) | B Gas Press (Bar) | C Cutting Speed (mm) | D Pulse Freq. ($H_Z$) | Surface roughens (μm) |
|---|---|---|---|---|---|
| 1 | | 0.5 | 300 | 20 | 6.5 |
| 2 | | 0.5 | 500 | 25 | 7.43 |
| 3 | | 0.5 | 700 | 30 | 7.04 |
| 4 | | 0.6 | 300 | 25 | 9.0 |
| 5 | 1300 | 0.6 | 500 | 30 | 8.06 |
| 6 | | 0.6 | 700 | 20 | 8.91 |
| 7 | | 0.7 | 300 | 30 | 12.32 |
| 8 | | 0.7 | 500 | 20 | 6.75 |
| 9 | | 0.7 | 700 | 25 | 7.13 |
| 10 | | 0.5 | 300 | 25 | 11.4 |
| 11 | | 0.5 | 500 | 30 | 9.59 |
| 12 | | 0.5 | 700 | 20 | 6.83 |
| 13 | | 0.6 | 300 | 30 | 12.20 |
| 14 | 1500 | 0.6 | 500 | 20 | 14.86 |
| 15 | | 0.6 | 700 | 25 | 9.5 |
| 16 | | 0.7 | 300 | 20 | 16.59 |
| 17 | | 0.7 | 500 | 25 | 12.78 |
| 18 | | 0.7 | 700 | 30 | 7.97 |
| 19 | | 0.5 | 300 | 30 | 13.56 |
| 20 | | 0.5 | 500 | 20 | 16.27 |
| 21 | | 0.5 | 700 | 25 | 14.86 |
| 22 | | 0.6 | 300 | 20 | 18.19 |
| 23 | 1700 | 0.6 | 500 | 25 | 16.41 |
| 24 | | 0.6 | 700 | 30 | 13.44 |
| 25 | | 0.7 | 300 | 25 | 11.24 |
| 26 | | 0.7 | 500 | 30 | 17.23 |
| 27 | | 0.7 | 700 | 20 | 15.88 |

**Table 4. Layout Using $L_{27}$**

| Trial no | A | B | C | D |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 2 | 2 |
| 3 | 1 | 1 | 3 | 3 |
| 4 | 1 | 2 | 1 | 2 |
| 5 | 1 | 2 | 2 | 3 |
| 6 | 1 | 2 | 3 | 1 |
| 7 | 1 | 3 | 1 | 3 |
| 8 | 1 | 3 | 2 | 1 |
| 9 | 1 | 3 | 3 | 2 |
| 10 | 2 | 1 | 1 | 2 |
| 11 | 2 | 1 | 2 | 3 |
| 12 | 2 | 1 | 3 | 1 |
| 13 | 2 | 2 | 1 | 3 |
| 14 | 2 | 2 | 2 | 1 |
| 15 | 2 | 2 | 3 | 2 |
| 16 | 2 | 3 | 1 | 1 |
| 17 | 2 | 3 | 2 | 2 |
| 18 | 2 | 3 | 3 | 3 |
| 19 | 3 | 1 | 1 | 3 |
| 20 | 3 | 1 | 2 | 1 |
| 21 | 3 | 1 | 3 | 2 |
| 22 | 3 | 2 | 1 | 1 |
| 23 | 3 | 2 | 2 | 2 |
| 24 | 3 | 2 | 3 | 3 |
| 25 | 3 | 3 | 1 | 2 |
| 26 | 3 | 3 | 2 | 3 |
| 27 | 3 | 3 | 3 | 1 |

### *2.2.2 Kerf width Measurement*

The kerf width measurement was done by equipment using by digital camera and image tool programs. In which first digital camera was used to take the photographs of top bottom cut kerf of test piece, after that the photographs were transmitted in computer then after uploaded in image tool software for used to measure length along kerf gap.

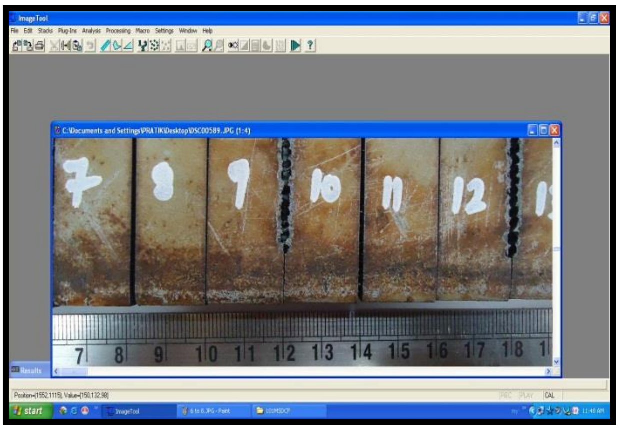

Figure 3 Print screen of image tool software

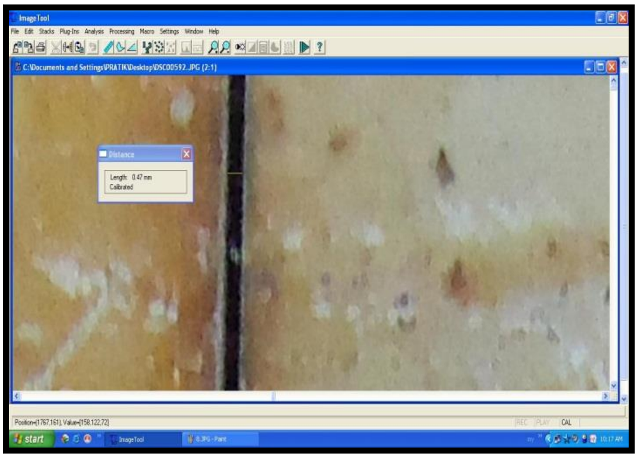

Figure 4 Print screen of image tool software measuring kerf width

We have performed experiments then after measured kerf width via image tool software according to above figure one by one take print screen shots and measuring kerf width values and displayed in results table below.

**Table 5.3. Results of kerf width obtained from experimental work**

| Trial no. | A Power (W) | B Gas Press (Bar) | C Cutting Speed (mm) | D Pulse Freq. (Hz) | Kerf Width (mm) |
|---|---|---|---|---|---|
| 1 | | 0.5 | 300 | 20 | 0.36 |
| 2 | | 0.5 | 500 | 25 | 0.23 |
| 3 | | 0.5 | 700 | 30 | 0.25 |
| 4 | | 0.6 | 300 | 25 | 0.19 |
| 5 | 1300 | 0.6 | 500 | 30 | 0.64 |
| 6 | | 0.6 | 700 | 20 | 0.30 |
| 7 | | 0.7 | 300 | 30 | 0.18 |
| 8 | | 0.7 | 500 | 20 | 0.98 |
| 9 | | 0.7 | 700 | 25 | 0.32 |
| 10 | | 0.5 | 300 | 25 | 0.85 |
| 11 | | 0.5 | 500 | 30 | 0.96 |
| 12 | | 0.5 | 700 | 20 | 0.24 |
| 13 | | 0.6 | 300 | 30 | 0.85 |
| 14 | 1500 | 0.6 | 500 | 20 | 0.88 |
| 15 | | 0.6 | 700 | 25 | 0.48 |
| 16 | | 0.7 | 300 | 20 | 0.97 |
| 17 | | 0.7 | 500 | 25 | 1.0 |
| 18 | | 0.7 | 700 | 30 | 0.36 |
| 19 | | 0.5 | 300 | 30 | 0.93 |
| 20 | | 0.5 | 500 | 20 | 0.67 |
| 21 | | 0.5 | 700 | 25 | 1.78 |
| 22 | | 0.6 | 300 | 20 | 1.36 |
| 23 | 1700 | 0.6 | 500 | 25 | 0.79 |
| 24 | | 0.6 | 700 | 30 | 2.30 |
| 25 | | 0.7 | 300 | 25 | 1.35 |
| 26 | | 0.7 | 500 | 30 | 1.26 |
| 27 | | 0.7 | 700 | 20 | 2.40 |

### 2.2.3 *Perpendicularity Measurement*

The perpendicularity measurement was done with the work piece cut through to reveal the cut surface variation in which same procedure as kerf width measurement using by digital camera and image tool programs. In which first digital camera was used to take the photographs of cut surface profile of test piece, after that the photographs were transmitted in computer then after uploaded in image tool software for used to measure length along cut profile in figure described sample of print screen of perpendicularity measurement.

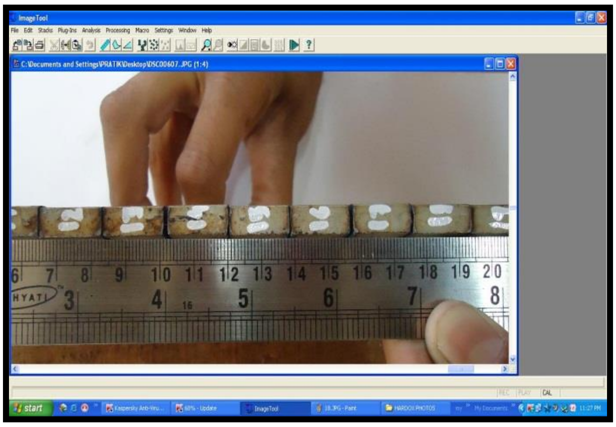

Figure 5 Print screen of perpendicularity sample of image tool software

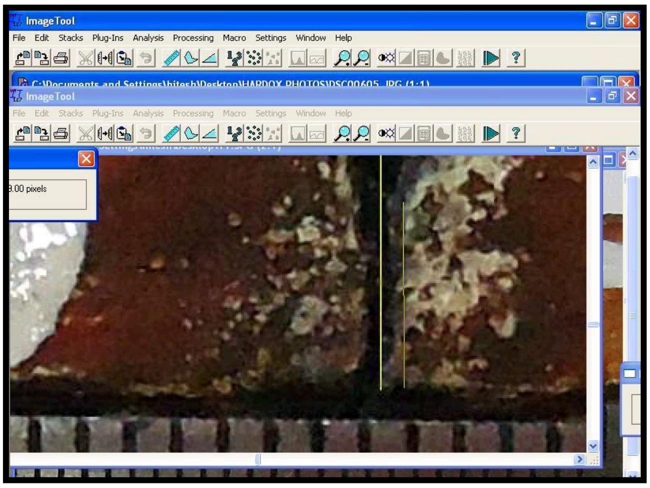


Figure 6 Print screen of measuring perpendicularity on image tool software

We have performed experiments then after measured perpendicularity measurement via image tool software according to above figure one by one take print screen shots and measuring perpendicularity measurement values and displayed in results table below.

| Trial no. | A Power (W) | B Gas Press (Bar) | C Cutting Speed (mm) | D Pulse Freq. ($H_Z$) | Perpendicularity (radian) |
|---|---|---|---|---|---|
| 1 | | 0.5 | 300 | 20 | 0.018 |
| 2 | | 0.5 | 500 | 25 | 0.015 |
| 3 | | 0.5 | 700 | 30 | 0.014 |
| 4 | | 0.6 | 300 | 25 | 0.013 |
| 5 | 1300 | 0.6 | 500 | 30 | 0.018 |
| 6 | | 0.6 | 700 | 20 | 0.017 |
| 7 | | 0.7 | 300 | 30 | 0.015 |
| 8 | | 0.7 | 500 | 20 | 0.016 |
| 9 | | 0.7 | 700 | 25 | 0.013 |
| 10 | | 0.5 | 300 | 25 | 0.020 |
| 11 | | 0.5 | 500 | 30 | 0.014 |
| 12 | | 0.5 | 700 | 20 | 0.013 |
| 13 | | 0.6 | 300 | 30 | 0.014 |
| 14 | 1500 | 0.6 | 500 | 20 | 0.018 |
| 15 | | 0.6 | 700 | 25 | 0.015 |
| 16 | | 0.7 | 300 | 20 | 0.021 |
| 17 | | 0.7 | 500 | 25 | 0.015 |
| 18 | | 0.7 | 700 | 30 | 0.012 |
| 19 | | 0.5 | 300 | 30 | 0.023 |
| 20 | | 0.5 | 500 | 20 | 0.021 |
| 21 | | 0.5 | 700 | 25 | 0.022 |
| 22 | | 0.6 | 300 | 20 | 0.020 |
| 23 | 1700 | 0.6 | 500 | 25 | 0.017 |
| 24 | | 0.6 | 700 | 30 | 0.026 |
| 25 | | 0.7 | 300 | 25 | 0.018 |
| 26 | | 0.7 | 500 | 30 | 0.017 |
| 27 | | 0.7 | 700 | 20 | 0.024 |

**Table 5.4 Results of Perpendicularity obtained from Experimental work**

## 3. RESULT AND DISCUSSION

Kerf width measurements at the top and bottom surfaces of the sample indicated that the top kerf width was slightly larger than that at the bottom for most of the cutting conditions, which is indicative of the tapered nature of the laser cut as caused by loss of beam intensity, defocusing, or loss of gas pressure across the thickness of the cut. It was also observed that the kerf width slightly increased with an increase in cutting distance along the cut [7, 8].

Cutting speed and laser power has important role in achieving desire kerf width in cutting of hardox-400.here I have got results on different laser power 1300, 1500 and 1700.

### 3.1 Effect of laser power at 1300w

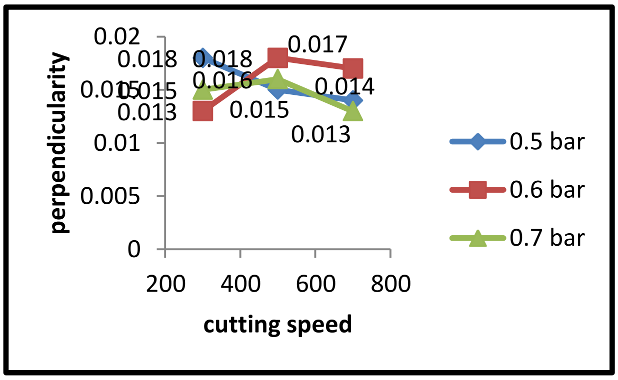


Figure.7 graph of cutting speed Vs. Perpendicularity with laser power 1300 watt

In above figure in which cutting speed Vs. perpendicularity at three different gas pressure with constant laser power 1300 watt indicated. when  gas pressure 0.5 bar in which cutting speed increase 300 to 500 mm/min then perpendicularity is decrease from 0.018 radian to 0.015 radian similarly cutting speed 500 to 700 mm/min then after increases form 0.015 radian to 0.014 radian. In gas pressure 0.6 bar in which cutting speed increase 300 to 500 mm/min then perpendicularity increase from 0.013 radian to 0.018 radian is similarly cutting speed 500 to 700 mm/min then after perpendicularity decrease from 0.018 radian to 0.017 radian. . in gas pressure 0.7 bar in which cutting speed increase 300 to 500 mm/min then perpendicularity is increase from  0.015 radian to 0.016 radian similarly cutting speed 500 to 700 mm/min then after perpendicularity decrease from 0.016 radian to 0.013 radian.

### 3.2 Effect of laser power at 1500w

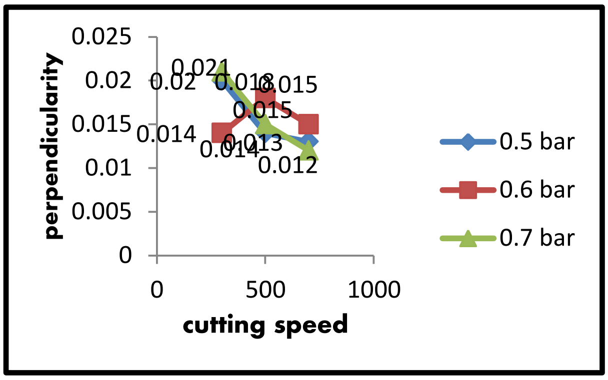


Figure 8 Graph of cutting speed Vs. Perpendicularity with laser power 1500 watt

In above figure in which cutting speed vs. perpendicularity at three different gas pressure with constant laser power 1500 watt indicated. When gas pressure 0.5 bar in which cutting speed increase 300 to 500 mm/min then perpendicularity is decrease from 0.020 radian to 0.014 radian similarly cutting speed 500 to 700 mm/min then after decreases form 0.014 radian to 0.013 radian. In gas pressure 0.6 bar in which cutting speed increase 300 to 500 mm/min then perpendicularity increase from 0.014 radian to 0.018 radian is similarly cutting speed 500 to 700 mm/min then after perpendicularity decrease from 0.018 radian to 0.015 radian. In gas pressure 0.7 bar in which cutting speed increase 300 to 500 mm/min then perpendicularity decrease from 0.021 radian to 0.015 radian is similarly cutting speed 500 to 700 mm/min then after perpendicularity decrease from 0.015 radian to 0.012 radian.

### 3.3 Effect of laser power at 1700w

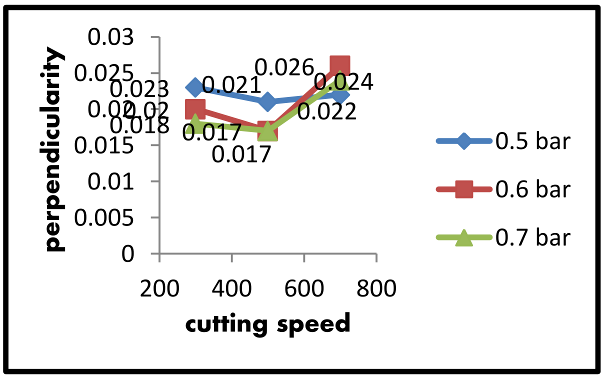


Figure 9 graph of cutting speed Vs. Perpendicularity laser power 1700 watt

In above figure in which cutting speed vs. perpendicularity at three different gas pressure with constant laser power 1700 watt indicated. when gas pressure 0.5 bar in which cutting speed increase 300 to 500 mm/min then perpendicularity is decrease from 0.023 radian to 0.021 radian similarly cutting speed 500 to 700 mm/min then after increases form 0.021 radian to 0.022radian. In gas pressure 0.6 bar in which cutting speed increase 300 to 500 mm/min then perpendicularity decrease from 0.020 radian to 0.017 radian is similarly cutting speed 500 to 700 mm/min then after perpendicularity increase from 0.017 radian to 0.026 radian. In gas pressure 0.7 bar in which cutting speed increase 300 to 500 mm/min then perpendicularity decrease from 0.018 radian to 0.017 radian is similarly cutting speed 500 to 700 mm/min then after perpendicularity increase from 0.017 radian to 0.024 radian.

## 4. CONCLUSION

After studied the performance the of $CO_2$ laser cutting of hardox- 400 for 8 m thickness with oxygen assistant gas cut by $CO_2$ laser cutting machine made by omada laser Technology. After the experiment the cut quality was defined by focusing on surface roughness, kerf width and perpendicularity.

After studied experiment work the reason can be clear that when laser power increase 1700 watt with medium gas pressure up to 0.6 bar ,low cutting speed ,low pulse frequency caused roughly cut result .if we if decrease laser power up to 1300 watts and also with low gas pressure 0.5 bar or low cutting speed with low pulse frequency than we got minimum surface roughness. So here gas pressure has important role played for achieving desire surface roughness in co2 laser cutting of hardox -400 materials of 8 mm thickness and optimum results for surface roughness displayed below in result table.

| Sr no. | Power (Watt) | Gas Pressure (bar) | Cutting Speed (mm/min) | Pulse freq. (Hz) | Surface Roughness (μm) |
|---|---|---|---|---|---|
| 1 | 1300 | 0.5 | 300 | 20 | 5.46 |
| 2 | 1700 | 0.6 | 300 | 20 | 18.19 |

After the experiment performed that it can be noticeable that at lower laser power 1300 watts ,medium gas pressure 0.6 bar and cutting speed decreasing up to 300 mm/min pulse frequency 25 (Hz) then got minimum kerf width. At higher laser power 1700 watts , high gas pressure up to 0.7 bar ,higher cutting speed 700 mm/min and pulse frequency 20 (Hz) in order to get maximum kerf width so optimum results for kerf width was indicate in result table below.

| Sr no. | Power (Watt) | Gas Pressure (bar) | Cutting Speed (mm/min) | Pulse freq. (Hz) | Kerf Width (mm) |
|---|---|---|---|---|---|
| 1 | 1300 | 0.6 | 300 | 25 | 0.19 |
| 2 | 1700 | 0.7 | 700 | 20 | 2.40 |

In our experiment work it can be clear that perpendicularity increased at higher power (1700 watt) , higher cutting speed 700 mm/min. and pulse frequency (25 hz) when laser power is lower (1300 watt) and lower cutting speed (300 mm/min) and pulse frequency (30 Hz) then got minimum perpendicularity so here cutting speed and pulse frequency has important role played for achieving desire perpendicularity in co2 laser cutting of hardox -400 material of 8 mm thickness and optimum results for perpendicularity displayed below in result table.

| **Sr no.** | **Power (Watt)** | **Gas Pressure (bar)** | **Cutting Speed (mm/min)** | **Pulse freq. ($H_Z$)** | **Perpendicularity (mm)** |
|---|---|---|---|---|---|
| 1 | 1300 | 0.6 | 300 | 25 | 0.013 |
| 2 | 1700 | 0.6 | 700 | 30 | 0.026 |

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