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ANALYSIS OF ACOUSTIC EMISSION ON SURFACE ROUGHNESS DURING END MILLING

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ABSTRACT

This paper discusses the findings on the analysis of surface roughness with the acoustic emission (AE) produced during end milling process. Different parameters were chosen for each experiment, namely cutting speed, feed rate and depth of cut. All data collected from the AE sensor were captured using AEW in software and later analysed in MATLAB software. Fast Fourier Transform (FFT) method was used for data analysis to convert time domain into frequency domain signal, allowing the RMS, amplitude and frequency to be calculated. The results indicate that the most influential parameter to the surface roughness are firstly feed rate, followed by cutting speed, and finally depth of cut. It is found that as cutting speed increases, the surface roughness decreases with a higher amplitude of RMS signal. In case of increasing feed rate, the surface roughness increases with a higher amplitude of RMS signal. Lastly, increasing the depth of cut shows negligible effect towards the surface roughness and amplitude of RMS. The result have shown that the AE components responded effectively to the changes of occurrences in milling process with respect to specimen's surface roughness.

Keywords: surface roughness, acoustic emission, end milling.

INTRODUCTION

Milling is an old traditional process that is the heart of most manufacturing sectors around the world. It is commonly the most encountered metal material removal process in industry[1]. For over a century it is believed that the basic mechanism of surface quality and different kind of milling parameter can be understood easily. On the basis of experimental measurement of different milling parameters, and the application of proper statistical techniques, it was possible to predict the surface quality of the work piece [2]. However on the basis of real manufacturing environment, experimental parameters are hard to be applied due to harsh manufacturing environment that greatly emphasize profit and deadline. This is due to the ever changing machine parameters such as tool wear, spindle speed, the quality of coolant, temperature and so on that it is hard to get the exact same quality for mass production

Typically in the manufacturing sector the surface quality of a milled work piece would be measured in a separate production room or by sampling technique which takes time and may cost them loss of profit if the batch produced does not meet the specific requirement. Therefore there is a need of a continuous monitoring system that is able to monitor the quality of the surface produced without interfering with the overall manufacturing processes.

This is where acoustic emission (AE) comes into light, due to its robustness and sensitivity to process parameters and non-interfering system where it has been applied to various fields of manufacturing and research[3]–[8].Based on the BS EN 1330-9:2000 standard for non-destructive testing, AE can be defined as 'transient elastic waves generated by the release of energy of within a material or by a process' [9].It can be further explained as when a material are altered from its original form it would emit a sound, therefore phenomena such as corrosion, forming, wear, shear, tensile and compression mechanisms are generators of acoustic emission in a body[10]. While in term of ultrasound, AE would refers to the propagation of elastic waves above 20 kHz, which are normally generated at the cutting zone. The AE signal would be originated from the release of vibrational waves in the lattice of crystalline materials, which are caused by the rearrangement of internal structure of the material. There are two types of AE signal that are released from the event in material structure, the burst type and the continuous type. The burst type are associated with crack growth, chip impact or tangling, while the continuous type is related to the plastic deformation in ductile materials[2]. AE are considered superior and highly desirable compared to other traditional sensor. The main reason is because it has a relatively superior signal to noise (S/N) ratio and sensitivity required to characterize surface finish, subsurface damage and cutting force at an ultra-precision scale due to the extremely low cutting forces around 0.1N and power consumption present in the machining process. Apart from that AE sensor are rugged, simple, comparatively low cost and high durability to erosion which makes it popular compared to other sensors[11].

EXPERIMENTAL SETUP

Makino KE55 CNC milling machine was used for indirect evaluation of acoustic emission on surface roughness during end milling operation. The cutting tool used for the experimentation was a single 20mm 4 flute high speed steel. For the work piece, a 50x50x100mm 6061-T651 grade aluminium extruded billet was used during the study.

Physical Acoustic PK15i AE sensor was used to acquire the acoustic emission signal. It is equipped with an integral pre-amplifier and an operating frequency range of between 100 to 450 kHz. A DAQ Node from Physical Acoustic was used to convert the analog signal into digital

signal and later stored and analysed in AE win software. The surface roughness of the work piece was measured by Surfcom 130A which had a resolution of 0.1 to 10 nanometres.

Three machining parameters were selected to study the relationship between acoustic emission and surface roughness during end milling operation. The chosen parameters are cutting speed, feed rate and depth of cut which are shown in Table-1. During all the machining tests,a constant flow rate of coolant has been used

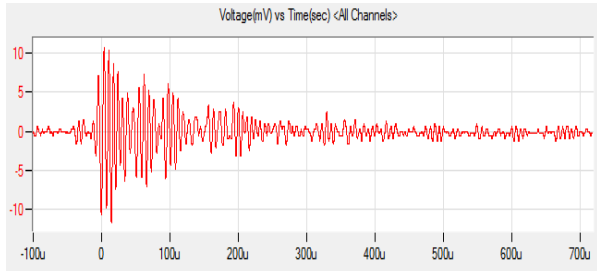
Table-1. Machining parameters and their respective levels.

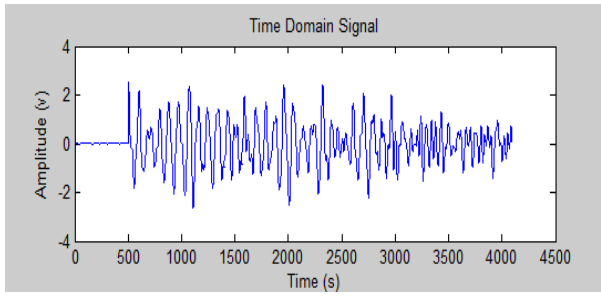
Parameters	Level				Unit
	1	2	3	4	
Cutting Speed	38	63	75	88	m/min
Feed rate	70	85	100	120	mm/min
Depth of cut	0.5	0.75	1.00	1.25	mm

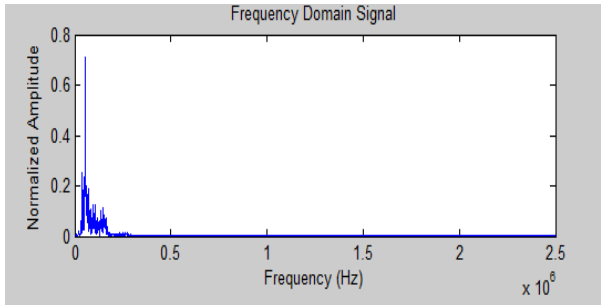
ACOUSTIC EMISSION ANALYSIS

The AE signals obtained from the system were processed and analysed to get some important data about the occurrences. AE signal captured from the conventional setup during machining process is a complex waveform and it consists of thousands numerous basic signals data. A lot of method can be used to analyse the AE signals such as root mean square (RMS), power spectral density (PSD), fast fourier transform (FFT) and time frequency domain (TFD). RMS and FFT are the most common methods that have been widely used by researchers to process the AE signals. While newer methods such as PSD are used to reduce the computational burden from other methods such as FFT to suit real time and online monitoring. While wavelet are a much newer method in which several complex information can be decomposed into several elementary information and later reconstructed with high precision thus allowing more components to be analysed. [12]. However, in the present study FFT method is used. As the DAQ system stored the data in digital values, the FFT are responsible to convert the time domain signals into frequency domain signals. I order to perform this operation, MATLAB coding for FFT is designed to get the data in command window. FFT is a very effective way in obtaining the frequency decomposition of the raw signals although the computational burden is high. The raw data of voltage (v) vs time (s) are collected in time domain signals and frequency domain signals.

Sample of raw data for AE signal and time and frequency domain signal







RESULTS& DISCUSSION

Effect of cutting speed on amplitude of rms signal and surface roughness

The effect of cutting speed on surface roughness is shown as in Figure-1. From the figure, it can be observed that the graph is in decreasing trend. As the cutting speed increases from 38m/min to 88m/min, the surface roughness decreased. It means that the surface finish is smoother when the speed is higher. Understandably, with a lower cutting speed, friction between work piece and the cutting tool is high due to the discontinuous chip deposited in the work piece and the tool interface. This leads to various interruptions during the cutting process, resulting in high force in machining, generating high energy, and producing high temperature in tool and work piece. This results into poor quality surfaces. If the cutting speed increases, there is a decrease in the coefficient of friction between the work piece and cutting tool interface, thus lowering the coefficient of friction with better surface quality. This results can be compared with the previous research by Ojolo Sunday Joshua[13] which found that with higher cutting speed, the surface roughness would decreases. Furthermore the use of cutting fluids in milling operation could improve the surface quality by reducing the temperature in the cutting area between the tool and work piece and also reducing the required cutting force.

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Figure-2, shows the effect of cutting speed on the RMS amplitude. The amplitude of AE rms increased with the increasing of cutting speed from 38m/min to 88m/min due to enhanced rate of strain hardening and stress development in the workpiece material. Hence, rms has a good sensitivity with cutting speed.

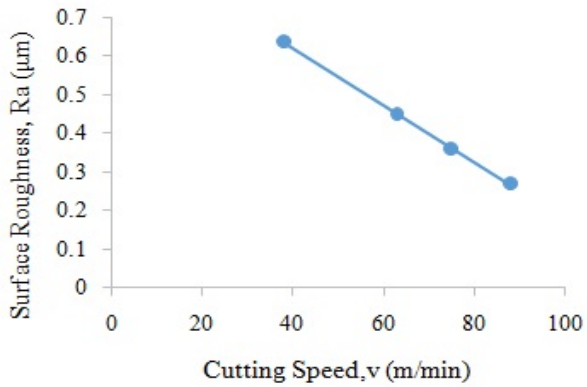

Figure 1. Effect of cutting speed on surface roughness.

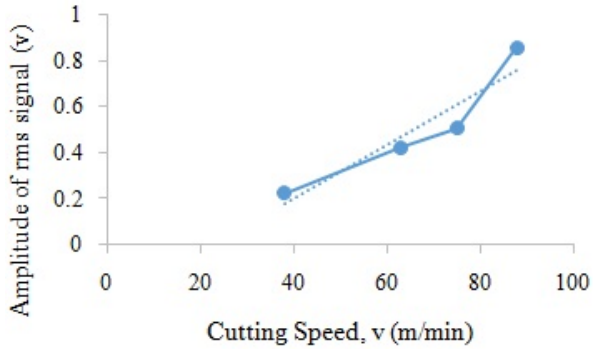

Figure -2. Effect of cutting speed on amplitude of rms.

Effect of feed rate on amplitude of rms signal and surface roughness

The graph of surface roughness against feed rate is shown in Figure-3. The graph shows that the surface roughness is directly proportional to the feed rate. When the feed rate increaes from 70mm/min to 120mm/min, the surface roughness also increases from 0.24 µm to 0.58 µm. The results indicate that the feed rate is the most influential cutting parameter that influence surface roughness due the the increasing linear trend found on Figure-3. Increasing the feed rate leads to poor surface finish. More chips are produced with a higher feed rate which will be consequently deposited between the cutting tool and the workpiece surface.This will cause more friction and higher heat generatedas well as cutting interruption thus resulting in poor surface quality. At a lower feed rate, chips formation during the milling process are continuous. This means less interruption between the workpiece-cutting tool and the cutting tool-chips leading to a reduced friction between the workpiece-tool interface. Increasing the feed rate, the chips become more discontinuous. In addition, coefficient of friction has also increased and it causes more interruption resulting in poor surface roughness. Palaniradja [14] has found a similar conclusion where increasing the feed rate results in a higher surface roughness.

Figure-4 shows the effect feed rate on the amplitude of RMS.It is found that as the feed rate increases from 70mm/min to 120mm/min, the amplitude of AE rms also increases. The trends follows the surface roughness which shows similar effect with increasing

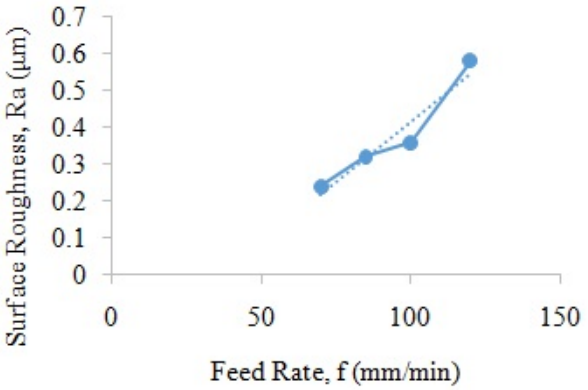

Figure-3. Effect of feed rate on surface roughness.

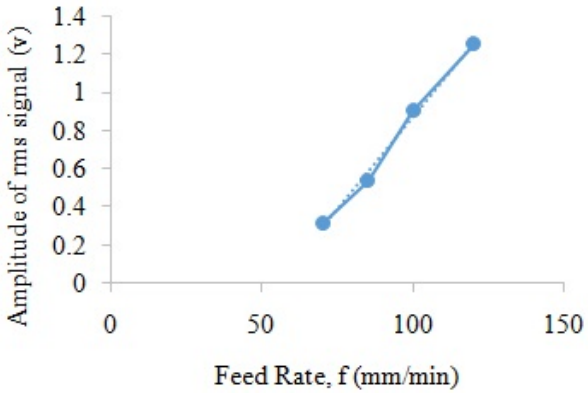

Figure-4. Effect of feed rate on amplitude of rms.

Effect of depth of cut on amplitude of rms signal and surface roughness

Figure-5 shows the effect of depth of cut on surface roughness. The graph follows a decreasing trend with an increase in depth of cut with an arbitrarily fluctuation on the surface roughness. Based on graph steepness, it can also be concluded that the increase in depth of cut has only a minimal influence on the surface roughness of the milled block. Increasing depth of cut causes only a little increase in the surface roughness. . This occurrence might be due to the width of contact between the tool and work piece surface, which leads to interruption in the cutting process. Greater force and energy are required for the cutting process and eventually causes the increasing degree of roughness especially at a higher depth of cut. This result agrees with the

investigation conducted by Hayajneh *et al.*[15]which also found that depth of cut has less significant effect on surface roughness.

Figure-6 shows the effect of depth of cut on the amplitude of RMS signal. In general, it shows an increasing trend with an increase of depth of cut although with some fluctuation. There is a sudden drop when the depth of cut is 1mm. This might be due to some disturbances during the milling process of the aluminium block.

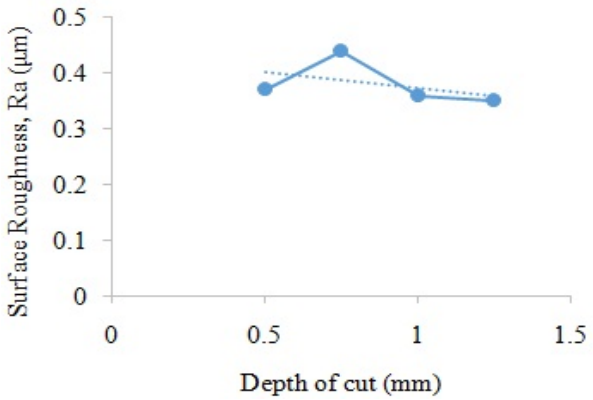

Figure-5. Effect of depth of cut on surface roughness.

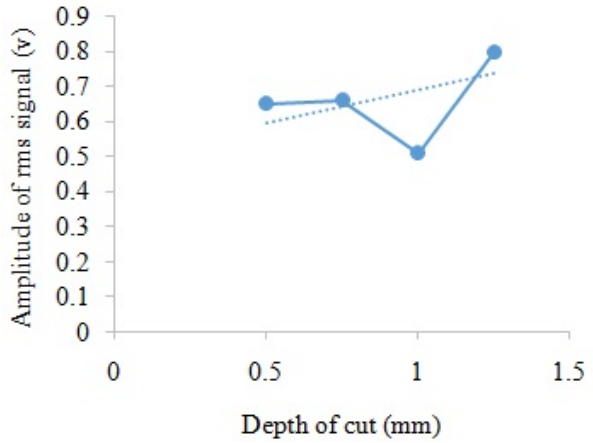

Figure-6. Effect of depth of cut on amplitude of rms.

CONCLUSIONS

The effect of end milling parameters on surface roughness were studied based on the analysis of acoustic emission during its operation. The surface roughness decreases with an increase in the cutting speed. However, the amplitude of RMS signal increases with an increase in the cutting speed possibly due to enhanced rate of strain hardening and stress development in the work piece material. Increasing the feed rate results in a higher surface roughness and amplitude of RMS. Finally, an increase in the depth of cut shows little influence on the surface roughness and amplitude of RMS. The results have shown that the AE components are responded effectively to the changes of occurrences in milling process with respect to specimen's surface roughness.

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