Application of acoustic emission sensor to investigate the frequency of tool wear and plastic deformation in tool condition monitoring

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Abstract

The metal cutting process initiates with the occurrence of plastic deformation of workmaterial and is followed by tear and removal of material from the workpiece. This process ultimately damages cutting tool and causes tool wear. An acoustic emission (AE) sensor has been employed to measure the signal frequency in machining. The AE signal component of tool wear and plastic deformation in turning are separated by simulating the process of tool wear by a grinding test where the workpiece of grinding test is the same tool-insert for tuning test, and the process of tool wear in turning is replicated by the process of material removal in grinding. The frequency of tool wear for this particular investigation is found to lie between 67 kHz and 471 kHz whereas for plastic deformation of workmaterial, it has a fluctuation within the range starting from 51 kHz to some value within 471 kHz.

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1. Introduction

Tool condition monitoring (TCM) denotes a process that persists to keep the cutting tool under surveillance during machining. To ensure an effective TCM, entire occurrences involved in machining should be investigated. Plastic deformation of workmaterial, crack propagation, progressive tool wear, tool fracture, tool breakage, chip formation, chip breakage, chip removal, chip tangling, process interruption, etc. all are dedicatedly involved with the process of metal cutting. The conventional metal cutting and removal process are generally accomplished into two stages, i.e. plastic deformation and crack propagation inside the workmaterial. The plastic deformation of workmaterial is the major occurrence verily engaged with metal cutting process. The workmaterials undergo plastic deformation before it is removed from the workpiece, and thus causes progressive tool wear to cutting tool. This is very common phenomenon during the process of metal cutting. According to generally accepted view of metal cutting, the new surfaces are formed simply by plastic flow around the tool [1]. The tool insert can penetrate through the sidewall of the specimens to generate chips and develop highly localized plastic deformation in the vicinity of the cutting tool [2]. During chip formation, the workmaterial undergoes a severe plastic deformation and that affects the integrity of the machined surface and changes the hardness as well as other mechanical properties of both the chip and the machined surface [3]. The resultant effect appeared on the cutting tool as wear [4].

The plastic deformation of material is accompanied by development of dislocation structures [5]. However, there is no influence of the dislocation density on the plastic deformation, mainly the grain size and orientation play more important role on final stage of the plastic deformation [6]. Slip on the other hand, is the preferred plastic deformation mechanism in FCC materials. This is also true for high stacking fault energy (SFE) materials, where creation of twin interfaces is less favorable than dislocation motion. The SFE of mild steel (workmaterial) is reportedly low [7]. The deformation mechanism twinning occurs at the earliest stages of deformation and the deepest layers of the material where plastic deformation takes place [8]. Therefore, the primary deformation zone is reportedly the seriously plastic deformation region in machining [9]. During plastic deformation of material, the mechanical work done is converted into heat by the ratio of the Taylor–Quinney coefficient [10]. With the increase of cutting velocity, the plastic deformation heat inside the workpiece increases. The temperature variation gradient on the tool rake face also becomes steeper. The distribution of normal stress in the case of highest velocity is evidently the seriously plastic deformation region in machining [9].
interfaces [11,12]. The resulting effects increase the rate of tool wear and eventually cause failure.

The different occurrences in turning including the plastic deformation of workmaterial and tool wear occur simultaneously during metal cutting. Therefore, they are hardly separable until any special setup or any indirect method is applied to capture them independently. The authors have successfully separated the influence of chip formation from the effect of tool wear and plastic deformation in turning introducing a custom-designed tool setup in their previous work [13]. This is still an unresolved challenge to separate the components of tool wear from the plastic deformation of workmaterial and others. An indirect approach has been taken up to investigate the components of tool wear and plastic deformation independently and to distinguish their frequencies. The investigation has been circumvented with the help of a grinding test where the turning tool insert was used as the workpiece for grinding.

A distinct difference between the process of turning and grinding is their mechanism. Plastic deformation of workmaterial is unavoidable in turning whereas material removal in grinding is accompanied without experiencing any plastic deformation. Therefore, the two different phenomena (plastic deformation and tool wear) can be investigated separately by deploying an indirect method of separation. If the turning tool insert is used as workpiece in grinding, the material removal from the workpiece would present only the tool wear, no plastic deformation components will be incorporated in measurement. The signal frequency of plastic deformation therefore is attempted to separate from the components of tool wear and other occurrences by comparing the results with the output of author’s previous investigation [13].

2. Relationship between turning and grinding process mechanics

Grinding is a microscopic multiple point multiple-pass two-body abrasive wear process involving the removal of particles, which are significantly larger than the grain size. Two control mechanisms of material removal have been identified in the abrasive wear process, i.e. microcracking and lateral cracking. Both of these mechanisms are influenced by the material microstructure. For the microcracking dominated mechanism, fine-grained materials, which exhibited larger short-crack toughness, have higher resistance to material removal by abrasive wear than coarse-grained materials. Conversely, lateral cracking can be suppressed when grain size exceeds a critical size. However, the grain morphology has a certain effect on microcracking and formation of lateral cracks during grinding [14]. Some researchers on the other hand, have investigated that the lower cutting speed and depth of cut in grinding increase the proportion of plowing rather than cutting and removing the material from the workpiece [15].

Even though, material grinding and turning are methodologically different, both of them are used for the same purpose to remove material from the workpiece. They can take each other’s place to perform a particular operation. However, there are some differences in the characteristics of residual stress profiles; turning with a sharp cutting edge geometry (honed or chamfered) generates a “hook” shaped residual stress profile characterized by compressive residual stress at the surface and maximum compressive residual stress in the subsurface. While grinding only generates maximum compressive residual stress at the surface. The surface residual stresses generated by the sharp tool can also be tensile, although the magnitude is much lower than that created with a worn tool. The depth of compressive residual stress in the subsurface by turning is much larger than that produced by grinding. But the magnitude of compressive residual stress at a ground surface is usually higher than that at a turned surface [16]. Despite, the magnitude of stress development in grinding and turning differs from each-other; the frequency of a particular occurrence must remain same. Therefore, to investigate the occurrences of tool wear in turning can be performed by assessing grinding of the same tool insert.

2.1. Monitoring the effect of tool wear and plastic deformation of workmaterial using AE

In turning, plastic deformation of workmaterial, tool wear, tool breakage, chip formation, chip breakage, chip removal, process interruption, collision among tool-workpiece, tool-chip, chip-workpiece, etc. are reportedly the major occurrences taken. Plastic deformations are permanent deformation and they are irreversible. The major strain developed during metal cutting is reportedly due to plastic deformation of the workmaterial [17]. Under continuous cyclic loads, the material undergoes rutting and failure due to accumulation of the irreversible plastic deformations [18], which is characterized as wear on the cutting tool. Plastic deformation, including its final stage (fracture) takes place under complicated non-homogeneous stress and structural changing, and is accomplished by releasing elastic energy, crack formation, heat flow, mass transfer (pure diffusion), and the movement and multiplication of dislocations [19]. Tool wear, tear and fracture of workmaterial on the other hand, are the most potential happenings in grinding that release energy during their progression. There is no plastic deformation either of grinding wheel or workmaterial happened. Therefore, material removal from workpiece due to tear and fracture, are likely to be measured by capturing the signal from the workpiece during grinding. This measurement of material removal would directly represent the tool wear of cutting tool during turning.

All solid materials have elasticity and they become strained or compressed under external forces and spring back when released. The higher the force and, thus, the elastic deformation, the higher is the elastic energy. If the elastic limit is exceeded a fracture occurs immediately if it is a brittle material, or after a certain plastic deformation. If the internal stress in materials or structures is suddenly redistributed such as crack initiation and growth, crack opening and closure, deformation, dislocation movement, void formation, interfacial failure, corrosion, fiber–matrix de-bonding in composites, tiny cracks in materials or structures will emit very intense ultrasound bursts, rapidly relaxing the materials by a fast dislocation. These waves propagate through the material and eventually reach the surface, producing small temporary surface displacements [20,21]. This rapid release of elastic energy is an AE event [22,23]. The AE derived from turning consists of continuous and transient signals, which have distinctly different characteristics. Continuous signals are associated with tool wear and plastic deformation of workmaterial while burst or transient signals result from chip formation, crack growth, chip removal etc. [24,25]. However, AE in the grinding process is usually observed as a continuous type signal. However, from a micro-topographic point of view, the cutting edges of grits are not at the same circumferential height [26]. Theoretically, each cutting-grit generates a burst type AE signal when it cuts through the workpiece. When numerous grits cut through the workpiece in such a way that the interval of two consecutive cuts (which are not necessarily in the same place) is much shorter than the decay time of each burst signal, then the continuous type AE is formed. Although it is an ideal situation to detect wheel-workpiece contact in the ‘grit contact’ stage, it is difficult to implement, since AE signals, especially the AE is too weak and the burst AE signal generated by grit cutting is easily confused with other noises, e.g. that induced by coolant. Continuous AE amplitude is generated in initial ‘wheel contact’ until the grinding depth is equal to the feed rate when the AE signal becomes relatively stable [26].
The sources of AE in a grinding process are also the chip formation stress, the bond and grain fracture, and friction stress between abrasive grain and workpiece. Besides, the transient thermal stress on the workpiece surface will cause microcracks, which creates acoustic emission. These impacts at their origin are a wideband oscillation movement and generally the stress waves are of low amplitude and of high frequency, usually between 50 and 2000 kHz in metallic materials. The AE sources in a grinding operation are mainly caused by the interaction of the wheel and the workpiece. There are different sources of noise during the grinding process. The noise from grinding wheel and grinding fluid are the most significant noises. Background noise consists only of frequency components below 100 kHz, so noise has only a small influence on the measurement system when its responding range is tuned to higher than 100 kHz. The noise at frequencies above 2.0 MHz could be attributed to the machine electrical system. By using a bandpass filter with cut-off frequency of 100–1200 kHz most of the noise generated by machine vibration and wheel rotation were easily eliminated from high frequency AE detection. Because the AE signal caused by grinding burn is relatively weak, the threshold, the prime variable to control AE system sensitivity, is usually in the range of 10–99 dB. It is judged that the threshold should be 30 dB to obtain higher sensitivity. Too low a threshold may bring background noise into the system.

The AE signal captured from a grinding process is complex wave like pattern, and it consists of numerous basic signals coming from different occurrences during machining. A wide range of signals included in the same output makes it hardly readable. The frequencies due to chip formation, material removal from workpiece, wheel engagement and disengagement, micro-crack formation on the workpiece surface, etc. exist in raw signal. So further processing is required to extract the features from the signal. Usually, the pattern recognition analysis of AE signals is used to trace and extract the feature from the signal. The cutting process is stochastic in nature, and a number of process parameters like material properties, tool geometry, etc., can vary during machining. Therefore, all the features need to be considered recognizing a change in the progressive wear of the tool and making the sensing system more efficient. The pattern recognition technique is used to do this; whereas the feature reduction is done by selecting only the best features using class mean criteria [27]. It is generally agreed that the continuous-type AE signals are associated with plastic deformations of workmaterial and tool wear during metal cutting, while the burst- type signals are observed during crack growth inside the material. Additionally, tool fracture, chip breaking, chip impacts or chip tangling generate a burst-type AE signal [28–30]. The RMS value of burst AE signal due to tool fracture depends on the fracture area [31]. However, for interrupted cutting, it is not significant at the point of tool failure [32]. The signal processing using RMS signal may result in the loss of important surface cracking and contact data [33]. Therefore, the use of time domain raw AE as well as the frequency analysis of the same signals would significantly expedite the monitoring to investigate the different occurrences in turning.

### 3. Materials and experimental methods

The investigation of tool wear in turning is analogical with the investigation of material removal from the workpiece in grinding, only if the used workmaterial is made of same material that is used for turning tool insert.

#### 3.1. Materials

A grinding test has been conducted on a surface grinding machine, type: NI-450 AV to indirectly investigate the frequency of tool wear during turning. A CBN diamond wheel of type: D181C75B has been used as grinding tool whereas the workpiece was a tool insert coated of carbide, type: CNMA 12 04 12-KR, which was used in turning. The tool insert was assembled on to a tool holder of type: PSBNR 2525M 12, which itself was mounted on a magnetized table of the grinding machine. A piezoelectric AE sensor was placed on the tool holder at a safe distance near to the grinding regime to capture the AE signal from the workpiece during operation. The removal of tool material by grinding has been considered to be equivalent of tool wear in turning.

#### 3.2. Methods

Even though, turning and grinding are methodologically different, the mechanism of tool chipping during turning and chip formation during grinding are more likely similar. For turning, the tool insert is subjected to cutting force developing shear stress inside the tool material. The tool particles tear away as the level of stress crossing its ultimate strength point and that is reportedly manifested as tool wear in turning. For grinding, on the other hand, the material removal from the workpiece is accomplished following the similar mechanism as the tool wear in turning. In this case, the workpiece is objected to grinding force that develops stress in workmaterial progressing to tear of workpiece particle under ultimate stress condition. The stresses produced during the process of material machining are reportedly the sources of acoustic emission, which are easily capturable by the acoustic emission sensor.

The acoustic emission produced during grinding is required to be captured and recorded for further analysis. The procedure of AE signal acquisition from the workpiece (carbide tool insert) during material removal follows the pattern schematically illustrated in Fig. 1.

A KISTLER 8152B AE-piezoelectric sensor has been mounted on the tool holder and is placed as close as possible to the grinding point. The AE sensor has a frequency range from 50 kHz to 1 MHz. The sensor hold-down force of several Newtons is used for AE sensor to ensure good contact and to minimize the coupling thickness. Because of high impedance of the AE sensor, it must be directly connected to a coupler which contains a buffer amplifier. A KISTLER-5125B type coupler and a DEWE-43 module were used in the signal acquisition system. The coupler allows the signal to pass through a high-pass filter and cut off below 50 kHz frequencies, and the DEWE-43 module filters out very high frequencies above 1000 kHz. The coupler and DEWE-43 module jointly acts as a band-pass filter which has a low cutoff frequency of 50 kHz and a high cutoff frequency of 1000 kHz. The AE signals pass through both the modules, i.e. the Coupler and DEWE-43 in series before storage. The necessary modification of the raw signals was undertaken inside these modules. Low-frequency noise components, which are inevitably present in AE signal, are considered not to be correlated with the occurrences. Besides, it requires much energy to amplify such low frequencies and thus affect the useful band of the signals to amplify properly. Therefore, those components should be eliminated (using the high-pass filters) at the earliest possible stage of signal processing to enable usage of full amplitude range of the equipment. The low-pass filter is used to filter out the high-frequency noise components of AE signal to avoid electric sparks or aliasing of frequencies. The filtered AE signals are then amplified and digitized before storing for further processing.

#### 3.3. Experimental details

The experiment was conducted in dry grinding mode for this investigation. The cutting conditions and tool-workpiece combination have a significant role on tool wear and thus on surface rough-
Cutting conditions for turning test.

<table>
<thead>
<tr>
<th>Cutting conditions</th>
<th>Table 1</th>
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<tbody>
<tr>
<td>Wheel rotational speed (rpm)</td>
<td>3450 (clock wise)</td>
</tr>
<tr>
<td>Feed rate, ( f ) (m/min)</td>
<td>0.00 (steadily hold on the workpiece)</td>
</tr>
<tr>
<td>Depth of cut, ( d_{oc} ) (( \mu )m)</td>
<td>0.5, 1, 1.5</td>
</tr>
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Cutting conditions for grinding test.

<table>
<thead>
<tr>
<th>Cutting conditions</th>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting speed, ( v ) (m/min)</td>
<td>385</td>
</tr>
<tr>
<td>RPM (rpm)</td>
<td>2450</td>
</tr>
<tr>
<td>Depth of cut, ( d_{oc} ) (( \mu )m)</td>
<td>0.5</td>
</tr>
<tr>
<td>Feed rate, ( f ) (mm/rev)</td>
<td>0.15</td>
</tr>
</tbody>
</table>

The AE signals were captured during grinding of cutting tool insert under a certain wheel rotational speed of 2450 rpm (clockwise) and with three different depths of cut of 0.5 \( \mu \)m, 1 \( \mu \)m and 1.5 \( \mu \)m respectively.

The tool wears were measured, and the AE signals were captured from a turning process carried out under some cutting conditions that imitating the cutting conditions used for grinding the tool-insert. A same type of tool-insert was used to cut a circular workpiece of ASSAB-705 steel rod of 6.0 cm diameter and 25 cm long on a COLCHESTER VS MASTER3250 (165 mm x 1270 mm) gap bed center lathe machine. The cutting was conducted in dry mode. The cutting conditions used in the turning test are presented in Table 2.

4. Result and discussion

The AE sensor has been used to determine the tool wear and thus to predict the material removal from the tool insert during machining. This is done to separate the frequency of tool wear from the occurrence of plastic deformation of workmaterial involved in turning. The AE signals captured from machining are essentially complex and stochastic in nature. A more informative signal processing system is therefore indispensable to demonstrate the raw AE signal to extract the useful features out of them.

4.1. Differentiation between the AE signals from turning and grinding processes

The AE signal captured from a turning process contains varieties of frequencies including tool wear and plastic deformation of workmaterial. The AE signal from grinding on the other hand shows merely the tool wear when the turning tool insert was used as workpiece to grind. This is because there is no plastic deformation of workmaterial during grinding process that takes place.

From Fig. 2(a), the AE signal has two distinct patterns of signal frequency i.e. continuous and transient types. The continuous type low amplitude signal components are reportedly from plastic deformation of workmaterial whereas the transient type frequencies are generated from the tool wear, chip formation and some other high amplitude producing occurrences during turning [13]. From Fig. 2(b), though, there is some low amplitude signal frequencies observed; only transient pattern of signal becomes conspicuous on the AE signal. The transient patterns of signal show the material removal from tool insert and thus demonstrate the tool wear, whereas the low amplitude frequencies of AE signal are coming from different sources of noises.

Fig. 3(a) and (b) shows the RMS of AE signals of Fig. 2(a) and (b) respectively. From Fig. 3(a) and (b), the difference between the nature of AE signals are very obvious. From Fig. 3(a), there are both transient and continuous types of pattern available on the AE signal. However, only high amplitude transient pattern are observed from the AE signal of Fig. 3(b). This observation justifies that there is no plastic deformation of tool insert taking place during AE signal acquisition from grinding. The captured signal is therefore free from frequency of plastic deformation and shows only the phenomenon of tool wear.

The raw AE signals captured from turning process contain entire frequencies generated from all occurrences in turning. The most damaging factors for tool life are the occurrences of plastic deformation, tool wear and chip formation. A certain identification of these occurrences would predict the tool life and thus ensure a better tool condition monitoring.

In one of the authors' previous work, the AE signal frequency of chip formation was successfully separated with some special dummy tool-holder arrangement [13]. However, could not distinguish between the AE signal frequencies coming from plastic deformation and tool wear. The same arrangement was used to capture the AE signal to validate the grinding test data.

After separating the AE signal frequencies of chip formation from the whole domain, the signal frequencies of plastic deformation and chip formation were remained together. The AE signal frequencies of tool wear were then separated from that of plastic deformation by recreating the process of tool wear as the process of material removal from the workpiece in grinding.

Raw AE signal frequencies (plastic deformation + tool wear + chip formation) – AE signal frequencies of chip formation (using dummy tool-holder setup) = AE signal frequencies (plastic deformation + tool wear) – AE signal frequencies of tool wear (using grinding process) = AE signal frequencies of plastic deformation.

The AE signal shown in the following Fig. 4 was captured from the turning process at flank wear of 0.21 mm and from grinding process after removal of a same amount of material.
The AE signals from the turning process were captured at cutting speed of 385 m/min when the spindle speed was 2450 rpm, feed rate of 0.15 mm/rev and depth of cut of 0.5 mm. The same cutting conditions were used for capturing the AE signal from chip formation in turning. However, for grinding, the grinding speed was same like that of spindle speed in turning of 2450 rpm, whereas the depth of cut was 1.5 μm, i.e. 0.015 mm, and feed rate was 0 μm. From the signals of Fig. 4, it was obvious that the raw AE signals captured from the turning have a large range of amplitude, whereas the AE signals captured from the dummy tool arrangement representing the chip formation occurrences have only high amplitudes. This has been proven in authors’ last publication [13]. The AE signals captured from grinding of tool insert contain burst type signal frequencies with considerably high amplitudes, which were merely from material removal, because there were no plastic deformation or chip formation occurrences taken places. Therefore, the AE signal has shown the occurrence of tool wear only. The amplitude of AE signal obtained from tool wear, and its
frequency content are reportedly lower than that of chip formation occurrence, which was also obvious from these signals shown in Fig. 4.

4.2. AE signal frequency purely from tool wear

The AE signals recorded from tool insert grinding under different feed rates have remarkable change in the variation of machining conditions. More importantly, the amplitudes of AE signal components under different cutting conditions fluctuate and maintain a certain trend, which behaves similar to the pattern of tool wear in turning.

Fig. 5 represents the nature of tool wear under different cutting conditions. From the figure, the rate of material removal indicating tool wear is reasonably low at 0.5 μm whereas tool goes beyond its operational limit i.e. tool fails within very short time for the remaining three conditions. The tool wear rate at depth of cut of 0.5 μm was found only to resemble with the nature of tool life graph in turning, which is considered as optimum depth of cut for this investigation and all the data to be presented and analyzed in this paper are to justify this. The amplitudes of AE signals that have been captured at depth of cut of 0.5 μm fluctuate at different stages of tool life depending on the contact area. The influences of thermal effect are not taken into consideration to simplify the analysis.

Fig. 4. Raw AE signal captured from (a) turning process, (b) chip formation occurrence in turning, and (c) grinding process.

Fig. 5. Nature of AE signal under different depth of cut per stroke.

Fig. 6(a)–(i) shows the AE signals that have been captured at different point of tool wear i.e. at different stages of material removal during grinding at depth of cut of 0.5 μm. From the AE signals above, the RMS amplitude of AE signals were observed to increase gradually over the machining time until the final point of material removal. The amplitude of AE signal increases with the increase of tool wear. Even though, the depth of cut is constant, the amplitudes of AE signals are observed to increase. This is due to the reason that with the increase of tool wears the area of friction
between grinding wheel and tool insert is increased. Though the circumferential contact area between the grinding wheel and tool insert remains almost constant, the area of contact from lateral side of grinding wheel increases with the increase of depth of cut (i.e. with the increased tool wear) which results more friction and higher grinding force. This increased friction phenomenon influences the acoustic emission generated from the process of material removal, which is found to increase with the increase in tool wear.

This observation was more obvious from Fig. 7, which represents the variation of AE signal amplitude corresponding to different stages of material removal.

From Fig. 7, the amplitude of AE signal was observed to increase almost steadily at the early stage of tool wear, which then increased rapidly at middle stage followed by a steady increase again at the final stage of tool wear. This behavior of the AE signals amplitude corresponding to material removal more or less similar to tool life in turning.

Fig. 8 shows the area of friction which reportedly increases with tool wear along the tool flank. From Fig. 8(a), the hatched areas, A1 and A2 are the surface areas. It was observed that there is no considerable change throughout the machining at the area A2, while area A1 increases with the increase of material removal during grinding. The enclosed area of Fig. 8(b), is the respective friction

![Fig. 6. Variation of AE signal amplitude at different stages of tool wear (material removal).](image-url)
During grinding, materials were gradually removed from the tool insert face which increases the length of 'L₁' and eventually increases the friction area of A₁. The increased frictional area causes more friction between the grinding wheel and tool insert and consequently generates high amplitude of acoustic emission. The frequencies of captured AE signals fluctuate at various cutting condition and at different stages of material removal (Fig. 9). No plastic deformation takes place during grinding and the cause of wear of the tool insert used as workpiece in this investigation was due to material removal. The AE signals captured from grinding process therefore essentially contain the frequency of tool wear. From the analysis, the frequency of AE signal for tool wear varies at different depths of cut. For depth of cut of 0.5 µm, the frequency of tool wear was found to fluctuate between 67 kHz and 281 kHz; for depth of cut of 1 µm, the frequencies remained within the band of 72–410 kHz. For depths of cut of 1.5 µm and 2 µm, the tool wear frequencies varied within the bands of 75–334 kHz, and 77–471 kHz respectively. The authors could successfully separate the AE frequency of chip formation from the occurrences of tool wear and plastic deformation of workmaterial in their previous work. However, separation of frequency of tool wear from the frequency of plastic deformation remained unsolved. The chip formation frequency of AE signal during turning of ASSAB 705 steel was found to fluctuate between 68.3 kHz and 634.83 kHz [13]. While the complex raw AE signal containing all the frequency including tool wear, plastic deformation of workmaterial and chip formation has been found to lie between 50 kHz and 720 kHz under same cutting condition of cutting speed 250 m/min, feed rate 0.32 mm/rev and depth of cut 1 mm. The remarkable thing is that the tool insert used as workmaterial in turning was similar to workpiece used in this particular investigation of grinding. From this investi-
gation, the frequency of tool wear lies in the band of 67–471 kHz, whereas the frequency of plastic deformation is still unresolved. The sources of AE signal of tool wear and plastic deformation might be different or cognate; therefore, their frequency would be distinct or somewhat overlapping. The analysis shows that the frequency of plastic deformation remains within a range starting from 51 kHz to some value within 471 kHz.

5. Conclusions

The tool wear in turning has been replicated through grinding of tool insert where the material removal from the tool insert is equivalent to tool wear. For turning of ASSAB 705 steel using the same carbide tool, the frequency band was 68 kHz to 635 kHz for chip formation occurrences whereas the frequency of tool wear and plastic deformation of workmaterial was inseparable. In the replicated grinding test, the frequency of tool wear has been separated and is found to lie between 67 kHz and 471 kHz. The frequency of tool wear has fluctuated at various rates and different stages of tool wear. The amplitude of AE signal increased with the increase of tool wear and depth of cut i.e. with the increased rate of material removal.

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