PAPER • OPEN ACCESS

Feasibility of using acoustic method in monitoring the penetration status during the Pulse Mode Laser Welding process

View the article online for updates and enhancements.

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Feasibility of using acoustic method in monitoring the penetration status during the Pulse Mode Laser Welding process

M F M Yusof [1,2], M Ishak[1], M F Ghazali[2]

[1]Joining & Welding Research Group (J&W), Faculty of Mechanical Engineering, Universiti Malaysia Pahang (UMP),26600 Pekan, Pahang, Malaysia,

[2]Advanced Structural Integrity & Vibration Research Group (ASIVR), Faculty of Mechanical Engineering, Universiti Malaysia Pahang (UMP),26600 Pekan, Pahang, Malaysia,

E-mail: fadhlan@ump.edu.my

Abstract. In this paper, the feasibility of using acoustic method to monitor the depth of penetration was investigated by determine the characteristic of the acquired sound throughout the pulse mode laser welding process. To achieve the aim, the sound signal was acquired during the pulsed laser welding process on the 2 mm structural carbon steel plate. During the experiment, the laser peak power and pulse width was set to be varied while welding speed was constantly at 2 mm/s. Result from the experiment revealed that the sound pressure level of the acquired sound was linearly related to the pulse energy as well as the depth of penetration for welding process using 2ms pulse width. However, as the pulse width increase, the sound pressure level show insignificant change with respect to the change in the depth of penetration when the pulse energy reaches certain values. The reported result shows that this was happen due to the occurrence of spatter which suppressed the information associated with the generation of plasma plume as the product of high pulse energy. In this work, it was demonstrated that in some condition, the acoustic method was found to be potentially suitable to be used as a medium to monitor the depth of weld on online basis. To increase the robustness of this method to be used in wider range of parameter, it was believed that some other post processing method is needed in order to extract the specific information associated with the depth of penetration from the acquired sound.

1. Introduction

In recent years, there have been increasing demands on the laser welding process in wide variety of industries due to its ability in promoting small heat affected zone, aesthetic appearance, less post-weld machining process and high production rate [1]. Accordingly, numerous studies associated with laser welding process have been recorded since past several decades. One of the problem angle emphasized by many researchers are the optimum parameters for the process. However, many scholars hold the view that the studies on the robust monitoring method for the process are also essential. According to [2], process monitoring is important because it could promote greater control during the process. Over the past several years, many methods inclusive of electrical, thermal, optical as well as acoustic method for monitoring laser welding have been studied. Among those methods, acoustic method

received some great attention recently due to low cost, simple, high responsible speed and convenient features [3-5].

In many industries, defect such as incomplete penetration is intolerable because it might affect the strength of the component. Therefore, over a few decades, most of the researcher had tried to find the deeper understanding on the feasibility of using the acoustic method to monitor the penetration status during the laser welding process. In early stage, the correlation between acoustic spectral features and depth of penetration during the laser welding process on Aluminum 1100 have been investigated by Duly and Mao [6]. According to the result, it was reported that peak within 9 kHz to 10 kHz was increasing in its amplitude with gaining laser intensity which simultaneously increased the depth of penetration. Similar work also have been reported by Farson et al., [7] whereas the experiment was done on 304 stainless steel plate. However, the significant range was recorded to be within 1 kHz to 2 kHz in which its energy drops when insufficient penetration detected. In the extended study by Farson et al., [8], the investigation was done in broader range of power and travel speed. It was describe that the Root Mean Square (RMS) of acoustic signal was high at moderate full penetration and it was decreasing as the penetration status felt into partial penetration class. In other research involving high power or keyhole welding, Farson et al., [9] reported that the depth of penetration status could be classified into full penetration, overheat penetration and half penetration. In this study, the overheat penetration was referred to weld produced by excessive linear heat input which consequently caused a significant level of top surface concavity as well as larger heat affected zone. Unlike the other studies, Huang and Kovacevic [3], have demonstrated the use of spectral subtraction method prior to classification process in order to diminish the influence of noise during laser welding. It was described that the overall sound pressure increases align with the growing in penetration depth whilst the power density of frequency spectrum at 500 Hz to 1500 Hz was large for full penetration case as compared to half penetration. Since classifying the penetration status is insufficient for the case where the depth of penetration needs to be quantitatively measured, Huang & Kovacevic [10] have utilized the Artificial Neural Network analysis in attempt to quantitatively characterize the relation between the captured sound and the depth of penetration.

Commonly, in various laser welding application, the process was done either in continuous or pulse mode. Between both wave mode type, pulse wave mode seems to be advantageous due to several reason. By using pulse wave mode, high average power laser machine are unnecessary [1] in order to achieve high penetration. Moreover, pulse laser welding promotes very low heat input to the weld, which gives low distortion as well as giving more chances to weld heat-sensitive components [11-15]. Up to now, far too little attention has been paid to the study of sound behavior during the pulse laser welding. It is believed that the understanding on the sound behavior emitted during the pulse laser process would widen the option in using acoustic method for monitoring the weld penetration on real-time basis. In this paper, the characteristic of the acquired sound throughout the pulse mode laser welding process will be determine in order to investigate the feasibility of using this method to monitor the depth of penetration. The relation between sound pressure levels of the acquired sound with the depth of penetration will be presented and further discussed.

2. Experimental Procedure

In order to establish the relation between sound emitted from the pulse laser welding process and the depth of penetration, the experiment was set up as illustrated in figure 1. Basically, the bead on plate laser welding process was done onto the structural carbon steel specimen with dimension of 25 x 60 x 2 mm. Prior to the experimental work, each of the specimen was sanded using 120 grid sand paper intently to increase the absorptivity of the laser energy.   The peak power and pulse width were set to be varied according to table 1. The focal length and angle used in this experiment were fixed to 148 mm and 50 respectively. For each of the parameter set, the experiment was repeated 10 times. During the welding process, the specimen move with constant speed of 2 mm/s while the argon gas with flowrate of 15 L/min was used as shielding gas.

Meanwhile, the emitted sound was acquired using PCB piezotronics free-field microphone which capable of capturing the flat response signal between 20 Hz to 10 000 Hz. Prior to the acquisition process, the sampling rate was set to be 25.6 k. Sample/s which was determine according

to Nyquist theorem. Meanwhile, the sound pressure level, SPL was determine using formula as stated in equation (1) whereas P and Pref are the sound pressure and pressure reference respectively.
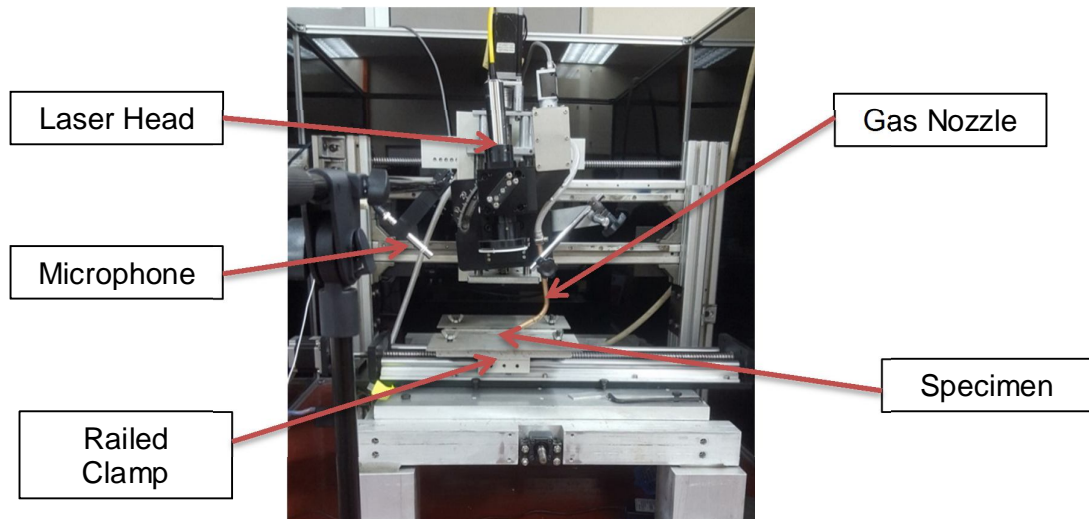
$$SPL = 20 \log_{10} (P / P_{ref}) \hspace{3cm} (1)$$

Figure 1. Experiment Setup.

Table 1. Parameter variation for pulse laser welding process.

Pulse width (ms)	Laser Peak Power (W)	Pulse width (ms)	Laser Peak Power (W)	Pulse width (ms)	Laser Peak Power (W)
	400		400		400
	600		600		600
	800		800		800
2	1000	4	1000	6	1000
	1200		1200		1200
	1400		1400		1400
	1600		1600		1600

3. Results and Discussions

In this work, the first question aimed to look into the acoustic signal behavior originated from laser welding process. As illustrated in figure 2, for laser welding with pulse width of 2 ms, it is apparent that the overall amplitude increased with gaining value of peak power. This trend further support the idea from the previous work [16, 17] whereas it was reported to happen because of the plasma plume size produced from the laser welding process with different peak power. According to Hoffman et al [2], the pressure produced from the plasma plume could produce sound. High air pressure produce sound with large overall amplitude and the amount of air pressure is depending on the plume size whilst it is rely upon the peak power.

As comparison was made with the result from the welding process with pulse width of 4 ms and 6 ms in figure 3 and 4 respectively, the striking observation emerged from the overall amplitude value. For both cases, the overall amplitude of sound barely changes at certain value of peak power. No significant change was recorded on the overall amplitude of sound signal when peak power was

1200W and above for welding process with pulse width of 4ms. Similar pattern also occur for laser welding process with pulse width of 6 ms when peak power was recorded to be above 800W. A possible explanation for the result trend might be found from the image captured during the welding process as presented in figure 5 to 7. Referring to the figure 5, with pulse width of 2ms, high amount of spatter occurs only when the peak power reach the maximum value. As the pulse width increase, spatter starts to take place earlier, For instance, based on the captured image, spatter was detected when the peak power reach 1200W and 600W for the case of 4ms and 6ms pulse width respectively. This could be discovered from figure 6 and 7. According to Dawes [1], one of the reasons of the spatter occurrence is the excessive laser power. Hence, by looking into the trend of spatter occurrence from this this experiment, it is believed that barely changed overall amplitude of the acquired sound was probably due to the large amount of noise produced by it. In essence, spatter could occur due to instability of keyhole caused by large amount of pressure from the evaporation of melt surface [18]. Meanwhile, in case of pulse laser welding, the amount of melt surface evaporation is relying on the laser energy which influenced by both peak power and pulse width together.
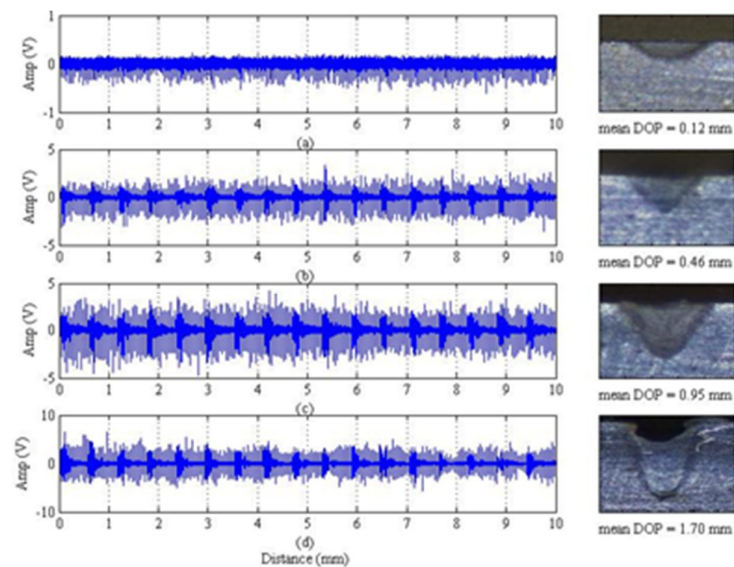

Figure 2. Sound signal acquired from welding process with pulse width of 2 ms and peak power (a) 400W (b) 800W (c) 1200W (d) 1600W.
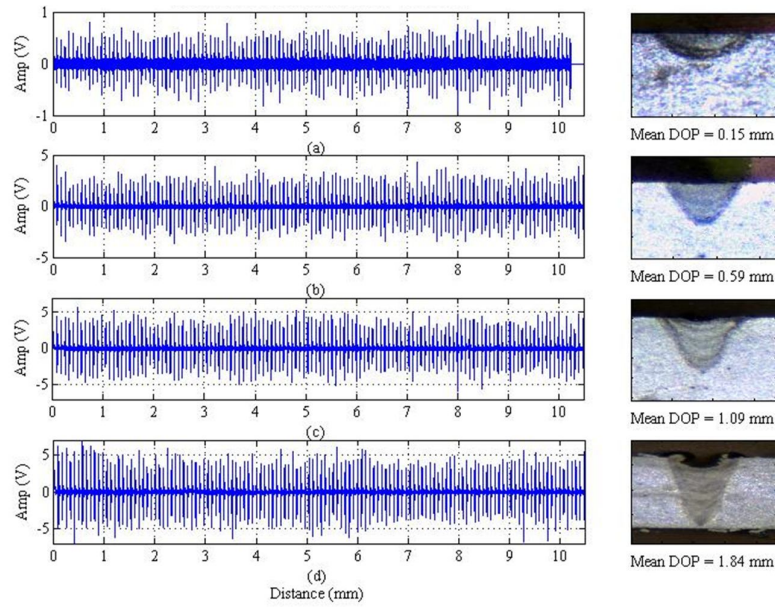
Figure 3. Sound signal acquired from welding process with pulse width of 4 ms and peak power (a) 400W (b) 800W (c) 1200W (d) 1600W.
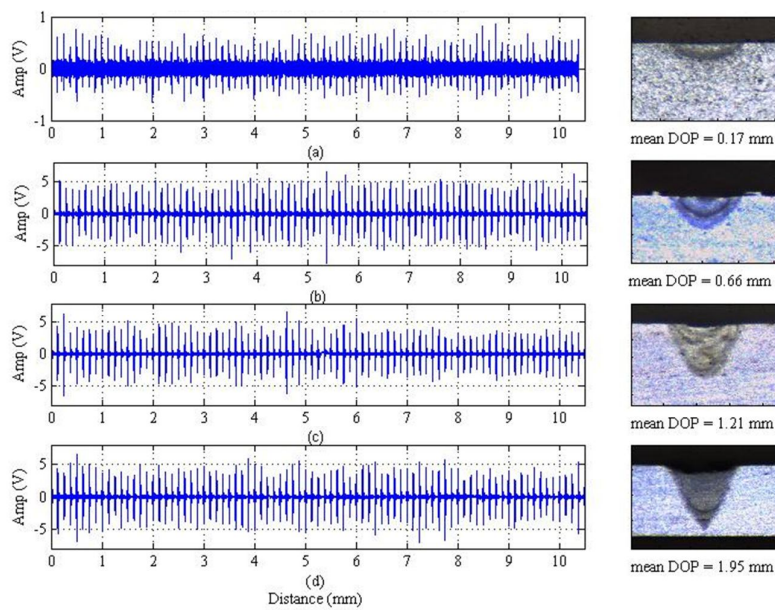

Figure 4. Sound signal acquired from welding process with pulse width of 6 ms and peak power (a) 400W (b) 800W (c) 1200W (d) 1600W.
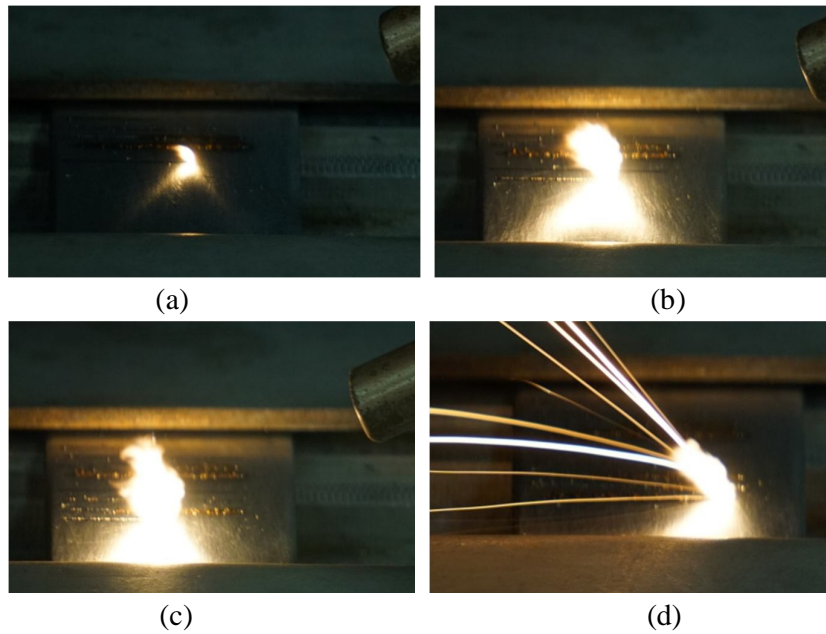
(a)   (b)

(c)   (d)

Figure 5. Laser welding process with pulse width of 2ms and peak power
(a) 400W (b) 800W (c) 1200W (d) 1600W.

(a)   (b)

(c)   (d)
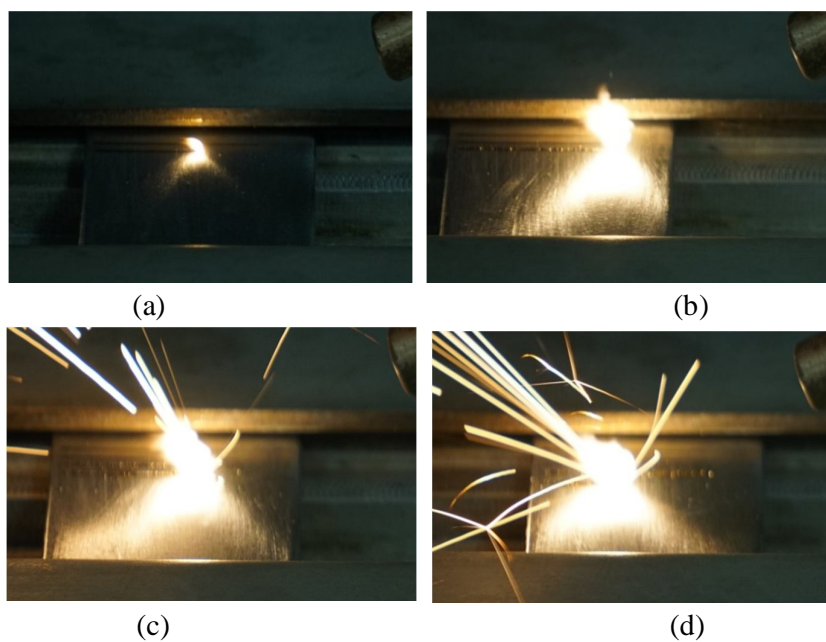
Figure 6. Laser welding process with pulse width of 4ms and peak power
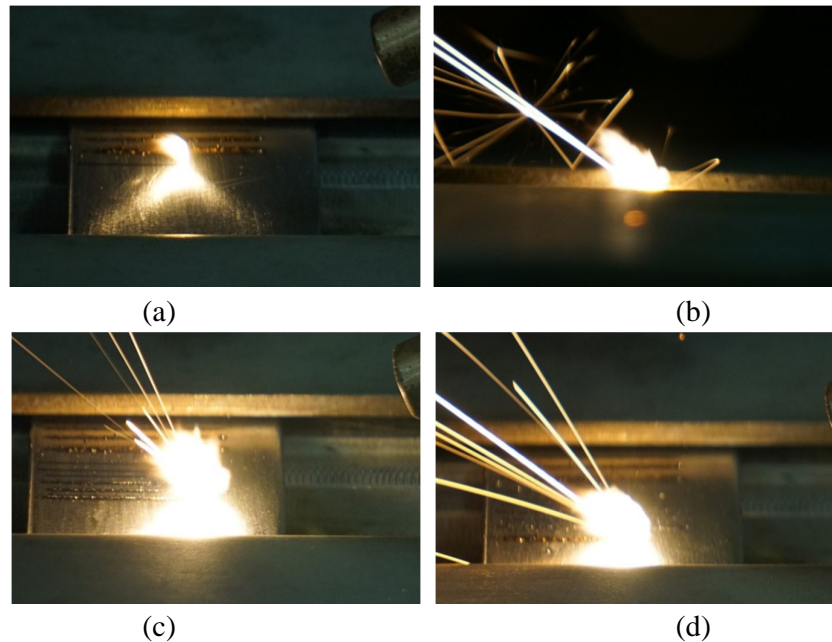(a) 400W (b) 800W (c) 1200W (d) 1600W.

Figure 7. Laser welding process with pulse width of 6ms and peak power
(a) 400W (b) 800W (c) 1200W (d) 1600W.

To show the overall relation between the acquired sound pressure, depth of penetration, as well a the laser energy, the plot between laser energy and depth of penetration was plotted as shown in figure 8 while the colerration between laser energy and sound pressure level was illustrated in figure 9. Both relations was plotted separatedly according to pulse width due to the reason that there will be a significant different in weld geometry cause by changing in pulse shape. Meanwhile, plotted sound pressure level was the average value from 10 repetitions for each experiment. As could be observed from the figure 8, conclusion could be drawn from the overall trend of the relation between laser pulse energy and depth of weld. It was evident that the depth of penetration is directly related with the laser pulse energy. However, contradict trend was recorded when relation between laser pulse energy and sound pressure level was made in figure 9. It could be obviously noticed that the sound pressure level values were slightly inconsistent when pulse energy reach certain values. This could be seen when pulse energy was 4 J and 4.8 J for the case of welding with pulse width of 4ms and 6ms respectively. Moreover, for both cases, the fluctuation range was within 1 dB to 2 dB. If the information from figure 8 and figure 9 was combined, it could be acknowledge that at pulse width and pulse energy was 4 ms and 4J, the depth of penetration just reach 0.99 mm. Meanwhile, the depth of penetration was recorded to be 0.66mm when pulse energy was recorded to be 4.8 J for the case of laser welding process with pulse width of 6 ms. As reported in the previous study [16, 17] the sound pressure would increase with the larger value of pulse energy. This is due to the amount of plasma plume that influenced by the pulse energy. However, in this study, the occurrence of spatter might suppress the sound generated by the plasma plume. Consequently, the trend of sound pressure level with increasing amount of pulse energy as well as the penetration depth was unclear at the moment the spatter starts to occur. In other words, insignificant trend was detected when the process are unstable.
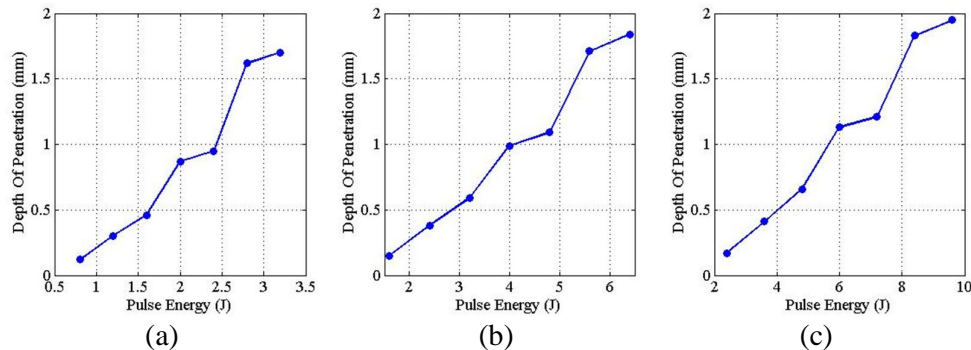
Figure 8. Relation between laser pulse energy and weld depth
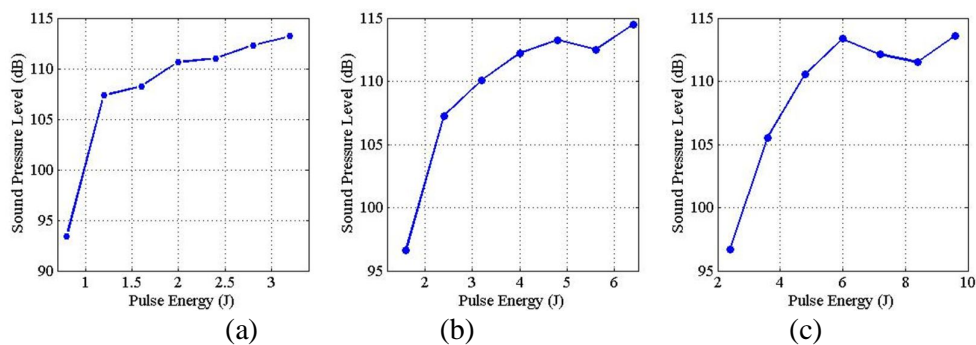(a) Pulse width 2ms (b) Pulse width 4ms (c) Pulse width 6ms.

Figure 9. Relation between laser pulse energy and sound pressure level
(a) Pulse width 2ms (b) Pulse width 4ms (c) Pulse width 6ms .

4. Conclusion

In this work, the feasibility of using acoustic signal to monitor the depth of penetration for the case of pulse laser welding was investigated. Result from the experiment revealed that the sound pressure level of the acquired sound was linearly related to the pulse energy as well as the depth of penetration for welding process using 2ms pulse width. However, as the pulse width increases, the sound pressure level show insignificant change with respect to the change in pulse energy as well as the depth of penetration when the pulse energy reaches certain values. The reported result shows that this was happen due to the occurrence of spatter which suppressed the information associated with the generation of plasma plume as the product of high pulse energy.

To conclude, the acoustic method was found to be potentially suitable to be used as a medium to monitor the depth of weld on online basis. However, some other post processing is needed in order to eliminate the influence of noise which affecting the trend of the result.

References

[1]   Dawes C 2008 Laser Welding A Practical Guide. United Kingdom (Abington Publishing)
[2]   Hoffman J, Szymanski Z, Jakubowski J and Kolasa A 2002 Analysis of acoustic and optical signals used as a basis for controlling laser welding processes *Welding International* 2002/01/01. **16** 18-25
[3]   Ao S, Luo Z, Feng M and Yan F 2015 Simulation and experimental analysis of acoustic signal characteristics in laser welding *The International Journal of Advanced Manufacturing Technology* **81** 277-287
[4]   Huang W and Kovacevic R 2009 Feasibility study of using acoustic signals for online monitoring of the depth of weld in the laser welding of high-strength steels *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* **223** 343-361

[5]   Luo Z, Liu W, Wang Z and Ao S 2016 Monitoring of laser welding using source localization and tracking processing by microphone array *The International Journal of Advanced Manufacturing Technology* **86** 21-28

[6]   Duley W W and Mao Y L 1994 The effect of surface condition on acoustic emission during welding of aluminium with CO 2 laser radiation *Journal of Physics D: Applied Physics* **27** 1379

[7]   Farson D, Hillsley K, Sames J and Young R 1996 Frequency–time characteristics of airborne signals from laser welds *Journal of Laser Applications* **8** 33-42

[8]   Farson D, Ali A and Sang Y 1998 Relationship of optical and acoustic emissions to laser weld penetration *Welding journal* **77** 142. s-148 s

[9]   Farson D, Ali A and Li X 1999 Laser weld penetration monitoring with multiple emission signal measurements *Journal of Laser Applications* **11** 47-53

[10] Huang W and Kovacevic R 2011 A neural network and multiple regression method for the characterization of the depth of weld penetration in laser welding based on acoustic signatures *Journal of Intelligent Manufacturing* **22** 131-143

[11] Frewin M and Scott D 1999 Finite element model of pulsed laser welding *WELDING JOURNAL-NEW YORK-* **78** 15-s

[12] Wu D, Ma G, Niu F and Guo D 2013 Pulsed laser welding of Hastelloy C-276: high-temperature mechanical properties and microstructure *Materials and Manufacturing Processes* **28** 524-528

[13] Assuncao E and Williams S 2013 Comparison of continuous wave and pulsed wave laser welding effects *Optics and Lasers in Engineering* **51** 674-680

[14] Liu J, Weckman D and Kerr H 1993 The effects of process variables on pulsed Nd: YAG laser spot welds: Part I. AISI 409 stainless steel *Metallurgical and Materials Transactions B* **24** 1065-1076

[15] Weckman D, Kerr H and Liu J 1997 The effects of process variables on pulsed Nd: YAG laser spot welds: Part II. AA 1100 aluminum and comparison to AISI 409 stainless steel *Metallurgical and Materials Transactions B* **28** 687-700

[16] Conesa S, Palanco S and Laserna J J 2004 Acoustic and optical emission during laser-induced plasma formation *Spectrochimica Acta Part B: Atomic Spectroscopy* **59** 1395-1401

[17] Khosroshahi M E, Pour F A, Hadavi M and Mahmoodi M 2010 In situ monitoring the pulse CO2 laser interaction with 316-L stainless steel using acoustical signals and plasma analysis *Applied Surface Science* **256** 7421-7427

[18] Kaplan A and Powell J 2011 Spatter in laser welding *Journal of Laser Applications* **23** 032005.