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Investigation on the Effect of Pulsed Energy on Strength of Fillet Lap Laser Welded AZ31B Magnesium Alloys

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Abstract. AZ31B magnesium alloy have been hugely applied in the aerospace, automotive, and electronic industries. However, welding thin sheet AZ31B was challenging due to its properties which is easily to evaporated especially using conventional fusion welding method such as metal inert gas (MIG). Laser could be applied to weld this metal since it produces lower heat input. The application of fiber laser welding has been widely since this type of laser could produce better welding product especially in the automotive sectors. Low power fiber laser was used to weld this non-ferrous metal where pulse wave (PW) mode was used. Double fillet lap joint was applied to weld as thin as 0.6 mm thick of AZ31B and the effect of pulsed energy on the strength was studied. Bond width, throat length, and penetration depth also was studied related to the pulsed energy which effecting the joint. Higher pulsed energy contributes to the higher fracture load with angle of irradiation lower than 3 º

1. Introduction

Laser welding applications have been widely used in this century associated with the joining technology developments. There were a few commonly used lasers welding in industry such as CO2 gas laser, Nd: YAG laser, Disk Laser, and Fiber laser. Fiber laser is the newest laser technology where it was claimed to be the best method among the other laser welding types especially in term of operating cost [1]. In laser welding application, materials such as ferrous and non-ferrous metal could be joint it was proven that this method is a new welding technique which can produce high power with lower heat input, high strength joint and low distortion [2, 3]. A few of researcher have been used laser welding to joint non-ferrous alloys such as aluminium and magnesium alloys which is difficult to be joint due to their lower melting point compared to steel. Fiber laser is one of Q-Switch type lasers which could generate two modes, which is pulse wave (PW) mode and continuous wave (CW) mode. In this paper, PW mode was selected because it also could produce continuous welding with the usage of lower laser power compared to CW mode. Different values of pulsed energy will be studied in this experiment where the calculation of pulsed energy as shown in Equation (1) below.

$$\text{Average Peak Power (W)} = \text{(Pulsed Energy (EP))}/\text{(Pulse Duration }(\Delta t)) \quad (1)$$

Past researcher used PW mode in welding application of steels, alloys, and thin sheets metal [4-7]. However, they neglected the effect of pulsed energy on the welded metal. AZ31B was selected in this experimental work due to its characteristics of super light density, and high-resistance of corrosion. It was firmly used in automobile industry as it can reduce the cost and weight of the product [8, 9]. So

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far, the study on laser welding of AZ31B Magnesium alloys has been reduced especially towards the thin sheets AZ31B. Usually, unstable weld pool and crack was found on post weld magnesium. However, AZ31B could be welded with crack-free joints with lesser porosity and good surface quality [10, 11]. The intention of this experimental work is to investigate the effect of pulsed energy, EP of PW mode by low power fiber laser on the macrostructure evaluation and the joint strength.

2. Experimental Procedure

2.1. Material

AZ31B Magnesium alloy with thickness of 0.6 mm was used in this study. The major alloying element for this material is aluminium (Al), and zinc (Zn). Before the metal subjected to the laser welding, it was cut by dimension 53 × 20 × 0.6 mm. Samples were polished with 180 grit sand paper in order to remove the oxide layer presented at the welding area. The element composition was presented in Table 1 which collected from the spectrometer test.

Table 1. Chemical composition for as received AZ31B.

Element	**Al**	**Zn**	**Mn**	**Si**	**Cu**	**Fe**	**Mg**
Weight,%	2.8	1.2	0.4	0.02	0.002	0.02	Bal.

2.2. Welding Setup

Pulse wave (PW) mode was used in this experiment where the pulsed energy, EP used are 1.8, 2.0, and 2.2 J with constant pulse width and pulse repetition rate of 2 ms and 60 HZ, respectively. The angle of irradiations used is 2, 3, and 4 degrees and the welding speed used is 2, 3, and 4 mm/s. Figure 1 shows the laser welding condition in order to produce double fillet lap joint.

Fifteen samples were welded in this experimental work and the bond width, throat length, and penetration depth of all samples were measured and collected. Figure 2 shows the schematic illustration of the macrostructure evaluation. Tensile-shear test was carried out for all welded samples. The average values of three tested samples were collected accordingly to the number of experiment.

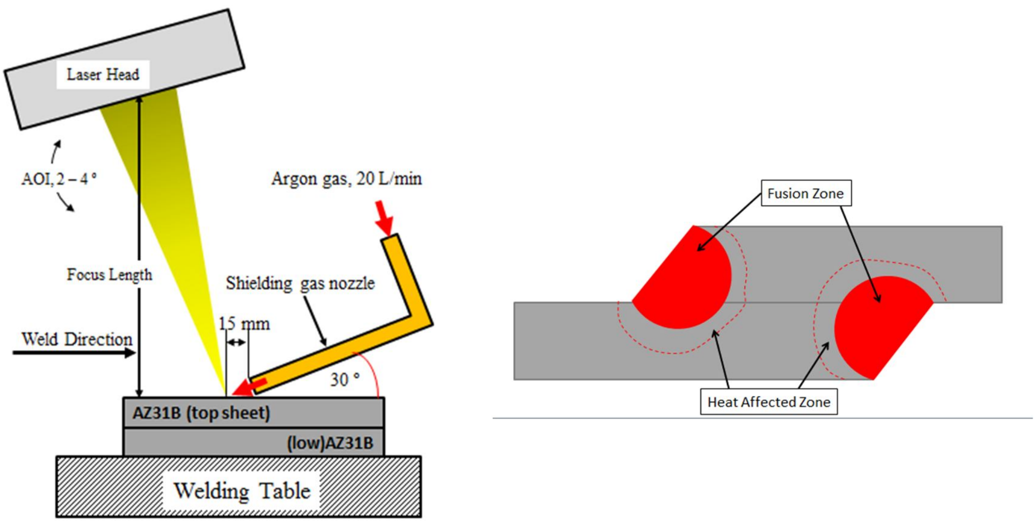

Figure 1. Double fillet lap laser welding condition.

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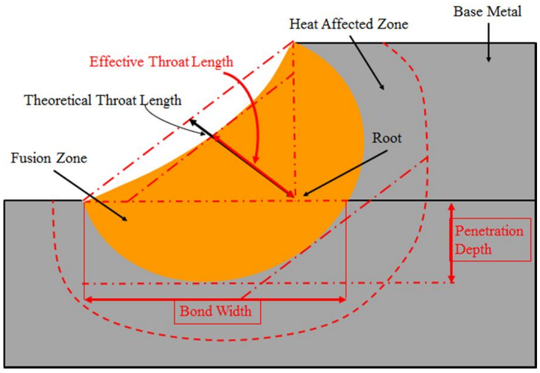

Figure 2. Schematic illustration of macrostructure evaluation.

3. Results and Discussion

The values of bond width and throat length were calculated and tabulated in Table 2 below. Bond width is the highest factor that determines the strength of the joint instead of penetration depth in case of lap joint method. The effects of the parameters on the fracture load were analyzed based on the macrostructure evaluation where the bond width, throat length, and penetration depth are measured and tabulated in Table 3.

Table 2. Fracture load result according to experiment order.

Sample	EP (J)	WS (mm/s)	AOI (°)	Fracture Load (N)
1	1.8	2	3	101.5
2	2.2	2	3	589.8
3	1.8	4	3	195.5
4	2.2	4	3	482.7
5	1.8	3	2	257.6
6	2.2	3	2	629.3
7	1.8	3	4	515.5
8	2.2	3	4	549.1
9	2.0	2	2	740.2
10	2.0	4	2	593.4
11	2.0	2	4	292.1
12	2.0	4	4	180.4
13	2.0	3	3	520.0
14	2.0	3	3	426.3
15	2.0	3	3	450.0

From Table 2, it was observed that sample 9 welded by pulsed energy 2.0 J, 2 mm/s welding speed and 2 ° irradiation angle has the highest fracture load with a value of 740.2 N. Meanwhile, the lowest fracture load possessed by sample 1 (EP 1.8 J, WS 2 mm/s, 3°) with a value of 101.5 N which was 7.29 % lower than the highest one. It was observed from this table that lower pulse energy with higher angle of irradiation contributes to the lower joint strength. From Table 3, it was observed that samples which have undercut defects experienced the lower fracture load. It was clearly seen that there was no undercut measured from the cross section of sample 9 compared to sample 1 which has 31 µm undercut depth. Highest undercut depth was observed from sample 2 (151 µm), however the fracture load still higher since it was welded with pulsed energy 2.2 J. From Table 3, three graphs were constructed in order to observe the effect of different pulse energy to fracture load when it affects the results of bond width, actual throat length, and penetration depth of the double fillet lap product.

Table 3. Fracture load result according to experiment order.

Sample	Bond Width (µm)	Actual Throat Length (µm)	Penetration Depth (µm)	Undercut (µm)
1	734	241	353	31
2	1079	156	802	151
3	669	199	270	43
4	1026	197	810	209
5	736	208	523	70
6	610	342	217	None
7	883	244	566	50
8	884	182	779	70
9	806	236	357	None
10	581	285	109	None
11	1090	232	629	125
12	736	204	383	58
13	674	196	347	None
14	664	208	346	None
15	670	195	342	None

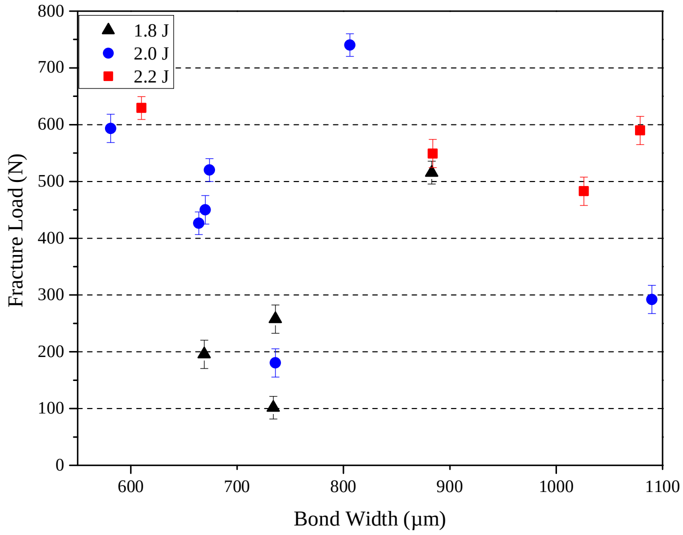

Figure 3. Fracture Load (N) versus bond width (µm) at different pulsed energy.

Figure 3 shows the relationship between average value of fracture load and the bond width of the joint at varying pulsed energies. High fracture load could be achieved as the pulsed energy is applied at 2.0 J with the middle value of bond width. The highest fracture load was observed from sample 9 with fracture load of 740 N which had 806 µm of bond width with no undercut defect presented as shown in Table 3. However, the fracture load was found to be lower at bond width of 736 µm although 2.0 J energy was used due to the undercut defect presents which has a depth of 58 µm. Larger bond width (1090 µm = 10.9 mm) produced by a 2.0 J pulse energy creates as low as 292.1 N as observed from sample 11.

High undercut depth of 125 µm was measured which was thought to be the main factor to the lower joint strength. Based on the figure, the lowest fracture load was found at the bond width 734 µm possessed by sample number 1 where the pulse energy used is 1.8 J. Undercut defect was observed from sample 1 with 31 µm depth. It has been observed that sample welded by pulsed energy of 2.2 J (highest energy used in experiment) produced the fracture load higher than 450 N. The highest fracture load as using pulse energy of 2.2 J was observed at 629 N and the lowest fracture load at 482.7 N as shown in Table 2.

Figure 4 and 5 show the relationship of the throat length and fracture load to the fracture load with three types of pulsed energy values. From Figure 4, it was shown that the highest fracture load was possessed by the samples with the pulse energy of 2.0 J and the throat length of 240 µm. At the same throat length of 240 µm with pulsed energy of 1.8 J, the fracture load was dropped to approximately 100 N. With throat length of 156 and 342 µm (sample 2 and 6), the fracture load was found to be approximately same at 600 N with the same pulsed energy of 2.2 J.

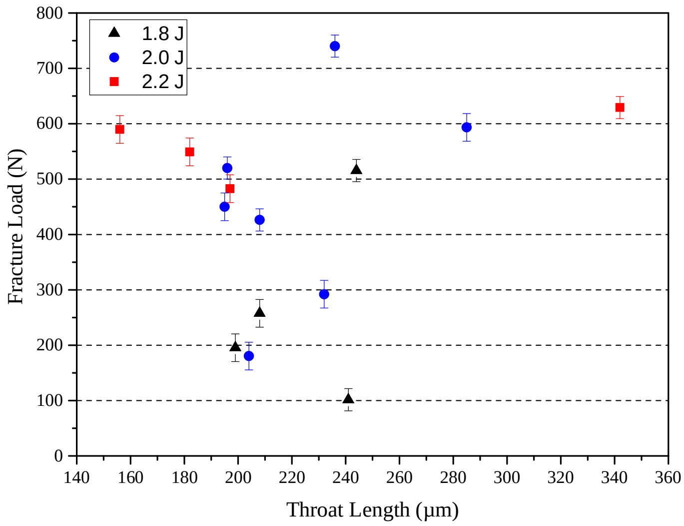

Figure 4. Fracture Load (N) versus throat length (µm) at different pulsed energy.

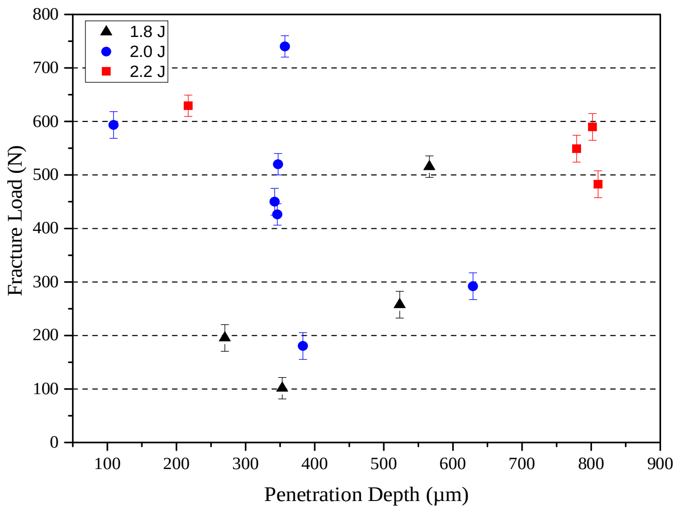

Figure 5. Fracture Load (N) versus penetration depth (µm) at different pulsed energy.

However, the differences in welding speed and angle of irradiation contributed to the larger throat length. Based on the figure, it was observed that the throat length increased to above 260 µm as the pulse energy used was 2.0 and 2.2 J. Meanwhile, pulse energy of 1.8 J produced throat length less than

260 µm with fracture load less than 600 N. Higher fracture load above 600 N could be achieved as the pulsed energy used above than 2.0 J with throat length 240 until 340 µm large. For Figure 5, it was observed that lower penetration depth of 109 µm (sample 10) possessed almost 600 N of fracture load using pulsed energy 2.0 J. However, the fracture load dropped to less than 300 N using 2.0 J of pulsed energy although the penetration depth was increased to 400 until 650 µm (sample 11 and 12).

It was observed in Table 3 that sample 11 and 12 possessed undercut defect at the weld region with undercut depth of 125 and 58 µm, respectively. For sample welded by higher pulsed energy (2.2 J), the penetration depth achieved was approximately 800 µm which indicated that the samples have already produced excess weld penetration. The fracture load produced for these samples were less than 600 N. However, higher fracture load above 600 N using the same pulsed energy could be achieved with penetration depth of 217 µm which was half of base metal thickness. Fracture load less than 600 N possessed by all samples welded with 1.8 J of energy.

4. Conclusion

The relationship of the fracture load with the macrostructure appearances such as bond width, throat length, and penetration depth with different values of pulsed energy has been studied. Fracture load as high as 740.2 N has been achieved with the bond width, throat length, and penetration depth of 806, 236, and 357 µm, respectively. The effective pulsed energy, EP to produce higher fracture load was 2.0 J. Based on the experiment, it could be concluded that the joint strength was higher if the usage of pulsed energy was higher as it could produce larger bond width. In addition, the usage of angle of irradiation affects the joint strength since it could produce undercut defect. Undercut defect could contributes to the lower joint strength.

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