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A new approach for detection of wear mechanisms and determination of tool life in turning using acoustic emission

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ABSTRACT

A methodology for detection of wear mechanisms and determination of end of life of the cutting tool based on the acoustic emission signals is proposed, using an innovative technique. With this technique, the AE signals generated in hardened AISI 4340 steel turning respond well to the tool wear evolution. The tests were made using common and nanostructured AlCrN coated and uncoated cemented carbide tools. The AE signal spectrum is correlated with the wear mechanisms identified in the cutting tools and compared to the excitation frequency values corresponding to the respective mechanisms validating the identification of the wear mechanisms. The evolution of maximum flank wear resulted in increasing amplitude of average of Power Spectral Density at the end of life.

1. Introduction

Since the advent of polycrystalline cubic boron nitride (PcBN) tools, hard turning has been presented as an alternative to grinding. In hard turning, the workpiece is subjected to heat treatment prior to machining and the required roughness and tolerances are obtained without the need of abrasive operations. Bartarya and Choudhury [1] state that the success of hard turning depends on achieving certain requirements in relation to the machine tool, cutting tool and cooling conditions, among other factors, thus confining this operation to particular situations. Owing to the fact that hard turning involves more resistant work materials, machining forces are higher, therefore the use of tool materials with low coefficient of friction is essential. Polycrystalline cubic boron nitride (PcBN) and mixed alumina (Al_2O_3+TiC) are widely used for this application and, more recently, the development of coatings and micro-grained tungsten carbide tools has increased the range of materials capable of tackling hard turning.

Several authors [2–4] claim that PcBN is the first choice for hard turning, followed by aluminum oxide based ceramics due to the fact that these materials combine the required critical properties, such as high hardness and low chemical affinity with the work material. Camargo et al. [5] used PcBN cutting tools for turning of AISI D6 hardened steel (57 HRC) and produced a mathematical model based on multiple regression analysis to estimate tool wear. The dominant wear mechanisms were abrasion and attrition. Micro-chipping was also observed. With the generated model the cutting conditions could be estimated aimed at minimizing tool wear without compromising production rate. Sahoo [3] conducted turning tests with AISI 4340 steel (47 HRC) using cemented carbide tools without coating and with multilayer coatings (TiN, TiCN, Al_2O_3 and TiN) and (TiN, TiCN, Al_2O_3 and ZrCN) and observed that the coating has great influence on the tool performance. The best performance was provided by the (TiN, TiCN, Al_2O_3 and TiN) coated tool due to its lower coefficient of friction and stability at high temperatures.

The exact time of tool change is still a challenge for the metalworking industry and subject of continuous studies in the scientific community. Some of these studies take into account indirect techniques for continuous monitoring, this probably being the most appropriate way to address the matter. This type of monitoring is widely used in manufacturing processes due to the difficulty of monitoring the directly involved parameters. Acoustic emission (AE) is a possibility in the case of indirect monitoring. The use of acoustic emission is already quite widespread, especially for monitoring static equipment such as pressure vessels.

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The energy released by a body when it is altered/removed from its original state/form emits sound. Thus, corrosion, forming, wear, shear, tensile and compression mechanisms are generators of acoustic emission in a body. The application of this technique in machining is still hampered by several mechanisms and phenomena in cutting which are still not completely understood. The frequencies at which some phenomena such as movement of dislocations, voids coalescence, twinned training, etc. happen are not well known. Furthermore, the contribution of temperature and wear and frictional processes in the workpiece-tool pair further complicates the system. In spite of that, AE is a promising technique for monitoring cutting tool wear and has been widely used in grinding [6,7] as well as in the machining with geometrically defined tools. Hase et al. [8] monitored the AE signals when turning a mold steel (AISI O1) with cermet tools and correlated the signals with the cutting phenomena. They noticed that the chip formation process, the chip form and the primary shear angle affected significantly the AE signals. The correlation with the workpiece surface finish and tool wear was also determined.

According to Li [9], acoustic emission is a wave of tension that travels through the material as a result of some sudden release of tensile energy. It can also be defined as the elastic energy released spontaneously during a local, dynamic and irreversible change in the microstructure of the material. Several natural phenomena such as earthquakes, avalanches, landslides and crack propagation in ice are accompanied by acoustic emission [10]. The peculiarity of the acoustic emission signal involved in tribological processes is the necessity to understand how the elastic interaction of surface roughness is converted into acoustic emission signals [11]. Hase et al. [12] studied the characteristics of the acoustic emission signals and correlated them with the wear mechanisms. They determined the frequency bands and voltage amplitude of the AE signals from several studies involving the phenomena and highlighted that abrasive wear covers a wide frequency band (from 250 kHz to 1 MHz), but the peaks are well characterized and can serve as a basis to identify which mechanism prevails in the experiment. Crack propagation acts in the range of 100 kHz to 700 kHz and therefore overlaps the excitement generated by abrasive wear. Adhesion and movements on the surface (stick-slip phenomenon) excites a narrow band (25–110 kHz) and overlap adhesive wear and particle interactions. Adhesive wear is classified into mild and severe wear, each of them exciting a different frequency band. In mild adhesive wear, rolling and collision of particles on the wear surface excites the frequency band of 10–100 kHz, while in severe wear transfer of particles between the surfaces excites from 1 to 1.5 MHz [13]. Hase et al. [12] confirm this statement and highlight that adhesive wear occurs with peaks in the frequency of 1.1 MHz. The other mechanisms have very characteristic peaks and promote a much narrower excitation band than abrasive wear.

Due to the dynamic cutting action occurring in machining, the tool wears out while the shape of the chip and the phase of the material can change, thus causing a variation in the AE spectrum. A compilation from various studies is presented in Table 1, which summarizes the principal mechanisms and the respective excited frequencies of the AE signal.

Table 1
AE signals frequencies of principal exciter phenomena in ordinary materials.

Phenomenon	AE frequency range (kHz)
Machining [14]	70–115
White layer [15]	>60
Isothermal phase transformation [16]	250–350
Mild adhesive wear [17]	0–120
Severe adhesive wear [17]	1000–1500
Adhesion and dragging [18]	25–110
Movement of dislocations [13]	10–220
Particle interaction [19]	120–350
Abrasive wear [8,13]	200–1000
Crack propagation [20,21]	350–550
Phase transformation [16]	350–550
Accommodation of vacancies [22]	220–380
Annihilation of dislocations [20]	100
Frank-Read dislocation [20]	1000
Plastic deformation [20]	50
Plastic deformation [20,17]	150–500
Elastic deformation [13]	25–250
Thermal noise [20]	10–100

Ferrer et al. [18] studied the effects of stick and slip between two metal surfaces and analyzed the acoustic emission signals produced by this phenomenon. The authors changed the compressive force, the relative displacement speed between the bodies and the contact surface geometry. The AE signals produced by this phenomenon excited a frequency range from 25 kHz to 110 kHz with a peak of 105 kHz.

The sources of acoustic emission signals in metals can be divided basically into three [20]: the first one is related to mechanisms that induce plastic deformation and to atomic movement processes (annihilation of dislocations and generation of dislocations by the Frank-Read mechanism), twinning and grain boundary sliding. The second source refers to mechanisms associated with first and second order phase transformations: polymorphic transformations including martensitic transformation, the second phase particle formation in supersaturated solid solution decomposition, phase transition magnetics and superconductors, magnetic and mechanical phenomena due to the contour changes and reorientation of a magnetic field with a variation of the external magnetic field. Finally, the third source takes into account mechanisms for damage such as origin and micro-defects accumulation, nucleation and growth of cracks and corrosive damage including corrosive cracking.

Chung et al. [19] studied particles interaction in hard disks when subjected to SiC and polystyrene injection mechanisms and subsequent wear on their surface. A particle injection system in which the hard disk run and maintained contact with a mechanism responsible for spreading SiC and polystyrene particles (with a diameter of 0.9 mm) on its surface was used. The signals from contact between the hard (SiC) and soft particles (polystyrene) and their deposition on the surface excited a frequency from 200 kHz to 350 kHz.

Mostafapour et al. [16] applied the wavelet technique and the time and frequency crossed spectrum to determine the acoustic emission source with varying frequency and speed of wave on a plate with an arrangement consisting of four AE sensors. The graphite breaking technique was applied on the plate at random points for the generation of acoustic emission signals, which were decomposed by wavelet in the range from 125 kHz to 250 kHz, then generating the crossed spectra of time and frequency. The signals are crossed and the delay time is calculated when the spectrum reaches its maximum amplitude while the wave velocity is calculated using the maximum frequency, which is captured from this maximum value. The wave speed determines the time delay between the sensors showing the position of the event. The authors concluded that the application of this technique is more accurate than the current correlation method in most software used for AE signals monitoring.

Marinescu and Axinte [14] studied the effectiveness of acoustic emission signals in the detection of failure in double-coated (TiAlN+TiN) carbide tools in milling operation of Inconel 718. The authors compared the AE signals with the signals of the cutting forces and demonstrated that AE has a greater sensitivity to wear.