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# Experimental Investigation in laser cutting of Hardox400

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***Abstract***
*Cutting hard and high strength material such as Hardox 400 using conventional machining is extremely uneconomical and time consuming. Non-conventional cutting is usually performed on such material. In this paper cutting using laser technique will be tested to find how far the surface quality is deviated. In carrying out this investigation 3 main factors, namely, cutting speed, gas pressure and standoff distanceare considered as the input parameters. Their effects on the response parameters represented by the Kerf width of the cut, surface roughness quality and the heat affected zone are investigated.*
***Keywords:*** *Laser cutting, Surface roughness, Taguchi Method, Minitab 17.*

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## I. Introduction

Laser cutting has been used for quite some time in production. Researchers has been working to cover several unclear areas. The research covered experimental, modeling and optimization aspects in the field of non-conventional machining.

Kothwala et al [1], they studied the Kerf characteristics as an indication of cut quality. They considered 4 factors with 3 levels and used Taguchi method for optimization of the experimental work. The factors were theLaser power (levels 1.1, 1.3 & 1.5 kw), Nozzle Diameter (levels 1.5, 2& 2.5 mm), cutting speed (1, 3 & 7 m/min) and thickness (1.5, 3 & 5 mm). They reached results showing that there is an effect on Kerf width and Kerf taper angle.

R. K. Bhatt et al [2] studied the effect of cutting speed, duty cycle and stand of distance were studied using Taguchi method for response surface methodology to optimize the affecting parameters. The response was limited to Kerf width. They concluded that the stand of distance is the main affecting factor, followed by the cutting speed and that the duty cycle has minor effect.

Manchalasadasivan R. & A. Bhargav [3] used CO2 Laser to cut AISI-304L Stainless Steel and to find the output response mainly of Kerf width and edge quality. The factors in their work were Laser power, cutting speed, gas pressure and focal distance. Results was analysed by Minitab 14 and the statistical values were quoted showing that it is a good tool to reduce Kerf width.

Kamil Jawad Kadhim [4], applied the Response Surface Methodology (RSM) to study the effect of the laser parameters on the resulted surface roughness. It varied from 0.68 µm to 8.56 µm when laser cutting ASME SA 36 Mild Steel material. The main parameters are the laser power, cutting speed and gas pressure. The paper did not consider the Kerf width and the geometrical form of the cut. In general, the work emphasised on using RSM method to optimize the process and to determine the interconnection between the affecting factors and the response on surface roughness.

M. Prabhakaran1 et al [5], used TLC005 Trumpf laser cutting machine to cut 2 and 3 mm AL-Alloy BS 1100. The influencing factors were laser power, gas pressure, standoff distance and the response parameters were the roughness, Kerf width and geometrical deviations of the cut. Equations based on regression analysis and optimal cutting parameters for improving the output parameters are given.

Mohamed Hassan Gadallah and Hany Mohamed Abdu [6], used laser cutting to cut stainless steel (316L). They developed a response surface model and considered 4 input factors, namely, laser power, cutting speed, gas pressure and frequency. The response ware on the kerf taper, surface roughness and heat affected zone. The analysis made by Taguchi method showed the optimal kerf quality is when power was at low value of 150 W, gas pressure is at o.5 $MP_a$, frequency is only 25 Hz and cutting speed is 200 mm/min. The paper, also showed the frequency and cutting speed has less effect on Kerf taper. The paper included experimental work to verify the Taguchi output.

As seen the main parameters affecting the quality of the produced surface are the cutting speed, the gas pressure and the cutting height (arc gap, standoff distance), so this paper will focus on studying the effect of the three parameters on the main output parameters (the Kerf width of the cut, surface roughness quality and the heat affected zone) This paper, also, applies the investigation on specially hard material (Hardox 400) which is becoming increasingly in use in several applications.

## II. Experimental Work

Laser cutting was performed on Trumatic L3020 Laser machine, fig 1, fitted with Siemens Sinumerik 840D CNC control. It operates with laser beam of 10.6 µm. The nozzle used in this investigation is 2.3 mm.


**Fig 1: Laser cutting machine with its control panel**

MARSURF PS1 surface roughness meter, fig 2 is used to measure the surface roughness which will be assessed through using its standard Arithmetical Average ($R_a$).The travelling length taken is 5.6 mm and the cutoff length is 0.8 mm.

The Kerf Width measurements is evaluated by using Workshop Measuring Microscope MM 320, fig 3**.**

**Fig 2: Mahr Surf PS1**

**Fig.3:Workshop measuring microscope**

An average of 8 measurements were taken along the 5cm cut in the middle of the pre-prepared sample.The standoff distance (arc gap) was measured using standard block gauges of 1, 1.5, 2, 2.5 and 3 mm. Heat Zone photos were taken by Carl Zeiss optical Microscope, fig 4.


**Fig 4: Carl Zeiss Optical Microscope**

The specimens used is made of Hardox 400, which has a chemical composition as given table 1.

**Table 1: Chemical composition of Hadox 400**

| Element | S | Si | Mo | Mn | C | Ni | B | P | Cr | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| Wt.% | 0.010 | 0.70 | 0.60 | 1.46 | 0.32 | 1.50 | 0.04 | 0.025 | 2.50 | Balance |

The designed factors are three namely, cutting speed (mm/min), Gas pressure (bars) and arc gap (standoff distance - mm). The number of levels is five. The designed tests are given in table 2.

**Table 2: Test conditions**

| Test # | Cutting speed (mm/min) | Cutting height (mm) | Gas pressure (Bar) |
|---|---|---|---|
| 1 | 200 | 2 | 17 |
| 2 | 300 | 2 | 17 |
| 3 | 400 | 2 | 17 |
| 4 | 500 | 2 | 17 |
| 5 | 600 | 2 | 17 |
| 6 | 400 | 2 | 15 |
| 7 | 400 | 2 | 16 |
| 8 | 400 | 2 | 17 |
| 9 | 400 | 2 | 18 |
| 10 | 400 | 2 | 19 |
| 11 | 400 | 1 | 17 |
| 12 | 400 | 1.5 | 17 |
| 13 | 400 | 2 | 17 |
| 14 | 400 | 2.5 | 17 |
| 15 | 400 | 3 | 17 |

## III. Results And Discussion

All the results given below are analyzed using the Taguchi Method through Minitab 17.

***Effect of Cutting Speed***

The effect of Cutting Speed on the three responses are given in the following sub-sections.

***i- Kerf width***

The cutting speed was found to have a great influence on the Kerf width, fig 5. The later gets narrower as cutting speed increases. It decreased about %7 of the width asthe cutting speed was increased from 200 mm/min to 600 mm/min. This may be attributed to excess energy produced than actually needed for the cutting of the specimen.

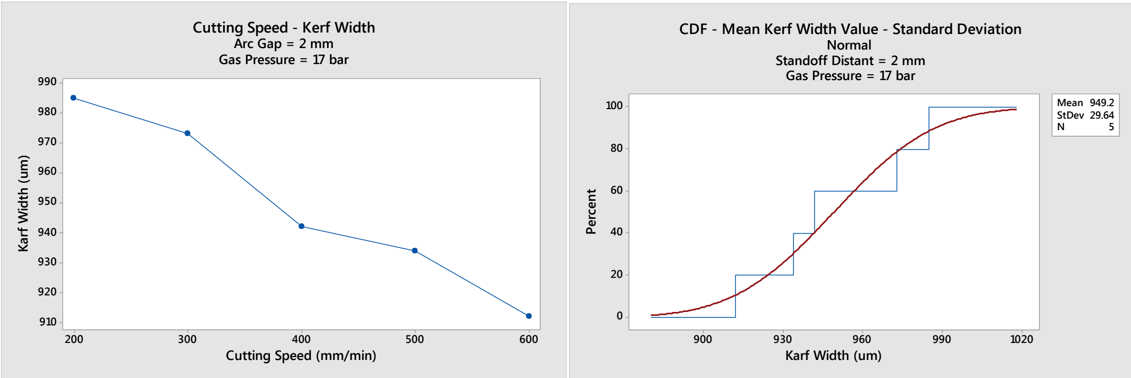


**Fig.** ***5: E*****ffect of cutting speed on kerf width**

Fig 6, shows two photos taken for the Kerf width at speeds 200 mm/min and 600 mm/min respectively.

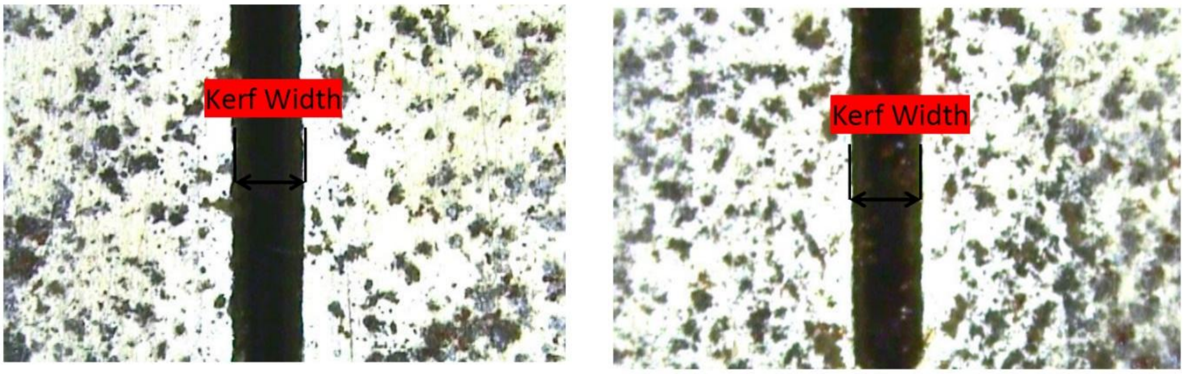


**Fig 6: Kerf width at 200 mm/min and 600 mm/min**

At high speed, the concentration of the heat generated by the laser beam on the workpiece is less than heat concentration on the workpiece at low speeds.In high speeds kerf width decreases as it supports the workpiece with the energy needed just to cut the material, so no excessive heating and material removal occurs.

***ii- Surface Roughness***

Fig 7, shows the results for the effect of cutting speed on the surface roughness. Improvement of the roughness from 5.579 to 4.165 μmis observed as the cutting speed is increased from 200 mm/min to 600 mm/min. The mean value of the roughness over the set of tests is 4.914 μm. The regression equation between the roughness ($R_a$ in μm)and cutting speed (S in mm/min) is given in binomial form:

$R_a$= - 3 x $10^{-6}$ $S^2$ – 0.0016 S + 6.0514

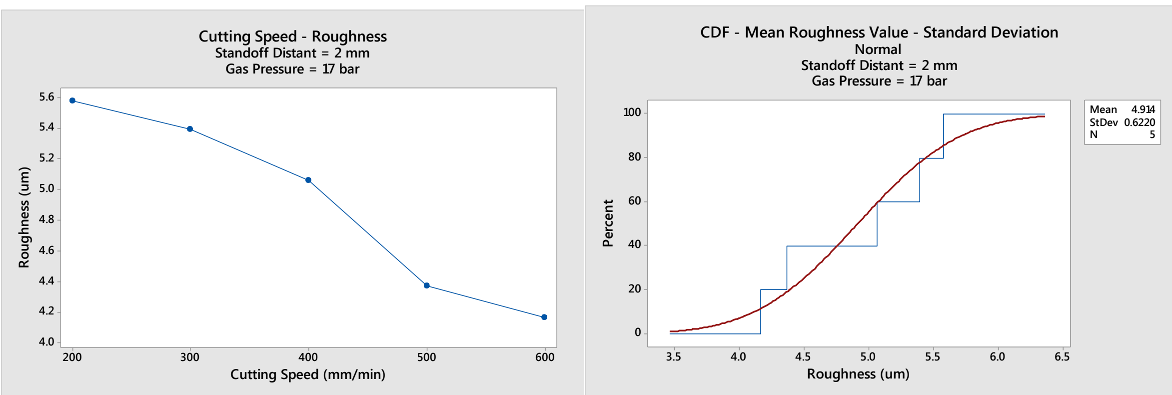


**Fig 7: Effect of cutting speed on roughness**

***iii-*** **Heat Affected Zone (HAZ)**

Prior to the cutting by laser all samples were prepared by grinding the surfaces manually to remove any slags and impurities. Automatic grinding was not used to guarantee that no extra heat would be added to the heat energy generated from laser cutting. After grinding the samples were etched using a Nital solution and dried.
Measuring the heat affected zone for some samples was quite difficult, however, fig 8 shows the heat affected zone (HAZ) when cutting with speed of 200 mm/min.


**Fig 8: Heat Affected Zone (HAZ) at 200 mm/min**

***Effect of Gas Pressure***

***i-*** ***Kerf Width***

Again, the Kerf width gets narrower as the gas pressure increases to a certain limit. Such optimal value falls in the range around gas pressure 18 bar where the Kerf width recorded a width of 0.919 mm. The cutting speed was then, 400 mm/min and the standoff width was 2 mm.

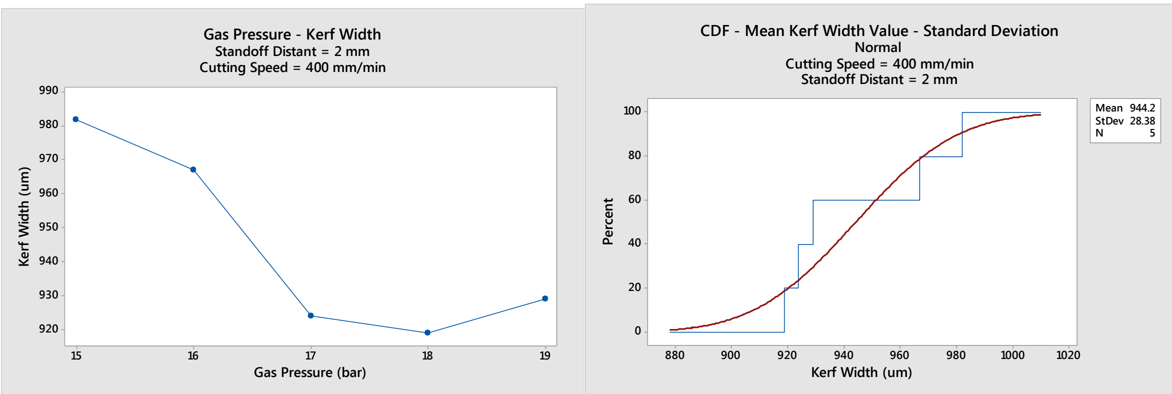


**Fig. 9: Effect of Gas pressure on kerf width**

***ii-*** ***Roughness***

Similar to the effect of cutting speed on roughness, as the gas pressure increases the roughness improves. The relation between roughness ($R_a$ in μm) and gas pressure (p in bar)) is expressed in binominal regression equation:

$R_a = 0.3036\ p^2 – 11.3\ p + 109.71$

The average roughness obtained over the investigated range is 5.967 μm.

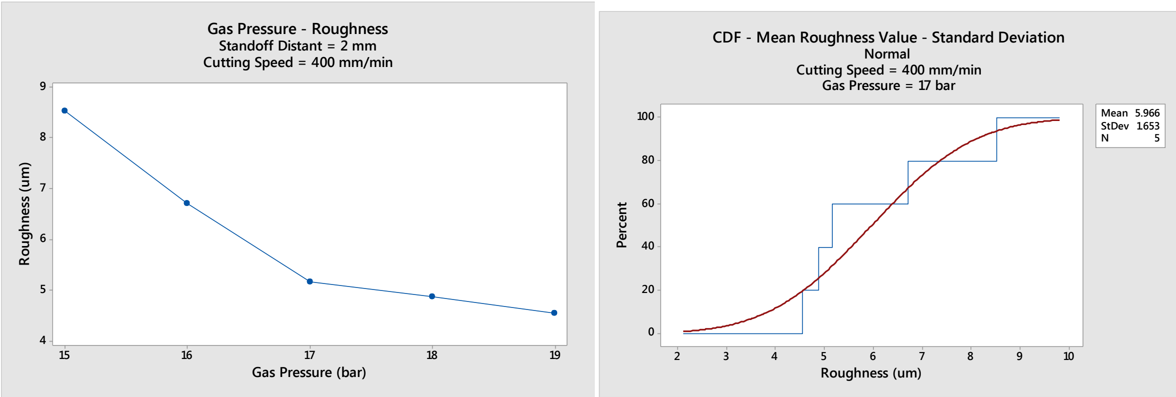


**Fig. 10: Effect of Gas pressure on Roughness**

***Effect of standoff distance***

***i- kerf width:***

Standoff distance has an effect on the kerf width measurements, As standoff distance increases the kerf width gets narrower. Comparing the readings of the Kerf width at 1 mm gap and 2.5 mm gap, the difference in the kerf width is nearly 100µm.

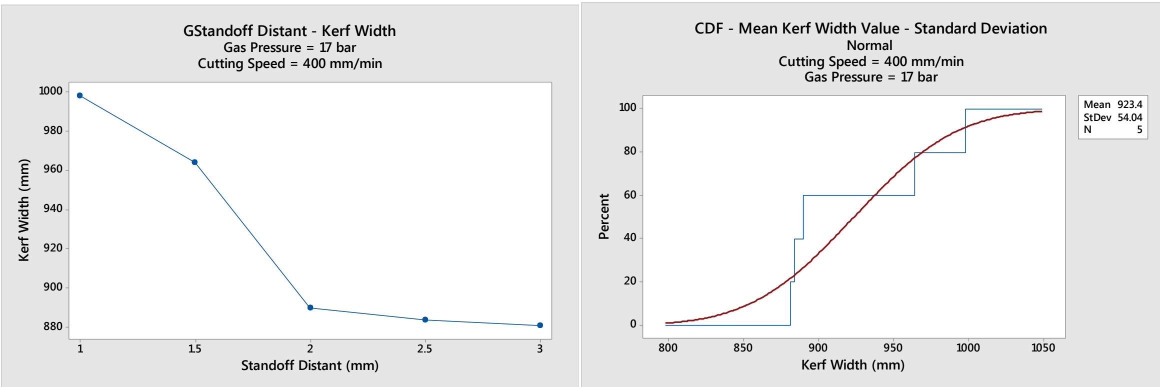


**Fig 11:Effect of Standoff distance on kerf width**

As the standoff distance decrease, the laser beam is more intense and concentrated on the workpiece thus delivering more heat to the workpiece and over melting the material giving wide kerf width.

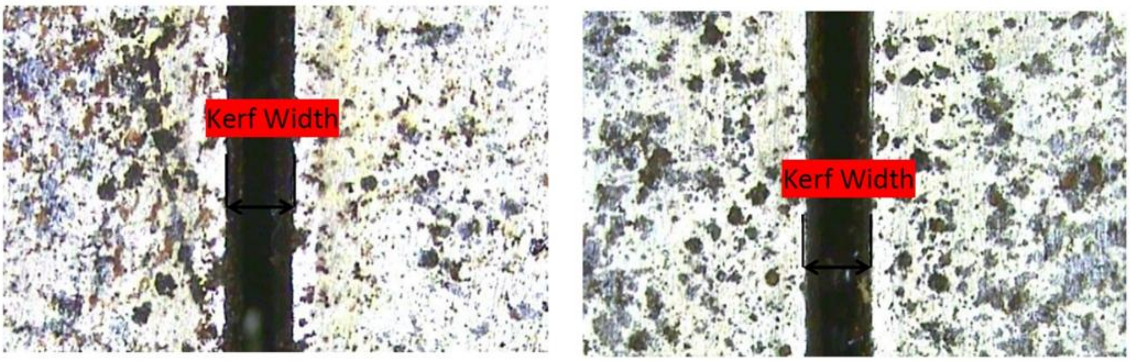


**Fig 12: Effect of Standoff Distance on Kerf width at 1 mm and 2.5 mm**

)n the other hand, as the standoff distance increases, the laser beam is less intense and concentrated on the workpiece thus delivering just enough heat energy to cut through the workpiece giving narrow kerf width.

***ii- surface roughness***

As the standoff distance increases the roughness gets better. This means that for the three considered factors the roughness improves as the cutting speed, gas pressure and the standoff distance increase. The average roughness is 4.909 µm. The regression relation between the roughness ($R_a$) standoff distance (d) is :

$$R_a = 2.1637\ d^2 - 11.099\ d + 17.372$$

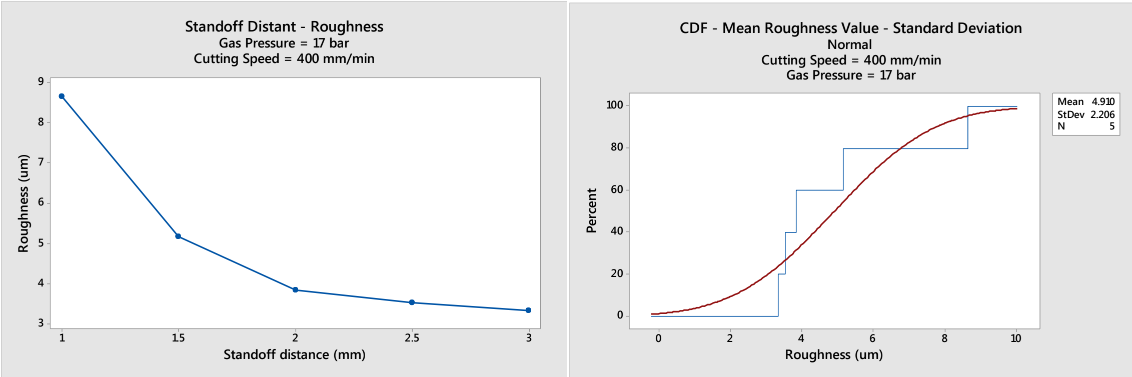


**Fig13:Effect of Standoff Distanceon surface roughness**

## IV. Conclusion

The data analysis using the Minitab 17 software is a useful tool. Statistical results are available. Regression relations were derived. The following are the main outputs which are valid for the performance of cutting Hardox 400 using laser cutting within the ranges of the experiments.

1. The cutting speed has a great influence on the Kerf width, the cut gets narrower as cutting speed increases.
2. Again, as cutting speed increases the surface roughness gets better.
3. Surface roughness and Kerf width werenear optimal when the gas pressure was around 18 bar
4. The average surface roughness calculated for the three factors falls within the range 4.9 to 6μm, which means that laser cutting is a roughing operation.
5. The standoff distance appears to have little effect on surface roughness within the range studied.

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