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PAPER

Hardness variation of welded boron steel using continuous wave (CW) and pulse wave (PW) mode of fiber laser

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Hardness variation of welded boron steel using continuous wave (CW) and pulse wave (PW) mode of fiber laser

K I Yaakob, M Ishak, S R A Idris M H Aiman and N Z Khalil

Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

E-mail: mahadzir@ump.edu.my

Abstract. Recent car manufacturer requirement in lightweight and optimum safety lead to utilization of boron steel with tailor welded blank approach. Laser welding process in tailor welded blank (TWB) production can be applied in continuous wave (CW) of pulse wave (PW) which produce different thermal experience in welded area. Instead of microstructure identification, hardness properties also can determine the behavior of weld area. In this paper, hardness variation of welded boron steel using PW and CW mode is investigated. Welding process is conducted using similar average power for both welding mode. Hardness variation across weld area is observed. The result shows similar hardness pattern across weld area for both welding mode. Hardness degradation at fusion zone (FZ) is due to ferrite formation existence from high heat input applied. With additional slower cooling rate for CW mode, the hardness degradation is become obvious. The normal variation of hardness behavior with PW mode might lead to good strength.

1. Introduction

In fulfilling the car manufacturer requirement for producing lightweight chassis with high safety features, boron steel is introduced replacing the conventional high strength steel (HSS). Apart from exhibiting high strength properties after hot press forming process, the springback issue also have been solved, allowing complex geometry parts design [1–10]. Poor energy absorbtion of boron steel promotes the tailor welded blank (TWB) technology in optimization of weight while maintaining the crashworthiness of the component [7,11–17]. Due to involvement of laser welding method in TWB, the comparative study between different types of laser welding conducted by Assuncau revealed that the fiber laser results higher efficiency and productivity. It was also found that the pulse wave (PW) mode is prominent in higher penetration efficiency compared to continuous (CW) under similar condition.

PW mode is where the laser produces short pulses and less amount of heat is transferred to the work piece. The advantages of PW when compared to CW mode includes the lower heat input, lower distortion, and higher efficiency [18–24]. The continuous weld also can be made by overlapping every spot of pulses from PW mode to form a fusion zone or seam is known as pulse seam welding. Contrast with CW mode which laser applied on the surface, create the molten pool and drag along the weld line according to welding speed. The welding speed of CW mode is inversely proportional to the width of fusion zone (FZ) and heat affected zone (HAZ) [25].

Both welding mode applied power density at various points in the weld zone may experience different thermal events along the weld area. It leads to various microstructure formation in the FZ and HAZ. The different microstructure lead to different mechanical properties and required further

investigation. However, most microstructures form in a small area and thus rather difficult to be observed. By determined the hardness properties of microstructure the difference of microstructure behavior can be determined instead of microstructure observation. It is also expected that the variation of hardness across the weld area also can be used to predict the weld area separation depending on its changes. Therefore, the aim for this work is to determine the hardness variation of welded boron steel. The comparison of hardness variation between CW and PW mode was made and discussed.

2. Experimental Procedure
This study was conducted by using 1.6 mm thick of uncoated 22MnB5 boron steel. The specimens were cut to 50 mm x 50 mm dimension sufficient for bead on plate (BOP) welding. The IPG-YLM-QCW series of a fiber laser with an average power of 200 W was used in CW and PW mode. Average power and welding speed for were fixed as 100 W of average power and 5 mm/s respectively for both welding mode. Additional 1 ms of pulse width and 60 Hz of pulse repetition rate were fixed for PW welding. The focus point was set as 15 mm below the specimen surface together with 15° of incident angle to avoid beam reflection. 15 L/min of Argon gas flow rate was use to protect the weld area blown by copper tube nozzle. The diameter the nozzle was 6 mm and the nozzle tip distance to beam were 30 mm with 20° of angle.

Table 1. Chemical compositions of boron steel (22MnB5).

| Composition (%)	C	Si	Mn	P	S	Cr	Ni	B
Boron Steel	0.26	0.30	1.24	0.016	0.003	0.20	0.016	0.004
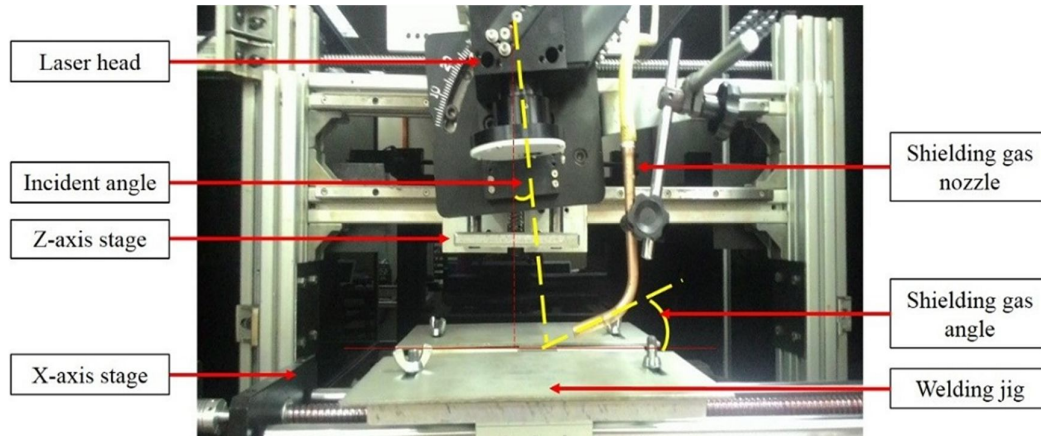
Figure 1. Welding process apparatus using fibre laser machine.

For the welding cross section observation, the specimens were finely cut and mounted. The mounted specimens were grounded, polished and etched using 2% of nital solution to reveal the microstructure difference. The observation of welded cross section area were carried out by the mean of optical microscope. The hardness test was conducted in a line across the weld area. The difference of hardness behavior across welded area between CW and PW mode were discussed.

3. Results and Discussion
Figure 2 shows the BOP cross section of CW and PW mode. It obviously shows that PW produce deeper penetration compared to CW mode. The penetration difference was due to the peak power density applied on the specimen by different welding mode. Even though both welding mode utilized similar average power, PW mode able to produce peak power. Meanwhile, CW mode only utilized average power as power output. Thus, the peak power density of PW mode is higher compared to CW mode which create deeper penetration. In another point of view, interaction time is the heating time of

the process on weld centerline which also might affect the penetration. However, high interaction time of CW mode only affect the HAZ width compared to penetration. Thus, the HAZ of CW mode is wider compared to PW mode which produce shorter interaction time.
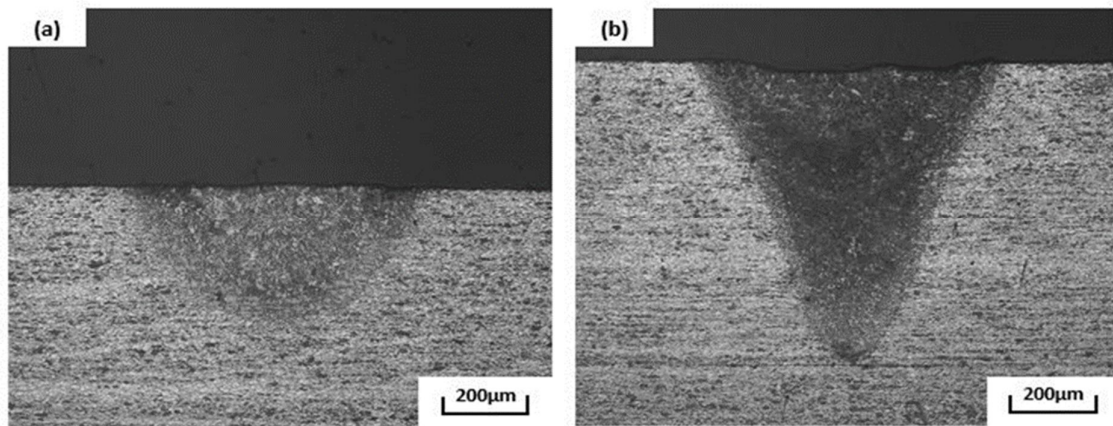

Figure 2. Welding cross section of (a) continuous wave and (b) pulse wave.

Figure 3 shows the hardness pattern across the weld area of CW and PW mode. CW mode produce wider weld area compared to PW mode. Both welding mode shows reduction of hardness value at the center of the weld. However, CW mode resulted wider weld area and huge hardness reduction compared to PW mode. This hardness variation might due to the microstructure transformation according to heat input and cooling rate during welding process. During welding process, the heat applied at FZ area high enough to melt the base metal. Followed by decrease in temperature during solidification might transform the base metal microstructure to martensite. However, the high temperature applied will enhance the boron element to rally at the boundary between FZ and HAZ. The boron concentration at this area might resulted borocarbide precipitation which promoting ferrite nucleation. Thus, the hardness of this area might reduce.

The heat from FZ will spread to the base metal and create HAZ area. HAZ consist of various microstructure due to temperature gradient moving from FZ to base metal. The temperature applied at HAZ might below the melting temperature. However, HAZ area near to FZ might experience the austenization temperature, Ac3 which optimum temperature for boron steel properties transformation. According to Naderi [26], starting from austenite temperature, 25 °C/s is the optimum cooling rate to obtain full transformation of boron steel properties to martensite microstructure. Thus, there are some HAZ area might result full martensite transformation.

The hardness of CW mode welding at FZ is lower than PW mode. During CW mode welding, FZ experience slower cooling rate compared to PW mode. It is because of the molten pool of CW mode is dragged along weld area which delay the solidification process and also reduce its cooling rate. The slower cooling rate also enhance the chances of borocarbide precipitation and ferrite nucleation which lead to hardness degradation. Contrast with PW mode welding which solidified faster in each pulse. Thus, the hardness degradation is not obvious compared to CW mode. HAZ hardness for both welding mode in the range of 500 to 600 HV. Even though the HAZ hardness of CW mode is slightly higher compared to PW mode, both welding mode might produce optimum temperature and cooling rate to produce full martensite transformation. However, HAZ of CW mode is wider than PW mode. It is due to slow cooling rate from FZ give sufficient time for heat to spread and create wider HAZ.
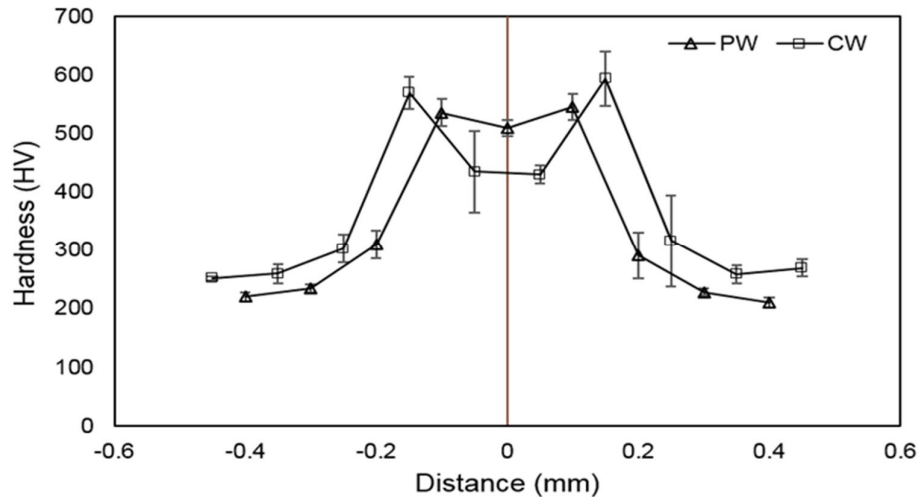
Figure 3. Hardness variation across weld area between continuous wave and pulse wave mode.

4.   Conclusion

In this study, the investigation of hardness variation of welded boron steel on CW and PW mode have been conducted. The conclusion can be summarized as follows:

i.   PW mode has better hardness distribution across weld area might lead to good strength.

ii.   The hardness width of CW mode is determined by high interaction time sufficient for wider temperature movement. The fast interaction time and also rapid cooling from PW mode create smaller HAZ width.

iii. High hardness at HAZ for both welding mode is due to optimum thermal experience transform boron steel to AHSS properties. Low hardness at FZ is due to high temperature applied for melt the surface lead to ferrite formation. Obvious hardness degradation observed for CW mode due to slow cooling rate related to molten pool movement.

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