

## EXPERIMENTAL EVALUATION OF CO<sub>2</sub> LASER CUTTING QUALITY OF UHSS USING OXYGEN AS AN ASSISTED GAS

Abdul Fattah Mohamad Tahir\*, Ahmad Razelan Rashid

Kolej Kemahiran Tinggi MARA Kuantan, KM 8 Jalan Gambang, 25150 Kuantan, Pahang Darul Makmur, Malaysia

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\*Corresponding author  
abdul.fattah@kktmkuantan.edu.my

### Abstract

Development of new material known as Ultra High Strength Steel (UHSS) able to improve the vehicle mass thus reflecting better fuel consumption. Transformation into high strength steel has been a significant drawback in trimming the UHSS into its final shape thus laser cutting process appeared to be the solution. This study emphasizes the relationship between Carbon Dioxide (CO<sub>2</sub>) laser cutting input parameters on 22MnB5 boron steel focusing on the kerf width formation and Heat Affected Zone (HAZ). Experimental research with variation of laser power, cutting speed and assisted gas pressure were executed to evaluate the responses. Metrological and metallographic evaluation of the responses were made on the outputs that are the kerf width formation and HAZ. Positive correlation for power and negative interaction for cutting speed were found as the major factors on formation of the kerf. For the HAZ formation, thicker HAZ were formed as bigger laser power were applied to the material. Cutting speed and gas pressure does not greatly influence the HAZ formation for 22MnB5 boron steel.

Keywords: 22MnB5, CO<sub>2</sub> laser, kerf width, HAZ

### Abstrak

Pembangunan bahan baru yang dikenali Keluli kekuatan ultra tinggi (UHSS) berupaya mengurangkan berat kenderaan sekali gus mengurangkan penggunaan bahan bakar. Transformasi kepada keluli kekuatan tinggi memberi kesan kepada proses perapian bentuk akhir UHSS justeru pemotongan laser merupakan solusi kepada permasalahan ini. Kajian ini menekankan hubungan di antara parameter masukan bagi laser Karbon Dioksida (CO<sub>2</sub>) kepada besi boron 22MnB5 terhadap lebar alur pemotongan dan zon terdedah haba (HAZ). Kajian eksperimen dengan variasi kuasa laser, halaju pemotongan dan tekanan gas pemangkin telah dijalankan untuk mengkaji hasil. Penilaian pengukuran dan pemerhatian terhadap hasil di jalankan iaitu kepada hasil alur pemotongan dan HAZ. Didapati interaksi positif bagi kuasa laser dan negatif bagi halaju pemotongan terhadap lebar alur pemotongan. Bagi penghasilan HAZ, HAZ tebal terbentuk apabila kuasa laser yang besar digunakan kepada bahan uji kaji. Halaju pemotongan dan tekanan gas pemangkin tidak memberi kesan yang besar terhadap pembentukan HAZ bagi 22MnB5.

Kata kunci: 22MnB5, Laser CO<sub>2</sub>, lebar alur pemotongan, HAZ

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## 1.0 INTRODUCTION

Carbon footprint and fuel consumption are the major issues in automotive industries nowadays. Light weight material has been introduced to overcome these problems. UHSS such as 22MnB5, 8MnCrB5 and 20MnB5 are widely used as it offers better strength to weight ratio after undergo the hot press process. Development of high strength steel (HSS) has

increased the strength in automotive chassis and reflectively reduce the weight and saving up to 30% [1]. This material that initially consist of ferrite-pearlite microstructure with the tensile strength of 600 MPa transformed up to 1500 MPa with fully martensitic microstructure after been austenitized at 950°C [2]. Table 1 shows the mechanical properties of 22MnB5 or usually known as Boron Steel. The significant increment of tensile strength of the hot pressed steel has made

laser cutting process as an alternative to trim the parts into its final shape. Laser cutting process is more economical and consume less downtime compared to conventional stamping process. This is the major factor that make laser cutting process as an alternative approach to the industries. Besides that, non-contact operation helps to reduce the setup time as no special fixtures and jigs needed for the workpiece. No tools wear and flexibility of laser cutting head were an added advantages of laser cutting process compared to conventional process.

CO<sub>2</sub> laser with 10.6µm wavelength is the most popular for profile cutting in sheet metal with 30% higher beam quality, higher depth of focus and smaller beam diameter compared to Nd:YAG laser [3]. Laser cutting output such as cutting quality is based on the proper selection of input parameters together with a suitable selection of working materials [4 - 5]. Since this material is considered new, less research has been done on UHSS thus interaction between input parameters unable to be determined. Yilbas [6] reported that less collection data regarding on High strength steel (HSS) cutting and it difficult to predict the quality of the cut especially for HSS.

Laser power is considered a crucial parameter in cutting process and required enough amount of power to melt the material before completing penetration through the working materials. This statement also agreed by Chen [7] that reported cutting quality and performance is depend on the laser power. Meanwhile Hasc [3] investigated the cutting quality of Inconel 718 and found that laser power and cutting speed contribute 26 % and 45% respectively on the kerf taper ratio. The effect of laser power also been concluded by Yilbas [4], Stournaras *et al.* [8] and Eltawahni *et al.* [9] where they reported that kerf width formation interact positively with laser power.

Effect of cutting speed have been reported by many researchers and 86% of CO<sub>2</sub> laser cutting researches were focusing on the cutting speed [10]. Powell [11] stated that selection of suitable cutting speed able to reduce excessive burning of the cut edge and dross formation during cutting process while maintaining the cutting quality. Decrement of cutting speed is needed as the thickness of the working materials increased [11 - 12]. Negative correlation happened between cutting speed and kerf width as lower speed will produce wider kerf [3], [8], [13].

Assisted gas was used to catalyze the cutting process while blowing the molten metal away from the working materials. Besides that, assisted gas were used to protect the lens from spatter while cooling down the working material. Radanovic [14] investigated and found that 8% of 50 researchers used assisted gas as the manipulated input parameters. The usage of oxygen as an assisted gas creates an exothermic reaction thus increasing the cutting quality. Chen [7] investigated the effect of assisted gas and concluded that the selection of suitable pressure of oxygen able to produce good outcome.

Industries have been used preset setting on the input parameters without knowing the element that could be reduced in order to achieve better cutting quality. With the outcome of this paper, interaction between input parameters could offer better cutting quality thus reducing the operational cost especially to automotive manufacturing industries. This project was developed to fill the gap in present contribution especially on trimming the 22MnB5 using CO<sub>2</sub> laser. Laser power, cutting speed and assisted gas pressure were varied to explore their effect on the kerf width formation and HAZ region. Visual observation was made together with the measurement process to evaluate the outcome obtained.

**Table 1** Mechanical properties of 22MnB5 [15]

Martensite temp (°C)	Yield stress (MPa)		Tensile strength (MPa)	
	Original	Hot Pressed	Original	Hot Pressed
410	457	1010	608	1478

## 2.0 EXPERIMENTAL

Mitsubishi HVII 3015 CO<sub>2</sub> laser cutting machine with 4kW resonator were used to conduct the experiment. B pillar of 22MnB5 boron steel with the thickness of 1.7mm were selected as the working materials obtained from Miyazu (M) Sdn Bhd. Rectangular shape of specimens as in Figure 1 were extracted from the B pillar to ease the experimental procedures. Test were conducted using continuous wave (CW) mode with the focal distance of 190.5mm. 1.7mm diameter nozzle was used together with the setting parameters as in Table 2.

Total 27 runs were conducted to evaluate the cutting quality that is the kerf width formation and HAZ region. Figure 2 shows the manipulated laser input parameters together with the responses evaluated. Manipulated laser input parameters selection were proposed from Miyazu (M) Sdn. Bhd. based on their common adjustment made especially in trimming 22MnB5. This input selection were also selected based on previous study and reviews summarized by Radanovic [14] that stated the most input parameters tested are laser power, cutting speed and assisted gas pressure.

**Table 2** Laser cutting parameters

Parameters	Unit	Setting
Laser power	W	750, 1750, 2750
Cutting speed	mm/min	1500, 2500, 3500
Gas pressure	MPa	2.5, 5.0, 7.5
Cutting mode		Continuous wave
Assisted gas		Oxygen
Nozzle diameter	mm	1.7
Focal distance	mm	190.5
Focus position	mm	0 (surface)

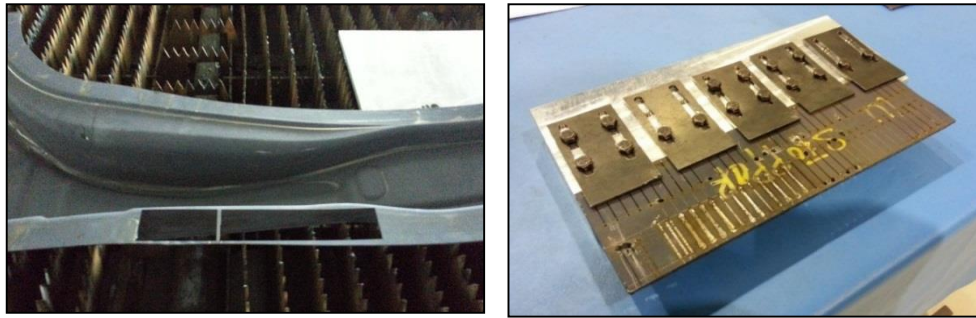


Figure 1 (a) Material that been extracted; (b) Extracted 22MnB5 attached with jig

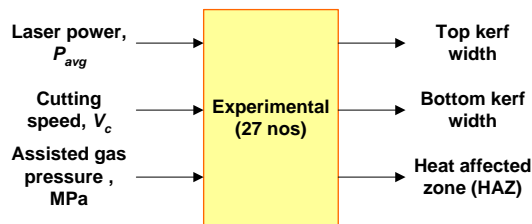


Figure 2 Input parameters and responses evaluated

20mm cutting distance were selected for all 27 runs with 5mm interval. This selection were made to ensure the integrity of HAZ region for each run. Details on the experimental operation were illustrated as in Figure 3. Cutting quality for kerf width formation were evaluated using optical microscope MITUTOYO TM 505 meanwhile evaluation for HAZ thickness were done using high magnifying measuring microscope OLYMPUS STM6. Specimens undergo sample preparation process as per ASTM E3-01 to reveal the changes region known as HAZ.

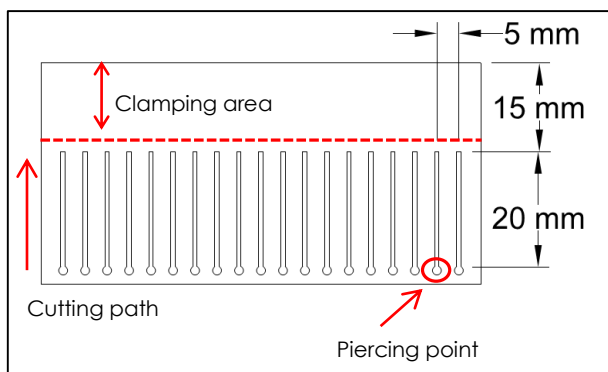


Figure 3 Experimental operation

### 3.0 RESULTS AND DISCUSSION

#### 3.1 Kerf Width Formation

Metrological evaluation for the top kerf and bottom kerf were made using MITUTOYO TM 505 optical microscope. Sample were extracted and mounted on

resin before the inspection were made. It found that positive interaction happened between laser power and kerf formation. Bigger laser power heated up the working material better; increase heat absorption rate while producing more material removal quantity. This resulting wider kerf width formation due to increment of laser power. Meanwhile, contradict effect occurred between cutting speed and kerf formation. Increment of cutting speed will produce narrower kerf width. This is because of less heating time happened at higher cutting speed thus reducing the heat absorption. Cutting speed is known as the rate of movement of laser head along a specific profile. Higher cutting speed means that less time consume to complete those profile while explaining that less time were allocated at specific point along the profile. This show that if higher cutting speed selected, narrower kerf formation formed as less heat were applied on the working material. Interaction for laser power and cutting speed on kerf formation were also in agreement with the findings found by most author that investigated the effect of input parameters on kerf width [4], [8], [16]. Stournaras *et al.* [8] also reported that laser power and cutting speed are the most important roles in cutting quality.

The power intensity that consists of laser power and cutting speed affected the material removal rate as higher laser power and small cutting speed produced bigger material removal rate. Figure 4 translated the effect of input parameters on kerf width formation. The effect of assisted gas pressure was found unconvincing especially at the bottom kerf where more than 0.25MPa assisted gas were supplied. This is due to the effect of oxygen that increase isothermal exposure at working material thus creating inconsistent kerf with high dross creation. Bigger isothermal exposure will spread the heat on the working materials thus creating wider kerf with bad cutting quality. Yilbas [4] and Chen [7] reported the oxygen assisted gas that beyond 6 bar will formed critical dross and unacceptable quality. Chen [7] also added that cutting quality deteriorated as oxygen were supply more than 2 bars for 3mm mild steel.

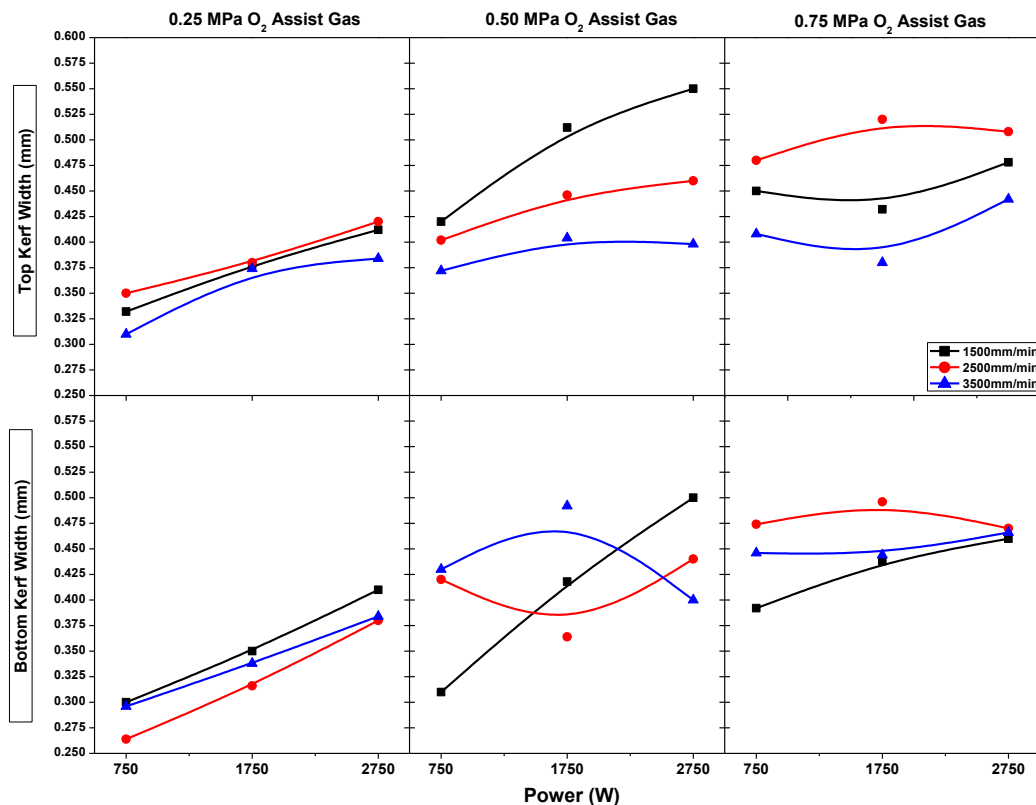
### 3.2 Heat Affected Zone

Heat affected zone is known as an area where the material properties changes due to thermal effect during cutting process. Commonly the zone of HAZ is rather small depending on the heat applied and material thermal conductivity. Table 3 shows the location of HAZ measurement made along the material thickness.

**Table 3** Location of HAZ measurements

Location	Measurement location (mm)
A	0.350
B	0.175
C	At center
D	-0.175
E	-0.350

5 locations were measured to evaluate the effect of HAZ. Figure 5 shows the HAZ region along the material thickness in box style with variation on laser power, cutting speed and assisted gas pressure. Thinner HAZ region were obtained at the bottom of the material thickness for all runs. This is due to assisted gas that is located at the top of the working material, thus producing bigger isothermal effect especially on the top surface of the working material. It is found that the laser power interact proportionally to the HAZ region as bigger laser power will produce thicker HAZ. Thomas *et al.* [1], Stournaras *et al* [8] and Lamikiz *et al.* [16] concluded that bigger laser power also producing thicker HAZ region. On the other hand, the effect of cutting speed and assisted gas pressure does not greatly influence the HAZ region formation. Minor changes on HAZ region can be seen as in Figure 5 where the HAZ region for all cutting speed and assisted gas pressure is almost same.



**Figure 4** Kerf width formation

### 4.0 CONCLUSION

Relationship between input parameters and outputs were identified at the end of this project. It is found that power intensity that consists of laser power and cutting speed influence the kerf width formation. Positive correlation for power and negative interaction for cutting speed was found as the major factors on formation of cutting kerf. Selection of

suitable gas pressure especially oxygen assisted gas is necessary in order to maintain the best cutting quality. Gas pressure more than 0.25MPa would deteriorate the cutting surface thus producing inconsistency kerf.

HAZ region should be controlled in order to preserve the material integrity especially at the cutting edge. Laser power is the crucial element needed to control in order to produce the thinnest HAZ region. Thicker HAZ were formed as bigger laser power were applied to the material. For 22MnB5, it found that the

cutting speed and gas pressure doesn't greatly influence the HAZ formation due to the material

properties that has been transformed into fully martensitic structure.

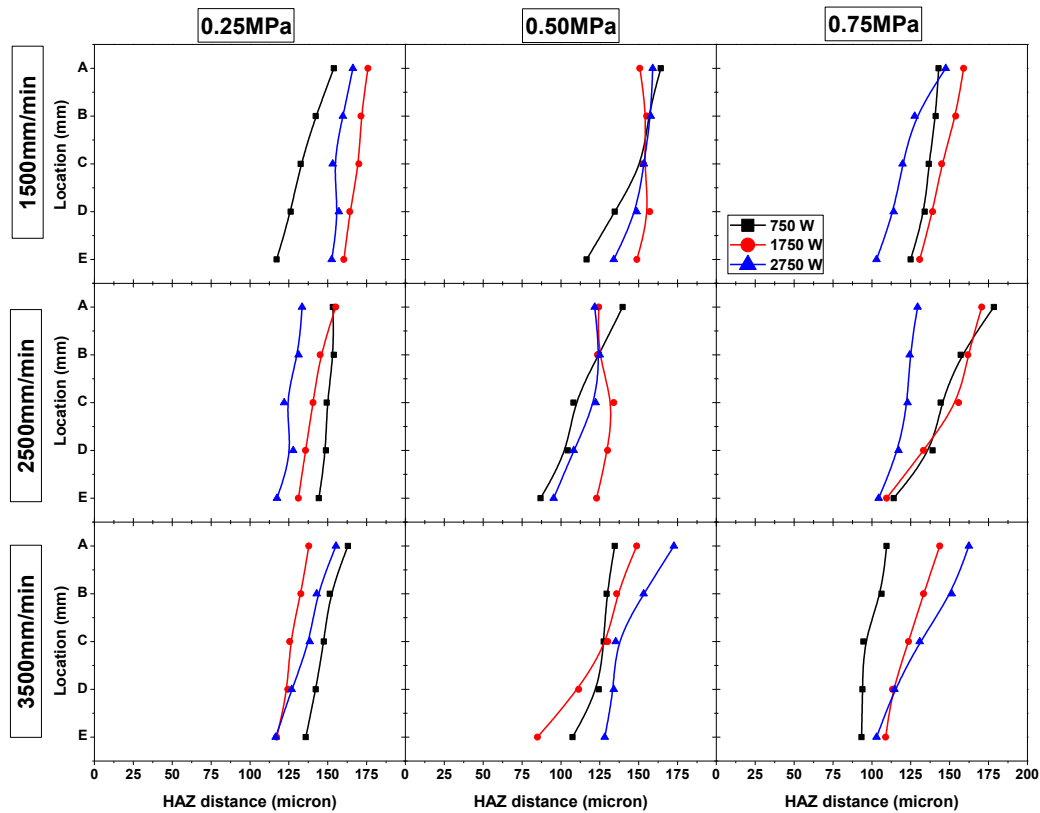


Figure 5 HAZ region along the material thickness

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