A STUDY ON BEAD ON PLATE WELDING OF AA7075 BY LOW POWER FIBER LASER

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ABSTRACT

AA7075 aluminium alloy has many advantages due to its light weight, low density, high corrosion resistance, and high strength metal. In order to have a strong weld joint, the weld penetration should be maximized, as well as the heat affected zone (HAZ) and weld width should be minimized. Laser welding method can produce the weld joint with these weld characteristics. Fiber laser welding process was known to be the best laser welding method among other laser welding processes such are YAG, CO_2, and LD (diode) laser due to its power, high beam quality, and low cost maintenance. The important thing need to be considered for the laser welding is the focus point of the laser beam and the penetration depth. Bead-on-plate (BOP) welding was carried out by heating the surface of AA7075. The images of welded line were captured using an optical microscope and beam width was measured. The beam diameter of focus point is 570 µm at focal length of 120 mm. Penetration depth also was measured from the captured image of cross-section of BOP welded sample by optical microscope. Pulse wave (PW) welding mode process produced the optimum depth approximately 1.0 mm with keyhole penetration produced compared to continuous mode (CW) welding, which produced 0.153 mm penetration depth.

Keywords: BOP welding; AA 7075; Fiber optic laser; focus point; optimum depth; microstructure.

INTRODUCTION

Fiber laser welding method was already known since 1961 from the demonstration in neodymium-doped barium crown glass fiber and it is less mature air-clad and dual air-clad/photonic crystal fiber systems which promising the better system than existing technology such as Neodymium-doped: Yttrium Aluminium Garnet (Nd:YAG) laser [1]. The application of fiber laser welding have been widely used in industrial application since this laser technology is easily automated and robotized and it is important in mass production such as automobile, shipbuilding, aerospace, computer, medical, electronic and other industrial products and it can performed a high laser power with only single mode [2, 3]. In laser welding, the physical properties of material were very important since the effectiveness of this welding method is depending on it [4]. For aluminium welding application, the fiber laser welding usually was selected due to its low cost maintenance compared to other solid state laser and CO_2 laser [5]. In addition, it could save the cost by using low power fiber laser machine. It can be the great advantageous to the transportation industry when light weight vehicle could be produce with lower density where it can increase the fuel efficiency. The weldability of aluminium alloys in terms of weld penetration when welded using only low fiber laser can be the significance of this study and can replace conventional arc welding since there is no filler metal used which can affect its density. From previous researcher, fiber laser was used to weld 1XXX series aluminium alloys such as AA1050 [6]. Laser welding of aluminium alloys was difficult due to their high reflectivity and heat conductivity compared to the ferrous metal [7]. However, laser welding can form a keyhole penetration profile which the heat affected zone (HAZ) will be smaller and can produce a strong weld joint once it can weld the metal.

Aluminium alloys has less density which is 1/3 than that of steel and it has strong mechanical properties. AA7075 aluminium alloys had been chosen in this study since it was less study welded by fiber laser welding method and its application remain obscure. The 7000 series itself is a typical heat-treated alloys which can be categorized into high strength Al-Mg-Mg-Cu type represented by AA7050 and AA7075 where the principle added elements used are Al-Zn-Mg [8]. Focus point play important role since it can affect the peak power density of laser, which measured by a beam profiler [6]. Spot diameter contains the energy of laser light, which is equivalent to the Gaussian distribution ($1/e^2$) [7]. This paper reports the effects of welding mode, pulse and continuous on the penetration depth, type of penetration, and microstructure of BOP welded AA7075 using low power fiber laser.

EXPERIMENTAL SET UP

Experimental Procedure

For the experimental studies, AA7075 was prepared by dimension of 100 mm x 100 mm with 2 mm thickness using shearing cutting machine. The chemical composition of AA7075 parent metal was checked using spectrometer and the composition were listed in Table 1.

Table 1. Chemical composition of AA7075.

Elements	Al	Zn	Mg	Cu	Fe	Si	Mn
Compositions (wt.%)	89.8	5.58	2.28	1.6	0.27	0.07	0.02

Ytterbium Laser Machine-Quasi Continuous Wave (YLM-QCW) Fiber laser machine was used with wavelength ranged at 1.0 µm. The maximum average power for the laser machine is 200 Watt with the peak power of 9 kW for pulse mode (PW), while 250 Watt for continuous mode (CW). Bead on plate (BOP) welding was carried out using both welding modes. The angle of irradiation is 0̊. Weld width was measured from the sample surface for all of the BOP welded line. Welded sample then was cut using cut-off machine and hot mounted to produce the welded cross-section parts. The welded sample was then prepared through grinding, polishing and etching process. The etching process was very important in order to reveal microstructure of AA7075. Keller’s Reagent solution was used for the etching process and the composition is shown in Table 2. Penetration depth was measured from the welded cross section and the microstructure was observed by optical microscope (OM). From the metallographic observation, the microstructure behaviour of welded sample will be analyzed.

Table 2. Keller's reagent composition.

Chemical element	Volume (ml)
Water (H_2O)	94
Nitric Acid (HNO_3)	5
Hydrochloric Acid (HCl)	3
Hydrofluoric Acid (Hf)	2

Experimental Design

In this experimental study, both PW and CW welding modes were selected for the fiber laser machine. The parameters for this laser machine such as power percentage (W), pulse width (ms), pulse repetition rate (Hz), and welding speed (mm/s) was remain constant. The variable parameter was only the focal length (mm). Welding configuration was shown in Figure 1. From Figure 1, the focal length datum is measured from the sample surface to the protective mirror. Table 3 presents the selective parameter to conduct the BOP welding using low power fiber laser welding. Figure 2 shows the method to analyze the weld width on the welded AA7075 surface and the weld penetration depth. The smallest weld width will be concluded as the focus point. The highest depth of penetration will be concluded as the optimum depth at the optimum focal position.

Table 3. Bead-on-Plate laser welding parameter.

Parameter	**Pulse Mode (PW)**	**Continuous Mode (CW)**
Power (Watt)	180 Watt (90%)	225 Watt (90%)
Welding Speed (mm/s)	2mm/s	
Pulse Width (ms)	1 ms	-
Pulse Repetition Rate (Hz), PRR	20 Hz	-
Focal Length (mm), F	60 mm – 200 mm	

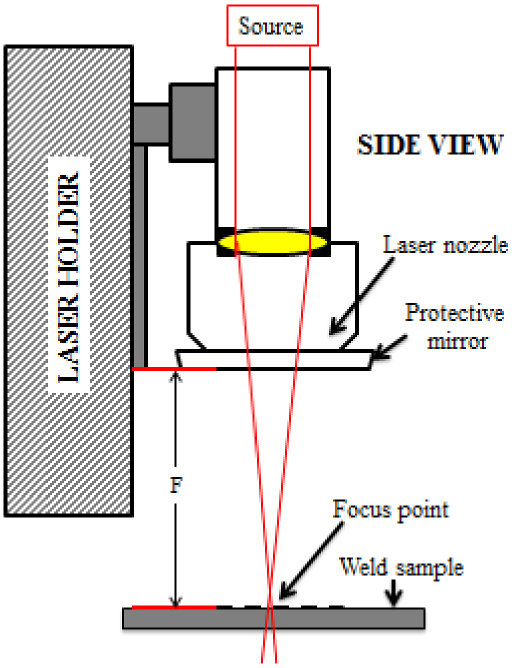


Figure 1. Fiber laser BOP welding setup.

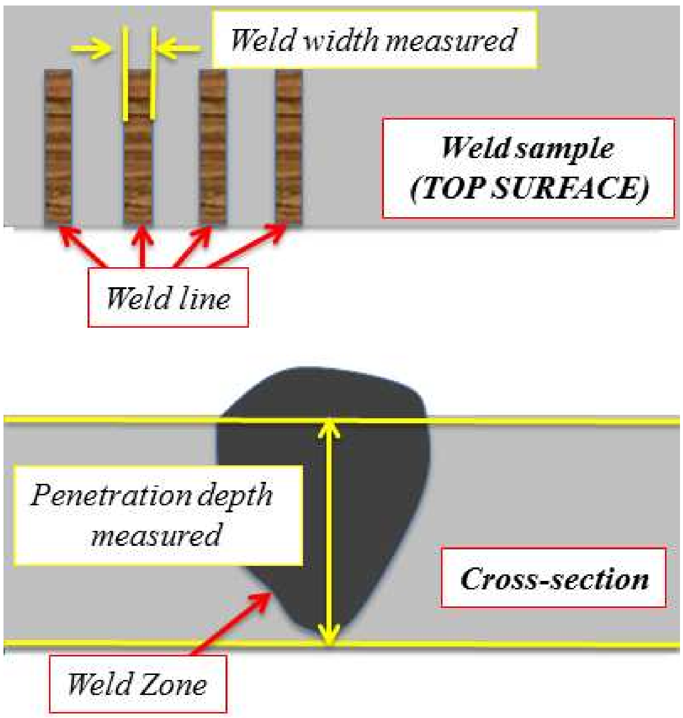


Figure 2. Weld width and depth of penetration analysis.

RESULTS AND DISCUSSION

Weld Width Analysis and Penetration Depth

15 weld lines (focal length ranged from 60 mm – 200 mm) had been made for both welding mode. Figure 3 and Figure 4 show the images of the welded line produced from the BOP laser welding for PW and CW mode, respectively. The result of measurement of the weld width and depth of penetration for both welding condition was tabulated in Table 4. The penetration depth measured from the sample cross-section obtained from the optical microscope.

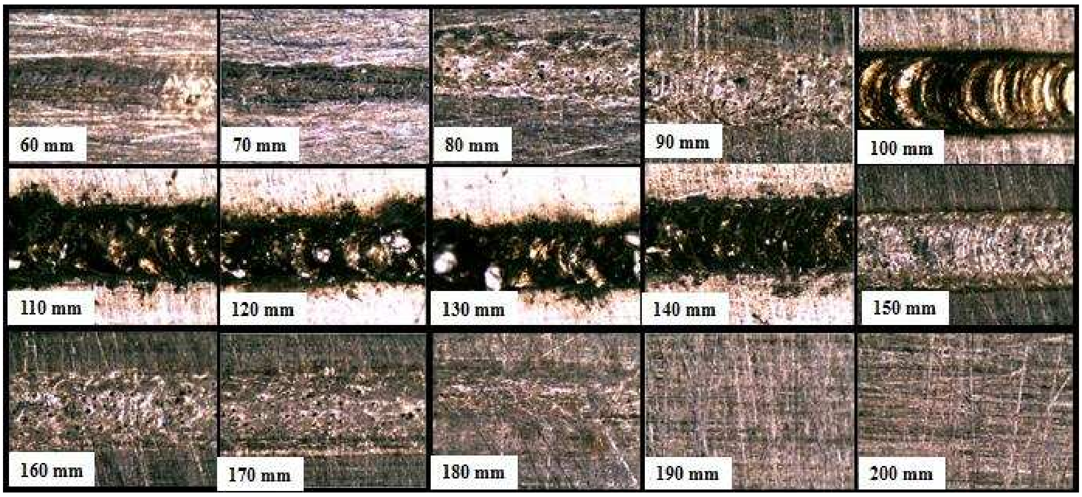


Figure 3. Weld line produced on sample surface (PW) (10x magnification).

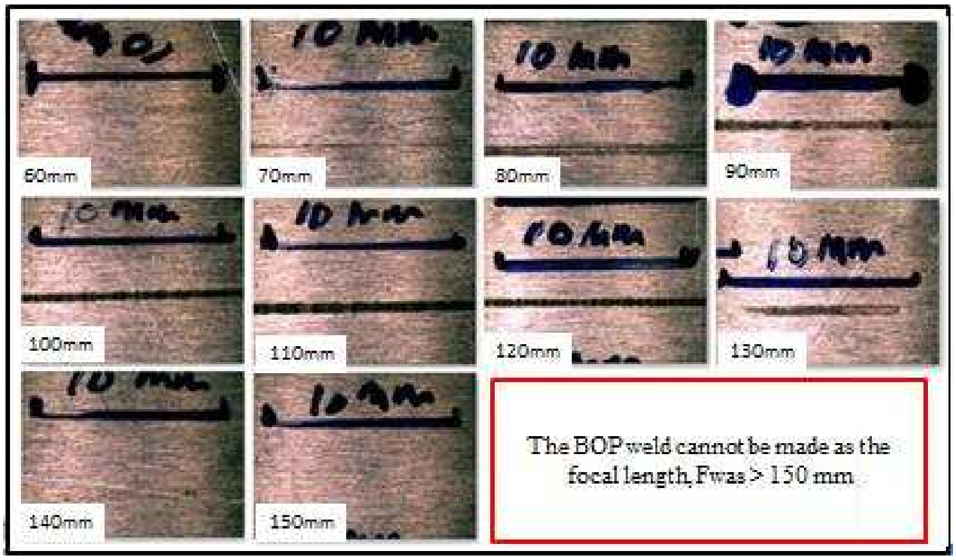


Figure 4. Weld line produced on sample surface (CW) (5x magnification).

From Figure 4, it was found that the weld line cannot be obtained at F=150 mm and above using CW welding mode compared to the PW welding mode. This is due to the laser power produced by PW was greater than the power produced by CW since PW have its high peak power at 9 kW.

Table 4. Weld width and penetration depth results.

Focal Length (mm)	Weld Width (µm)		Penetration depth (mm)	
	PW Mode	CW Mode	PW Mode	CW Mode
60	617	defocussed	0.030	defocussed
70	626	454	0.040	Non-observed
80	660	484	0.120	0.061
90	699	516	0.130	0.111
100	703	547	0.134	0.173
110	727	478	0.450	0.140
120	570	417	0.990	0.153
130	589	492	0.970	Non-observed
140	687	523	0.230	Non-observed
150	668	defocussed	0.140	defocussed
160	734	defocussed	0.100	defocussed
170	832	defocussed	0.040	defocussed
180	785	defocussed	0.050	defocussed
190	defocussed	defocussed	0.007	defocussed
200	defocussed	defocussed	0.012	defocussed

From Table 4, it was found that the smallest weld width measured was obtained at the F=120 mm for both welding mode with 570 µm and 417 µm for PW and CW mode, respectively. This can be concluded that the focus position of the laser machine is at F=120 mm.

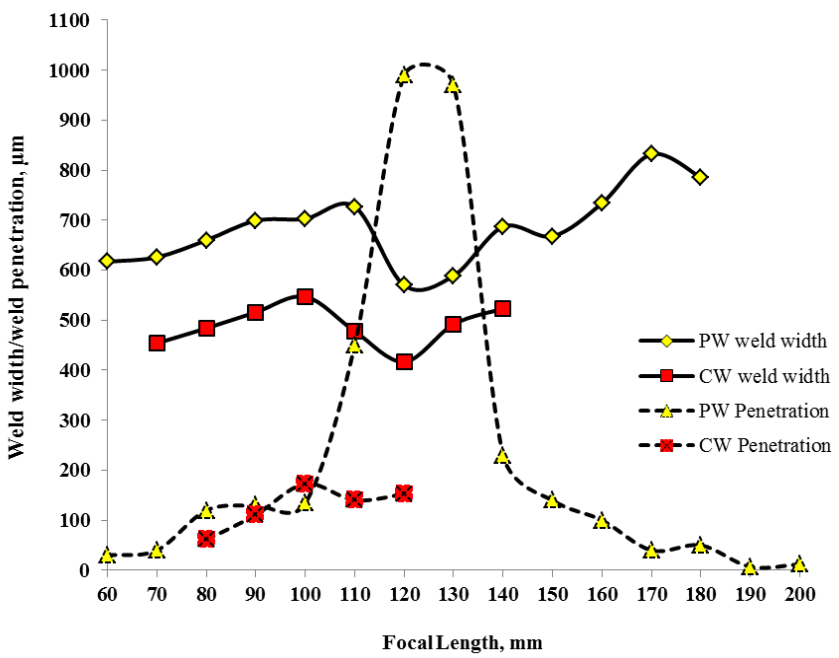


Figure 5. Weld width/weld penetration vs focal length.

Figure 5 shows the graph of weld width and depth of penetration versus Focal length. From the graph, it was clearly observed that both welding mode produced the focus position at the same focal length, F=120 mm. It was proved that the laser beam has the focus point at focal length of 120mm due to the smallest beam diameter produced for both welding mode. From the result, it was observed that PW mode produce highest depth of penetration at the focus point, F with 0.99 mm or half of AA7075 sample compared to CW mode, which only produced 0.173 mm as the highest at F=100 mm. This is due to the differences in the laser power since PW can produce 9 kW compared to CW, which only produces maximum power at 250 W. Higher laser power can produce a better penetration due to the amount of heat input produce was higher and efficient to make a weld joint with keyhole profile.

Microstructure analysis

After the BOP laser welding process, the cross section of the welded samples selected from the optimum depth for both welding modes was compared as shown in Figure 6. It was found that PW produced a narrow and deep penetration (keyhole profile) compared to the CW, which only could produce wider weld zone and low penetration depth (conduction profile). From Figure 6 (a), it was observed that the keyhole profile was produced at 0.99 mm depth, which is half of the sample thickness, 2 mm. However, underfill presents as the defects due to there is no shielding gas used in this experiment, where it could not protect the molten pool during the welding process.

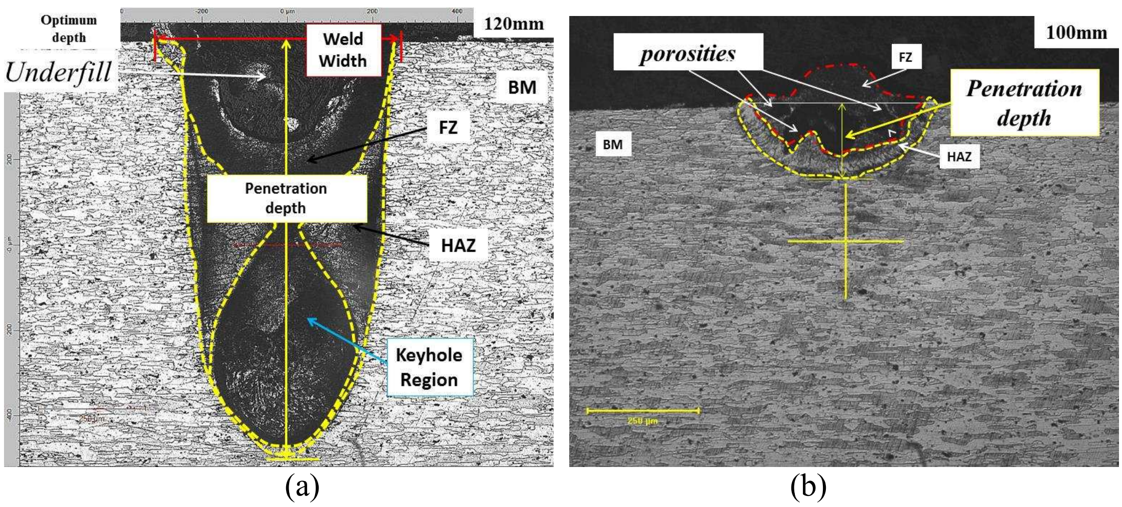


Figure 6. AA7075 BOP laser welded (a) PW (b) CW (10 x magnifications).

Figure 6 (b) shows that the CW produced conduction profile with 0.173 mm of penetration depth. It was found that porosity defect occurred at the welded zone of sample welded with CW mode, which also due to no shielding gas used. From the microstructure analysis, it was observed that PW welding mode could produces a good weld joint compared to the CW mode in term of weld seam profile, which can contributes to a higher welding joint. With low fibre laser welding machine, half depth of penetration could be achieved for 2 mm thickness of aluminium alloys. Double V-groove welding method could be selected and it can produces stronger weld joint compared to one side penetration for 2 mm thickness of AA7075.

Microstructure for base metal AA7075 shows spheroidal particles of black precipitate MgZn with the light grey of $FeAl_3$ particles [9] as shown in Figure 7, which present in aluminium solid solution and it was observed that the grains elongated horizontally in one direction. It was observed that the element presented in the base metal was proved to be Al, Mg, and Zn element with a small amount of Fe element.

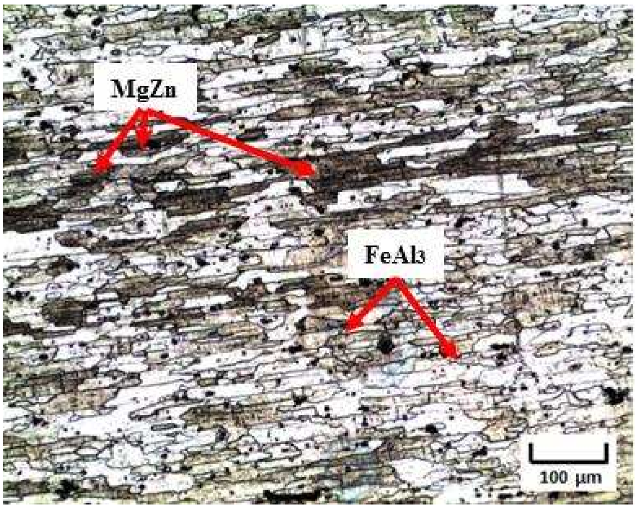
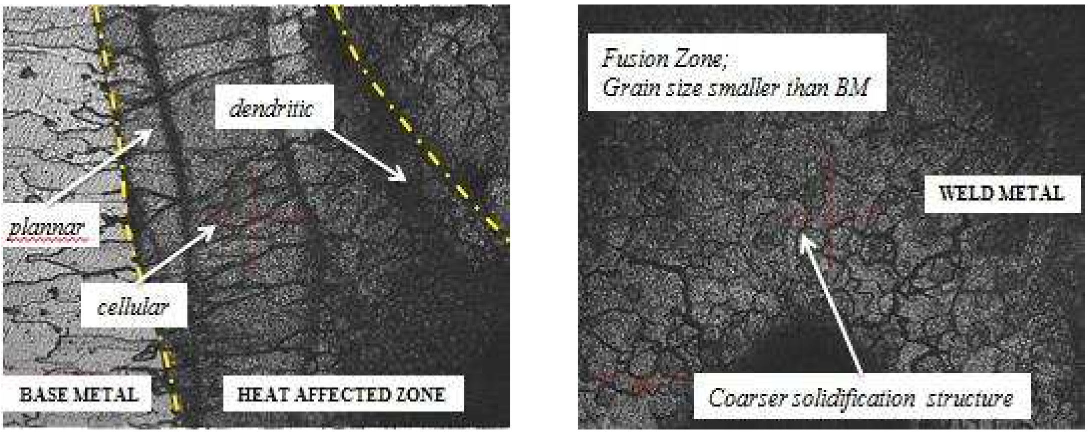


Figure 7. AA7075 base metal (10 x magnifications).



(a) (b)

Figure 8. Microstructure of sample welded by PW (keyhole) at (a) PMZ (b) Weld zone.

The best weld result was selected to discuss about the microstructure. Figure 8 (a) shows the microstructure changing from the base metal to weld metal through the partially melted zone (PMZ). The elongated grain structure starts changing to planar grain structure at the HAZ transition line because it was affected by heat from laser source and it turns into cellular grain structure at the centre of HAZ. Dendritic grain structure was observed at the transition line between HAZ and weld zone due to the high amount of heat produced. Basically, the hardness at HAZ was lower compared to the BM as it normally fractured at this point. From Figure 8 (b), it was found that coarser dendritic grain structure formed and the grain size was smaller compared to the grain size of base metal with the average value of grain size are 63.6 µm and 18.3 µm for base metal and weld zone, respectively.

CONCLUSIONS

From this study, it was proved that the weld joint of AA7075 sheet metal can be produced using low power fiber laser machine. The following points were concluded from this experiment;

1. PW welding mode shows the significant result with keyhole penetration observed from the cross-section microstructure approximately 1 mm penetration depth compared to the CW mode. Weld joint can be produced due to half penetration depth was achieved.
2. Both welding mode shows same result of focused point. The focused point measured from the sample surface to the protective mirror was at F = 120 mm.
3. The microstructure changes from elongated grain in base metal into dendritic grain in weld zone. Defects such as underfill and porosity occurred because no shielding gas was used during experiment.

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