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Analysis of acoustic emission during abrasive waterjet machining of sheet metals

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Abstract. The present paper reports on the analysis of acoustic emission (AE) produced during abrasive waterjet (AWJ) machining process. This paper focuses on the relationship of AE and surface quality of sheet metals. The changes in acoustic emission signals recorded by the mean of power spectral density (PSD) via covariance method in relation to the surface quality of the cut are discussed. The test was made using two materials for comparison namely aluminium 6061 and stainless steel 304 with five different feed rates. The acoustic emission data were captured by Labview and later processed using MATLAB software. The results show that the AE spectrums correlated with different feed rates and surface qualities. It can be concluded that the AE is capable of monitoring the changes of feed rate and surface quality.

1. Introduction

Abrasive waterjet (AWJ) machining today have become more common in wide variety of precision machining process. AWJ itself can compete and complement other types of non-traditional machining process such as laser cutting, electro-discharge machining and plasma cutting due to its unique advantage [1]. AWJ works by focusing a highly pressurised waterjet and abrasive are subsequently forced to accelerate at a high speed. The focused stream would impinge on the work surface and caused a focused erosion in which it cut the intended surface. Apart from cutting application, AWJ has been used in other processes such as drilling, turning, milling and shot-peening [2]. Due to the nature of the process, it's a unique technology which greatly benefits form negligible cutting force, zero thermal distortion and high machining flexibility [3,4].

Typically, in AWJ machine environment due to nature of using water and abrasive sensor and monitoring devices suffers from the harsh corrosive environment. Sensors such as force sensor, vertical force sensor are expensive and impractical to be used in the continuous monitoring of AWJ process in which the sensor suffers from the erosive nature of AWJ [5–7]. In addition, the need for an automated control system in which it enables the monitoring of the health or the process is highly required in the development of fully automated machining system. This is where a more practical sensor which can withstand the harsh corrosive environment is needed in order to enable the development of a fully automated AWJ system. Such system would be capable of detecting on-line, the disturbance in the process, register the changes and in case of failure occurs, stop the machine[8].

Acoustic emission (AE) can be defined as 'transient elastic waves generated by the rapid release of energy from within a material of by a process' by the standard BS EN 1330-9:2000 for non-destructive testing. AE in particular have been applied in various field of manufacturing process due to its sensitivity to changes in process parameter, and can be applied in processes involving friction, impact, plastic deformation and fracture [9]. In addition, typically AE sensor captures frequency content in excess of 100kHz, it well beyond the frequency generally associated with the dynamic behaviour of machine tools and cutting tools, the AE frequency response taken can be associated with the cutting process itself [10]. In AWJ particularly the sources of AE can be found from several sources such as the elastic impact of abrasive particles, ploughing without material removed, crack formation/propagation, material removal and single grain fracture [3].

2. Experimental Setup

The experiment for the study was conducted at Faculty of Manufacturing Engineering, Universiti Malaysia Pahang. The experimental set-up consists of three major components.

2.1. Waterjet machine

A self-developed waterjet machine is used to perform the experiment. The developed CNC waterjet machine is shown in Figure 1. The system consists of an air-driven water pump that is capable of producing up to 30,000 psi (~ 206 MPa) of pressurised water stream. The waterjet cutting head consisted of the typical system of a sapphire orifice (0.15 mm in diameter), mixing chamber (0.76 mm in diameter), abrasive flow-controller and nozzle. The position and movement of the cutting head are controlled by a computer numerical control (CNC) positioning table.

Two different sheet metals were used for the experiment namely aluminium 6061 and stainless steel 304 with a thickness of 1.5 mm and 1.25 mm respectively. The traverse rate was varied to 5 different speeds at 5 m/s, 10 m/s, 15 m/s 20 m/s and 25 m/s respectively. The standoff distance was fixed at 5mm, while pressure and abrasive flow rate remained constant at 137 MPa and 2.0 g/s respectively. The abrasive used in the experiment was 80 mesh garnet. The signal was collected when the cutting reaches the midsection of the cutting line as illustrated in Figure 2. The cut quality was measured in terms of surface roughness and kerf taper widths (i.e. top and bottom widths). The surface roughness was measured by using Surfcom130A which has a resolution of 0.1 to 10 nanometres. The kerf widths were measured using an optical video measurement system.

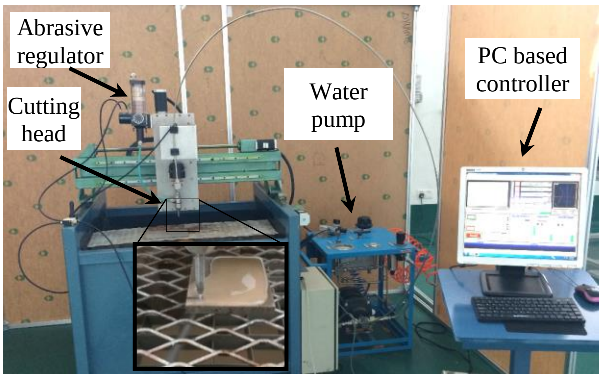

Figure 1. The self-developed CNC waterjet machine (The inset shows the cutting process).

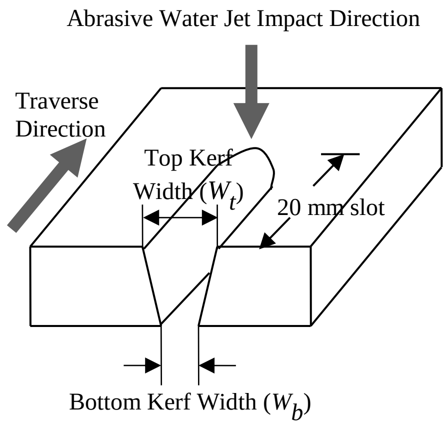

Figure 2. Kerf Geometry of an AWJ cut [11].

2.2. Acquisition system

National Instrument Compact USB DAC 9171 system coupled with National Instrument BNC 9223 module is used to acquire AE raw signal from the sensors. Labview software is used to collect the AE signals generated during the cutting process. The captured AE signals were further analysed in MATLAB software.

2.3. AE sensor
Physical Acoustic piezo-electric transducer PK15I AE sensor mounted on the work specimen are used to measure the acoustic signal. The sensor pre-equipped with an integrated pre-amplifier and an operating frequency range of 100 to 450 kHz

3. Results and discussion
Figure 3 shows the effect of traverse rate on surface roughness and kerf taper width for both aluminium 6061 and stainless steel 304. It can be seen that an increase in traverse speed increases the surface roughness of the cut as shown in Figure 3 (a). This result can be compared with the previous research done by Derzija Begic-Hajdarevica [12] which found that the increase of transverse speed has a great effect on the surface roughness especially the bottom of the cut. This is due to less overlap machining actions and fewer abrasive particles to impinge the surface at a higher traverses rate thus increasing the roughness of the surface. As a result, the abrasives could not erode the target material properly thus resulting in a rough surface. At a lower traverse rate, the abrasives particles will have enough time to impinge on the target material thus producing a well penetrated cut with a smoother surface. A slower traverse rate also gives a cleaner cut with a smoother surface [13]. For better quality of cut, the traverse rate has to be as low as possible as to give enough time for the jet to impact the surface thus causing the sufficient penetration.

The increase of traverse speed is found to be inversely proportional to the top kerf and bottom kerf width as shown in Figure 3 (b). This result can be compared with the findings of Wang and Jun [14,15] which reported that the top kerf width increases with the nozzle transverse speed because a slower pass allows more abrasive particle to impact on the work specimen and open a wider slot. This reason was further supported by Hascalik and Viscal Gupta [11,16]. In other words, the increase in the exposure time that was caused by decreasing traverse rate resulted in the increment in both of the kerf top and bottom widths.

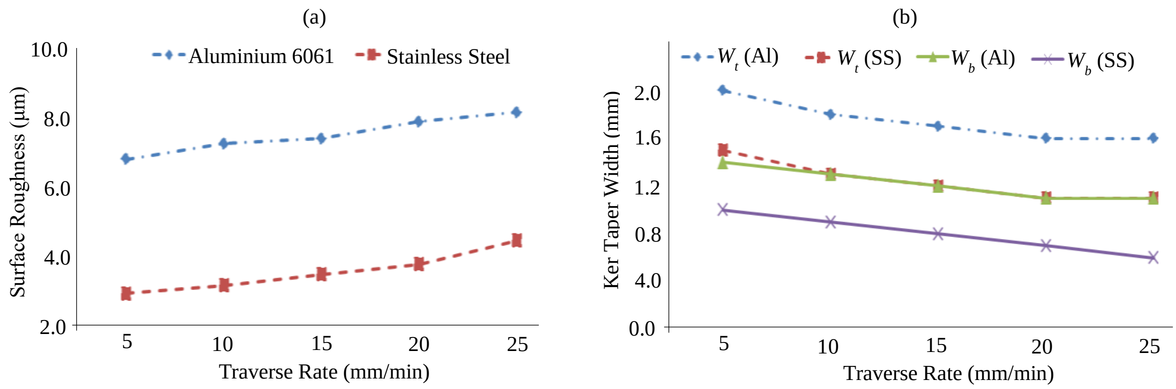

Figure 3. Effect of traverse rate on, (a) surface roughness and (b) kerf taper width.

The power spectral density (PSD) is a statistical estimation method that shows the strength variation of a signal in frequency domain. It is the statistical results of the structure response which excited by random dynamic loads and is a relationship curve with the values of PSD and frequency [17]. Figure 4 and Figure 5 show the PSD computed by Welch method for different traverse rates. It is difficult to interpret the data as the PSD signals generate spikes without any inclination to the frequency. This is also similarly found by Maia [18] which states that the signals generated by the PSD technique behaved as for random signals would generate lines without inclination. While for periodic signals, it would generate spikes with recurring frequency characteristic of the signal. Therefore, another approach has been used to differentiate the signal by using PSD via covariance method. This method causes the elimination of noise and the magnification of the cutting mechanism through the signal sum. Figure 6 and Figure 7 shows the PSD via covariance method. Based on both figures, the average PSD increases in amplitude as the transverse speed increases. This demonstrates that the PSD via covariance method has shown a more consistent trend with regard to varying the traverse rate. This is believed that the acoustic emission analysis using PSD via covariance method can be used to monitor the surface quality cut in abrasive waterjet machining process.

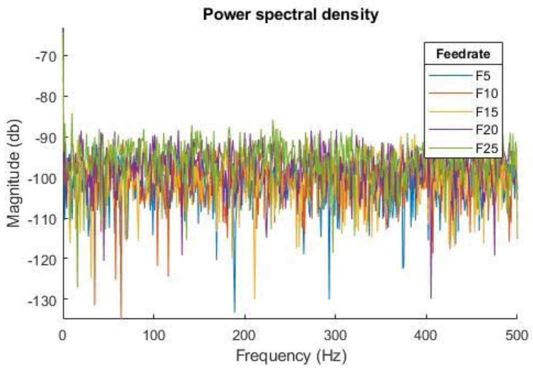

Figure 4. PSD of aluminium 6061.

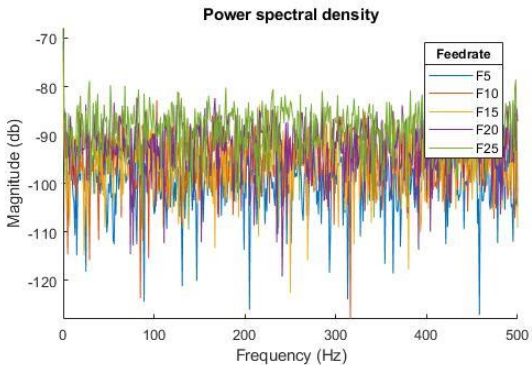

Figure 5. PSD of stainless steel 304.

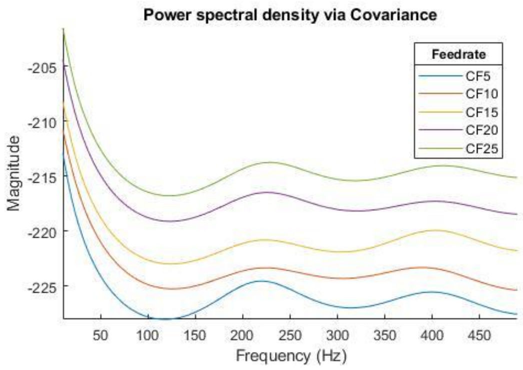

Figure 6. PSD via covariance of aluminium 6061.

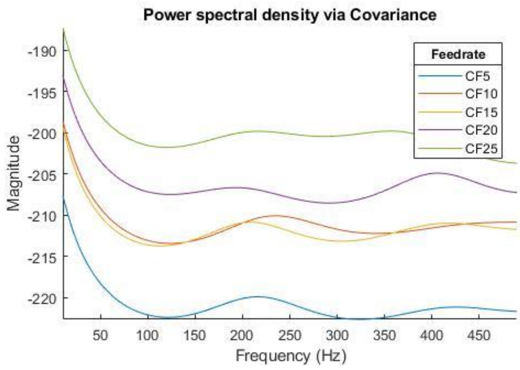

Figure 7. PSD via covariance of stainless steel 304.

4. Conclusion

This work reports the analysis of acoustic emission on the surface quality of aluminium 6061 and stainless steel 304 during abrasive waterjet machining process. Surface quality and traverse rate were assessed and the AE signal was collected during the experiment and further processed using PSD and PSD via covariance method. Thus, it can be concluded that monitoring the quality of the machined surface of sheet metals by the mean of PSD via covariance method is highly possible and the average PSD increases as the traverse speed increase.

Acknowledgments

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