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Studies On The Effect Of Different Nose Radius In Micro Turning Of Stainless Steel 316l

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Abstract- *This paper presents the effect of different tool nose radii of 0.03, 0.1, 0.2 and 0.4 mm on tool wear, surface roughness, chip morphology, signals acquired from different sensor such as Acoustic Emission (AE), accelerometer and cutting force dynamometer in micro turning of stainless steel (SS 316L). Experiments have been carried out with coated tungsten carbide insert up to 60 minutes. Measurements and the signals are analysed for every 1st minute and 10th minute. It is observed that tool wear and chip width is found to be increasing, while Ra is found to be following non-uniform trend with increase in the nose radius. From the AE and vibration signal analysis, it is found that the dominant frequency of the signals increases with increase in the nose radius. Among the cutting forces, the tangential force (Fy) is found to be more sensitive to the tool wear status compared to that of the thrust force (Fx) and feed force (Fz). This study will be useful for the manufacturers to monitor the condition of the tool online while micro turning of SS 316L.*

Keywords: Micro turning, Stainless steel SS 316L, Nose radius, Acoustic Emission, Accelerometer, Cutting force dynamometer, Tool Wear, Surface Roughness, Chip morphology.

I INTRODUCTION

Tool based micromachining is one of the emerging micromachining methods. It is the mechanical cutting of features with cutting edge/edges less than 1 mm and regardless of the size of the components manufactured [1], [2]. Tool based micromachining processes are broadly classified as micro turning, micro milling and micro drilling. Micro turning is used to produce micro components such as microelectrodes, micro shafts, etc, for different applications. It is the scaled down version of conventional turning process operating on a micro scale level of machining parameters [3], [4]. It is used to manufacture 3D micro-components with high aspect ratio and high geometric complexity, which are widely used in different fields such as auto motives, biotechnology, health care, communication, security, defence, etc [5], [6], [7]. Micro turning is normally carried out with a cutting insert of lesser nose radius. Difficulties in micro turning process include large cutting forces, vibrations due to size effects, minimum chip thickness, etc [8]. Hence, it difficult to detect tool wear, damages to the cutting edges etc, especially in the micromachining environment, which results in poor dimensional accuracy and surface quality [9]. Therefore, tool condition monitoring (TCM) in tool based micro machining processes is necessary. TCM is an in-process (online) method which detects the tool condition during the machining process and informs about the status of the tool. Few researchers incorporated sensors for TCM studies such as acoustic emission (AE), accelerometer, cutting force dynamometer, temperature, current, torque, strain, power, etc. to monitor the tool condition in macro-regime machining process [10], [11]. Few researchers have used different sensors in tool based micromachining process [12], [13], [14]. However, they have not studied the effect of nose radius during micro turning.

Literature surveys related to micro turning are briefly presented here. Rahman et al [15] carried out experiments on brass by varying the depth of cut, feed rate and spindle speed. It was found that depth of cut is the most influential cutting parameter in micro turning. At low depth of cut conditions, thrust force was the dominating force due to the plastic deformation, while larger depth of cut, tangential force is found to be much higher than that of thrust force. Patil et al [16] conducted some metallurgical studies such as grain

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size and density in the micro turned surface. They have observed that slight deviation in the micro structure leads to poor machinability. Mahajan et al [17] investigated macro-regime diamond turning of Oxygen Fuel High Conductivity Copper (OHFC). The effects of micro turning process parameters such as spindle speed, feed, and depth of cut and tool nose radius on surface roughness are studied. They have achieved Nano-meter level surface roughness values and also observed that tool nose radius is dominating than the parameters. Jagdesh and Samuel [18] studied the effect of micro turning on the surface roughness and cutting forces while machining titanium alloy. They have observed that cutting force is decreased with the increase in the cutting speed. They have concluded that the surface roughness is mainly influenced by the nose radius and the uncut chip thickness. Gopikrishnan et al [19] have investigated micro turning of aluminium alloy (AA 6061) using multiple sensors. They have observed that Ra, chip width and cutting forces were increased with increase in the tool wear. Tangential force is found to be more dominant than the thrust and feed force. From the signal analysis, they have observed that during machining with good tool condition, the dominant frequency of the AE and vibration signals are found to be 81 kHz-110 kHz and 2.07 kHz-3.84 kHz respectively, whereas with the worn out tool the dominant frequencies are shifted to higher levels. From the literature review, to the author's knowledge, it is observed that there were only few attempts have been made by researchers to study the effect of nose radius in macro-regime turning and no attempt has been made in micro turning. Therefore, in this work, an attempt has been made to study the effect of different nose radius during micro turning of SS 316L using multiple sensors approach.

II EXPERIMENTAL DETAILS

The experiments were carried out with multi process micro machine tool DT110 with a speed range of up to 5000 rpm (Figure 1). Micro turning is carried out up to 60 minutes at a speed of 47 m/min, feed of 20 m/rev and depth of cut of 50 m. The levels of these parameters are selected based on the preliminary experiments carried out by Response Surface Methodology (RSM). The cutting tool used in this study is the Sumitomo make triangular shaped multi-coated tungsten carbide insert with 0.03, 0.1, 0.2 and 0.4 mm nose radius. The cutting tool inserts are clamped to the tool shank which is mounted on the tool post. Work piece material is stainless steel SS 316L (Composition: C 0.03%, Mn 2%, Si 0.75%, S 0.03%, P 0.045%, Ni 10%, Cr 18%, N 0.10% and rest Fe), which is mostly used in the medical applications for cardiovascular, otorhinology, etc. [20]. SS 316L is in the form of a cylindrical rod with an initial diameter of 6 mm and machining length of 20 mm. Tool wear is measured by the non-contact video measuring system (VMS). Due to the low depth of cut, the nose wear is found to be more dominant than flank wear. The nose wear is measured from the tip of the top surface of the tool to the damaged portion in the nose edge of the tool. Ra is measured with the contact surface roughness tester. Chip width is measured using the non-contact VMS. Chip morphology studies are carried out by collecting the chips at regular intervals (every 1st minute and 10 minutes).

AE Signals are collected using AE, accelerometer and cutting force dynamometer. AE sensor (Make: Kistler,Model: 8152) is used to collect AE signals with a frequency range of 30 to 900 kHz. A compatible coupler (Make: Kistler, Type: 5125B) is used to amplify the AE signals obtained from the AE sensor. Thereafter, the amplified AE signals are converted into digital signals by using the BNC-2110 connector through the DAQ card. The sampling frequency of the AE signal is 2 MHz. Piezoelectric accelerometer (Make: Kistler, Model: 8702B) is used to collect the vibration signals with a frequency range from 1 to 10 kHz. A compatible coupler (Make: Kistler, Type: 5110) is used to amplify the vibration signals obtained from the accelerometer. The sampling rate of the vibration signal is250 kHz (250,000 samples per second). The data collected from the AE and accelerometer are transferred to the PC and then analysed off-line in the time domain and frequency domain at regular interval of time (10 minutes), to derive the necessary information about the condition of the tool. Two lakh data points are recorded for each machining trial. Out of which first 65536 data points were selected for the time domain analysis and first 2048 data points were selected for the dominant frequency analysis using MATLAB (R2010a). Piezoelectric cutting force dynamometer (Make: Kistler, Model: 9256C2) is used to collect the different forces arises during machining such as thrust force (Fx), tangential force (Fy) and feed force (Fz) with the sampling rate of 1000 Hz. The cutting force dynamometer is connected to a charge amplifier, which in turn connected to a PC for acquiring the data using data acquisition system with suitable software.

III RESULT AND DISCUSSION

The following sections deals of with the analysis of the effect of nose radius on tool wear, Ra, chip width, signals from AE, accelerometer and cutting force dynamometer.

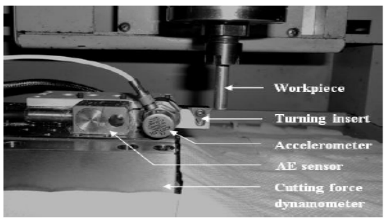

Figure 1. Photograph of the experimental setup

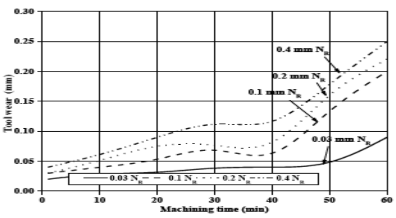

Figure 2. Tool wear with respect to machining time

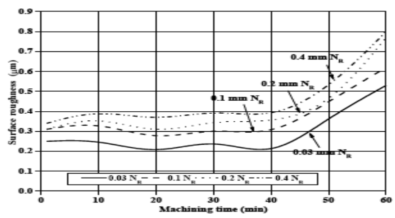

Figure 3. Surface roughness with respect to machining time

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A. Analysis of Tool wear, Ra and Chip width

From Figure 2, it is found that the tool wear is increasing with the increase in the nose radius and is proportional to the machining time up to 40th minute and thereafter an accelerated trend is observed. From Figure 3, it is observed that the Ra is increasing and decreasing with machining time up to 40th minute and afterwards it increases steeply. This is due to the effect of accelerated wear of the tool. Figure 3 also shows with the increase in the nose radius the surface roughness is also found to be increasing after 40th minute. This may be due to the increased tool-work piece contact area during machining. Chip width is also found to be increasing with the increase in the nose radius. Chip morphological studies indicate that, short ribbon (favourable) type of chips are observed while machining with 0.03 nose radius, a combination of loose arc (favourable) and short ribbon (favourable) type chips are observed while machining with 0.1 nose radius, loose arc and ear (favourable) type chips are observed while machining with 0.2 and 0.4 nose radius.

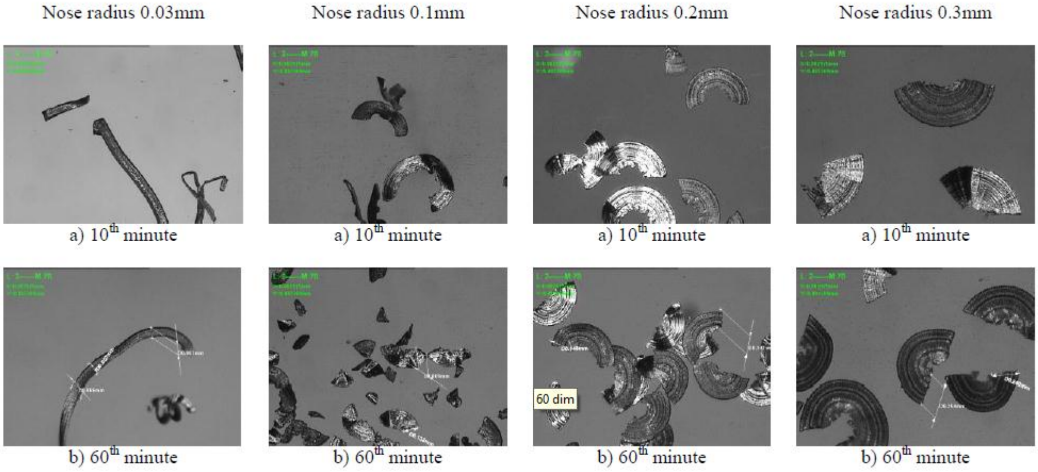

Figure 4 Chip images at different nose radius

B. Analysis of Sensor Signals

The acquired AE and vibration signals are analysed in the frequency domain. Power spectral density represents the energy distribution of the signal over the frequency domain. Table 1 shows the power spectral density of the AE and vibration signals with different nose radius up to maximum machining time (60th minute). Figure 5 and 6 show the power spectra of the AE and vibration signals respectively of 0.03mm nose radius.

TABLE I
EXPERIMENTAL RESULTS

Ex. No.	Machining time (min)	AE frequency (kHz)				Vibration frequency (kHz)			
		Nose radius				Nose radius			
		0.03 mm	0.1 mm	0.2 mm	0.4 mm	0.03 mm	0.1 mm	0.2 mm	0.4 mm
1	1	130	125	129	215	1.46	1.65	2.07	5.13
2	10	132	141	139	269	1.52	1.70	2.14	5.19
3	20	184	154	142	269	1.52	1.70	2.26	5.31
4	30	184	215	182	293	1.58	1.92	3.23	5.31
5	40	268	269	269	293	1.58	1.92	3.36	5.68
6	50	292	292	293	480	1.70	3.05	3.92	6.23
7	60	292	292	293	480	1.77	3.17	4.05	6.65

From Table 1 and Figure 5, it is observed that the dominant frequency of the AE signal lies between 130 kHz-292 kHz for 0.03 nose radius, 128 kHz-292 kHz for 0.1 nose radius, 129 kHz-293 kHz for 0.2 nose radius and 215 kHz-480 kHz for 0.4 nose radius. In the case of vibration signal from Figure 7, it is observed that the dominant frequency of the vibration signal is found to be between 1.4 kHz-1.7 kHz for 0.03 nose radius, 1.6 kHz-3.17 kHz for 0.1 nose radius, 2.1 kHz-4.05 kHz for 0.2 nose radius and 5.1 kHz-6.7 kHz for 0.4 nose radius from 1st minute to the 60^{th}minute. From Table 1, Figure 5 and Figure 6, indicates that the dominant frequency of the AE and vibration signal are found to be increasing with increase in the nose radius and also increases with the machining time. The dominant frequency of the AE and vibration signal increases linearly up to 40th minute and from 41st minute a sudden shift in the dominant frequency to higher level is observed. This indicates distinct accelerated wear region.

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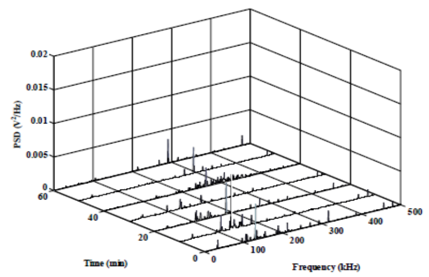

Figure 5. Spectra of the AE Signal (nose radius 0.03 mm)

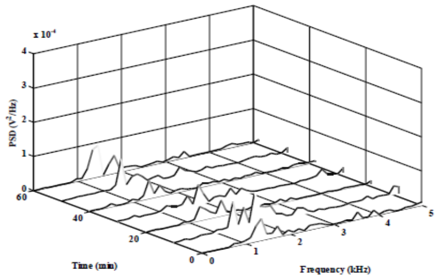

Figure 6. Spectra of the vibration signal (nose radius 0.03 mm)

Figure 7, 8 and 9 shows the thrust force, tangential force and feed force with respect to machining time. From Figure7, 8 and 9, it is observed that the cutting forces are increasing linearly with the increase in the nose radius. Among the three forces, the tangential force (Fy) is found to be more sensitive to the tool wear status compared to that of the thrust force (Fx) and feed force (Fz). This may be due to the resultant force acting towards the thrust direction. In the case of feed force, it is observed that with 0.03mm nose radius is found to be higher order than that of the feed force observed with 0.1, 0.2 and 0.4mm nose radius. In the case of thrust and tangential force, 0.4mm nose radius of for ceare found to be higher compare to the feed force with 0.03, 0.1 and 0.2mm nose radius.

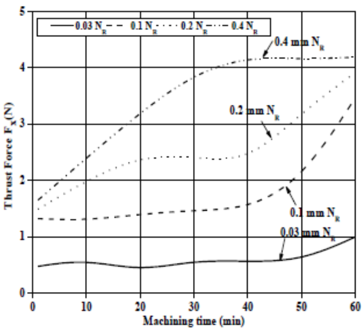

Figure 7. Thrust force (F_X) with respect to machining time

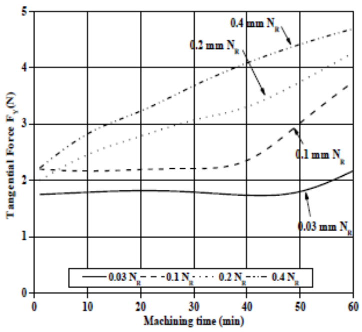

Figure 8. Tangential force (F_Y) with respect to machining time

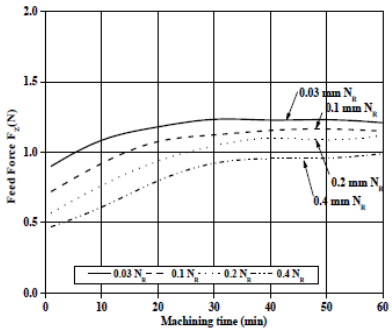

Figure 9. Feed force (F_Z) with respect to machining time

IV CONCLUSION

In this work, analysis of tool wear, Ra, chip width, AE, vibration signals and cutting forces, were carried out to investigate the effect of nose radius in micro turning of stainless steel SS 316L. The tool wears and chip width shows uniform trend, while Ra follows non-uniform trend with machining time. Chip morphological studies indicate that short ribbon type of chips are observed with 0.03 nose radius, combination of loose arc and short ribbon are observed with 0.1 nose radius, while loose arc and ear type chips are observed with 0.2 and 0.4 nose radius. From the signal analysis, the dominant frequency of the AE signal for good tool is found to be between 130 kHz-184 kHz for 0.03 nose radius, 128 kHz-214 kHz for 0.1 nose radius, 129 kHz-182 kHz for 0.2 nose radius and 215 kHz-292 kHz for 0.4 nose radius, while the dominant frequency of the vibration signal for good tool are found to be between 1.4 kHz-1.6 kHz for 0.03 nose radius, 1.6 kHz-1.9 kHz for 0.1 nose radius, 2.1 kHz-3.2 kHz for 0.2 nose radius and 5.1 kHz-5.3 kHz for 0.4 nose radius. Among the three forces, the tangential force (Fy) is found to be more sensitive compared to the thrust force (Fx) and feed force (Fz).

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