Acoustic Emission Characteristics in turning of AISI 303 Stainless Steel

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Abstract— The paper reports the acoustic emission (AE) characteristics in turning of AISI 303 Stainless Steel. During machining, the mechanism of material removal has significant effect on surface finish. The AE parameters such as RMS (Root mean square) and energy are selected as response variables during machining and demonstrated their effects on machining parameters. The analytical results are correlated with the surface roughness. The dry machining of AISI 303 Stainless Steel with tungsten carbide tool insert produces smooth surface with R_a value of 0.52µm.

Keywords-Acoustic Emission, AISI303 Stainless Steel, RMS, Energy

I. Introduction

Machining process monitoring is interesting and quite challenging part for the measurement and manufacturing domain. Due to its applicability to directly enhance the process optimization and system control, a lot of research is done so far. AE characterization is considered as an effective process monitoring technique as compared to other techniques. AE are transient elastic waves, from 25 kHz to several MHz, generated by the energy liberated from localized sources of materials suffering irreversible changes in their structure. AE signal is detected by mounting a piezoelectric transducer on the tool holder or the work piece and therefore, this technology seems to be promising for monitoring the machining process [1]. Past research work related to AE is mainly focused to monitor chip formation mechanism [2–5], surface generation mechanisms and surface alterations in continuous as well as intermittent cutting processes on various work materials. Alan et al. [6] correlated the cutting phenomenon and AE in a turning process with a steel work piece and a cermet tool. The investigation regarding the formation of AE waves during plastic deformation reported by Fisher and Lally [7] and by Gillis and Hamstad [8], can be applied to the generation of AE waves while chip formation. Mishina [9] and Hase [10] found that chip deformation under a high compressive stress is totally different from that associated with the tribological process. Hence, the AE signals related to tool wear involve the signals generated by wear and shearing of chips. Guo and Ammula [11] made an attempt to monitor the hard turning of AISI 52100 steel of 62 HRC work piece with CBN inserts using acoustic emission. The authors primarily attempted to monitor the response variable measured in terms of thickness of the white layer formed and surface roughness. Axinte et al. [12] correlated the quality of the machined surface after broaching with the response variables obtained from acoustic emission, vibration and cutting forces. Axintee et al. [13] have presented their work on correlating AE sensory data and machined surfaces in milling of Inconel 718 and found that more energy is required to remove the chip as the tool cutting edge wears out. Pawade et al. [14] observed that analysis of AE signal during turning of Inconel 718 can correlate the quality of the machined surface. They studied that cutting speed has a statistically significant effect on the AE frequency amplitude.

II. Experimental work

The present study is an attempt to analyze the AE signals with the surface roughness of AISI 303 stainless steel which is widely used in the applications like fasteners, gears, aircraft fittings, bushings and transmission shafts. It has been found that no work has been reported on AE characteristics of turning parameters in machining of AISI 303 steel. In view of the above, the investigation is done with the objective of correlating the turning parameters with AE characteristics in machining of AISI 303 steel. The sample of AISI 303 stainless steel workpiece in the cylindrical rod of ϕ 90×200 mm is selected for machining**.**

Chemical composition (% by weight)							
Fe	Ni	Cr	Mn	C	Si	S	P
69	9	18	0.2	0.1	0.1	0.040	0.2

Table 1. Chemical composition of AISI 303 stainless steel [15]

A tungsten carbide (K313) Kennametal tool insert is selected for cutting trials which is hard, low binder content and unalloyed WC fine-grained grade material having included angle of 80°, rake angle of -6° and clearance angle of 0°.

Fig. 1. Tool holder having nomenclature (ISO): PCLNL2525M12

A CNC Jobber XL lathe is used which has a variable spindle speed of up to 5000 rpm with a rating of 7.5 kW. Taguchi technique is widely recognized in many fields particularly in the development of new product and process in quality control as an important tool. Taguchi's approach dramatically reduces the number of experimental runs required to gather necessary data. The machining parameters were selected on the basis of past literature and L_{27} array is selected for experimentation with cutting parameters having 3 levels each. The L_{27} orthogonal array with cutting parameters and their levels are given in Table 2. The instrument used for measuring surface roughness is SJ 301 stylus type surface roughness tester which is capable of evaluating surface textures with a variety of parameters according to various national and international standards.
The AE setup used consist of one channel, USB cable, 18 bit A/D, Acoustic Emission subsystem, controlled and operated by a powerful, internal microprocessor, communicating with PC over a high speed USB 2.0 data connection. Fig. 2 shows the AE apparatus used in this work.

AEwin for USB software allows the viewing and recording of all acquired data using the typical data sets expected of all of our full systems. In this work, surface roughness, AE RMS and absolute energy are selected as response variables and measured during the turning operation. The experimental setup is shown in Fig. 3. In this work, an attempt is made to correlate the signals of acoustic emission to that of machined surface produced during cylindrical turning operation.

Parameters/Factors	Low	Medium	High
Cutting speed (m/min)	90	150	210
Feed (mm/rev)	0.12	0.22	0.32
Depth of cut (mm)	0.25	0.5	0.75
Machining Environment: Dry			

Table 2. Selection of Input parameter and their Levels

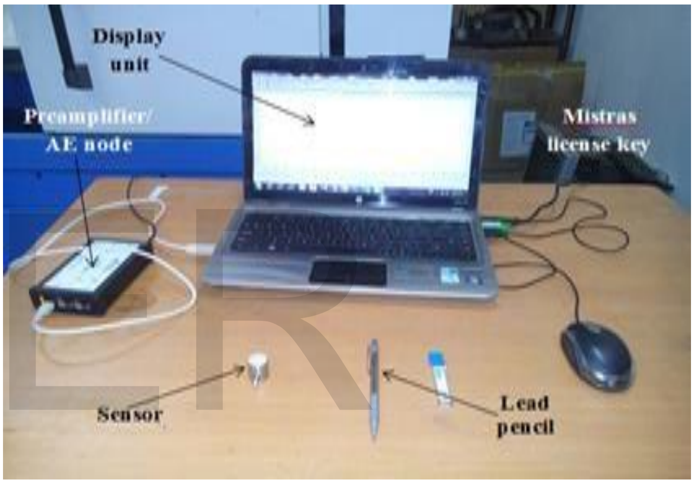

Fig. 2. AE apparatus

Fig. 3. AE experimental setup

III. RESULTS AND DISSCUSION

Surface roughness is measured in terms of arithmetic average value R_a. Surface roughness (R_a) values are measured using SJ 301 stylus type surface roughness tester. Effective comparison of surface roughness values R_a for different cutting parameters is studied. Table 3 shows the surface roughness values of the workpiece turned as per taguchiL_{27} array experimental design on CNC turning machine.

Experiment No.	Cutting speed V_c (m/min)	Feed *f* (mm/rev)	Depth of cut a_p (mm)	surface roughness replication 1 (R_a) µm	surface roughness replication 2 (R_a) µm
1	210	0.32	0.75	3.63	3.71
2	210	0.22	0.75	1.77	1.74
3	210	0.12	0.75	1.33	1.34
4	150	0.32	0.75	2.78	2.67
5	150	0.22	0.75	2.05	1.86
6	150	0.12	0.75	0.77	0.77
7	90	0.32	0.75	3.5	3.28
8	90	0.22	0.75	1.89	1.93
9	90	0.12	0.75	0.77	0.79
10	210	0.32	0.5	3.3	3.4
11	210	0.22	0.5	1.66	1.68
12	210	0.12	0.5	0.74	0.63
13	150	0.32	0.5	2.25	2.26
14	150	0.22	0.5	1.24	1.24
15	150	0.12	0.5	0.59	1
16	90	0.32	0.5	3.4	2.37
17	90	0.22	0.5	2.03	2.03
18	90	0.12	0.5	0.78	0.78
19	210	0.32	0.25	3.21	3.48
20	210	0.22	0.25	2.11	2.11
21	210	0.12	0.25	0.74	0.74
22	150	0.32	0.25	2.2	2.44
23	150	0.22	0.25	1.2	1.45
24	150	0.12	0.25	0.52	0.59
25	90	0.32	0.25	3.37	3.91
26	90	0.22	0.25	1.9	2.4
27	90	0.12	0.25	0.79	0.79

Table 3. Surface roughness values for L_{27} array with replication

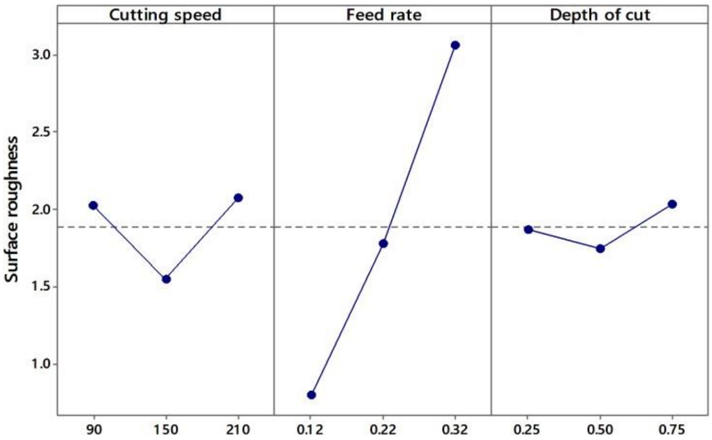

Fig. 4. Main effects plot for surface roughness

Fig. 4 shows main effects plot for cutting speed, feed and depth of cut on surface roughness (R_a). From the main effect plot, it is observed that increase in cutting speed decreases the surface roughness (R_a) by nominal value. The machined workpiece shows lower surface roughness at 150 m/min. Ihsan et al. [16] also found the same result for AISI 304 austenitic stainless steel. However, further increase in cutting speed increases the surface roughness. This happens because at higher cutting speed, machining chatter increases which damage the surface quality. The surface became very smooth as the feed rate or the depth of cut decreased. Hence, in these experiments, it is observed that surface roughness is higher at higher feed rate. At lower feed and depth of cut, good surface finish is observed.

Experiment No.	AErms replication 1	AErms replication 2	Absolute energy replication 1	Absolute energy replication 2
1	2.777	2.656	9.072E+10	8.988E+10
2	2.917	2.839	1.101E+11	1.452E+11
3	4.331	4.223	2.24E+11	2.367E+11
4	2.689	2.569	7.093E+10	7.134E+10
5	3.373	3.451	1.164E+11	1.211E+11
6	3.791	3.926	1.473E+11	1.773E+11
7	1.64	1.562	2.832E+10	2.765E+10
8	1.898	1.877	3.56E+10	3.63E+10
9	2.367	2.661	5.958E+10	5.856E+10
10	3.311	3.321	1.071E+11	1.457E+10
11	3.339	3.213	1.349E+11	1.444E+11
12	3.368	3.401	1.076E+11	1.124E+11
13	2.685	2.865	6.517E+10	6.817E+10
14	2.932	3.08	8.283E+10	8.683E+10
15	3.003	3.111	7.586E+10	7.7E+10
16	1.346	1.345	1.797E+10	1.97E+10
17	1.983	2.102	3.476E+10	3.457E+09
18	1.609	1.453	2.463E+10	2.304E+10
19	2.58	2.64	8.027E+10	8.009E+10
20	3.105	3.204	5.966E+10	5.63E+10
21	3.12	3.12	1.021E+11	1.208E+11
22	3.196	3.231	1.29E+11	1.4E+11
23	2.192	2.192	5.486E+10	5.56E+10
24	1.434	1.543	2.069E+10	2.09E+10
25	0.923	0.943	8.448E+09	8.328E+09
26	0.746	0.777	6.402E+09	6.025E+09
27	0.904	0.132	8.515E+09	8.753E+09

Table 4. AE signal values during turning operation

The main effect plots Fig. 5 shows the relation between different cutting parameters such as cutting speed, feed rate and depth of cut. From main effects plot, it is noted that as cutting speed increases there is a phenomenal rise in AE RMS. This is because of specific cutting energy which increases with increase in cutting speed thereby increasing the AE RMS also. It is also observed that with an increase in depth of cut, the AE RMS value also increases. This justifies that elastic waves generated are proportional to shear energy required during machining. AE RMS reduces as the feed increases from 0.12 to 0.32 mm/rev. At lower feed rate, the effect of hardened layer causes higher amplitude of AE signal. But, at high feed and high cutting speed, AE RMS value decreases because of temperature effects, which increase the ductility of deforming material.

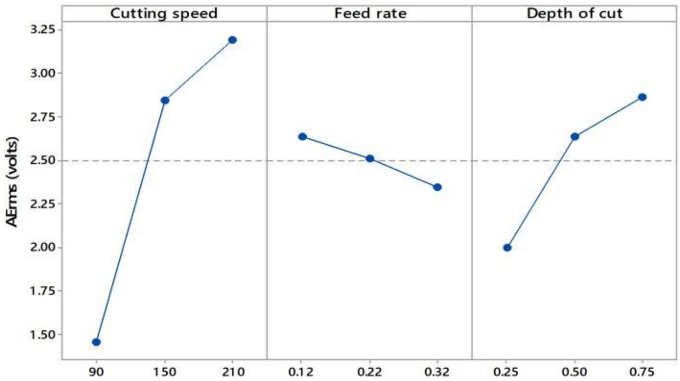

Fig. 5. Main effect plot for AE rms

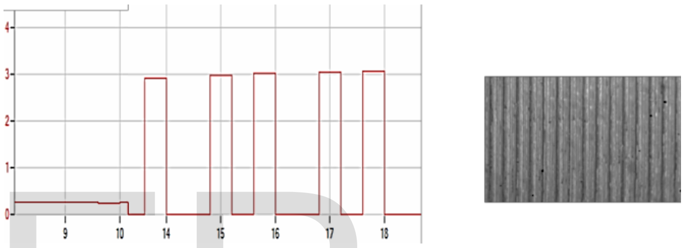

Fig. 6. Actual Profile of AE RMS for Expt No. 15

The Fig. 6 demonstrates AE RMS signals with respect to obtained machined surface in Experiment No. 15. It shows low amplitude and continuous signals and surfaces obtained from this run have a surface roughness values of 0.59 µm. Fig. 7 shows the main effects plot for AE absolute energy and machining parameters. From the main effects plot shown in Fig. 7, it is seen that AE energy increases slightly with increase in depth of cut. However, at higher depth of cut it rapidly increases. This is because deformation is severe at higher depth of cut, which dominates the strain hardening phenomenon, resulting in increase in the amount of AE energy released. The machining done with high cutting speed causes rapid deformation of material resulting in increase in AE energy. Also at higher cutting speed machining vibration increases, affecting the AE signals. It is observed that with increase in the cutting speed from 90 mm/rev to 210 mm/rev, AE energy is continuously increased. From the main effects plot, it is observed that AE Absolute energy decreases as the cutting speed increased from 90 to 150 m/min. However, further increase in cutting speed causes a large increase in absolute energy (average) which tends to deform the material rapidly and hence the energy emitted is high. At low feed rate, less variation in AE energy profile is observed. No variation in the energy profiles are observed for Experiment No. 15. The machined surface generated in this experiment shows high surface roughness value in the range above 3.3 µm. However, the machined surface obtained in experiment no. 15 is smooth showing very little surface damage. This surface shows a uniform AE energy profile.

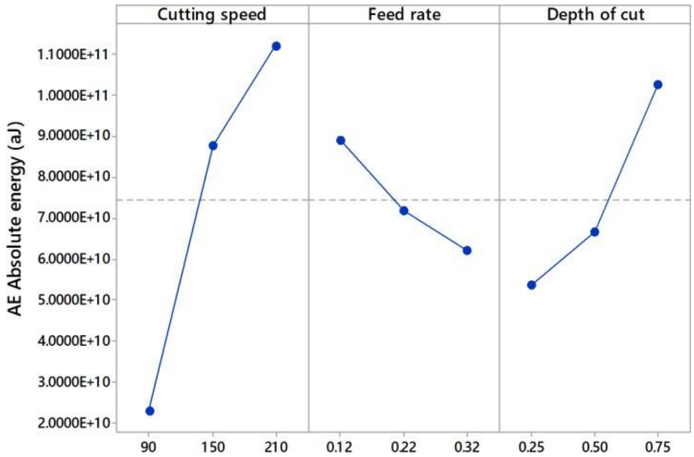

Fig. 7. Main effect plots for absolute energy

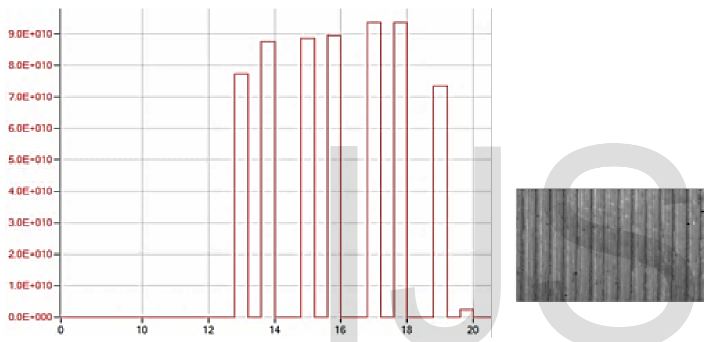

Fig. 8. Actual Profile of AE energy for Expt No. 15

IV. CONCLUSION

From this study, it is concluded that surface roughness variation can be monitored online by analyzing the AE parameters like RMS and energy. A correlation between the AE characteristics and surface topography shows that the AE energy profiles with more variations indicates surface roughness of 3.3 µm. However, AE signals with fewer variations in the energy profiles show a better-quality surface of roughness value 0.52µm.

V. REFERNENCES

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