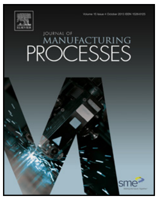
Journal of Manufacturing Processes 27 (2017) 114–125

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro



Acoustic emission signal analysis during chip formation process in high speed machining of 7050-T7451 aluminum alloy and Inconel 718 superalloy

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ARTICLE INFO

Article history:
Received 8 May 2016
Received in revised form 7 December 2016
Accepted 11 April 2017

Keywords:
Acoustic emission
Chip morphology
Frequency analysis
Cutting energy
High speed machining

ABSTRACT

Research on acoustic emission (AE) signal during chip formation process in high speed machining can help to reveal the workpiece-chip material separation mechanism. The aim of this paper is to explore the relationship between the AE signal with chip formation and cutting energy consumption. Firstly, the high speed orthogonal cutting experiments of 7050-T7451 aluminum alloy and Inconel 718 are carried out with the cutting speed ranging from 50 m/min to 8000 m/min, during which the AE signals are detected. Then the micrographs of chip morphology under different cutting speeds are collected and observed. The results show that dimples and ductile fracture are observed on the serrated chip free surface, which are caused both by adiabatic shear and severe plastic deformation, while brittle fracture is the mechanism for fragmented chip formation. All these deformation features are demonstrated to be the sources for AE signals generation. The time and frequency domain characteristics of detected AE signals during high speed machining of the two workpiece materials are analyzed. The chip serrated frequencies for the two workpiece materials during high speed machining are found to be nearly equal to their corresponding AE dominant frequencies. It confirms that the procedure of serrated chip formation makes a significant contribution to the produced AE signal. The dependence of AE root mean square (RMS) values on specific cutting energy during high speed machining has also been revealed. The material deformation and subsequent release of strain energy prove to be dependent on the conditional ductile and brittle mechanical properties of the machined material.

1. Introduction

In situ monitoring systems have been used to characterize, control, and improve the fabrication process of products to meet increasing requirements in precision and quality. Many different sensors have been applied to monitor the metal cutting process, including the monitoring of chip formation process [1], force detection [2], tool wear and tool failure [3], finished surface quality [4], etc. One of them is acoustic emission (AE) sensor, which can detect the elastic stress waves released rapidly from the material surface during machining process [5]. Sources of the detected waves include friction, dislocation movement, phase transformation, material breakage and fracture, etc [6]. Compared with other sensors, the main advantage of using AE sensor for monitoring high speed machining process is that the frequency range of the AE signals is much higher than those of the machine vibrations and environmental noises [7]. Taking full use of AE signals makes great sense to analyze the interactions within the tool-workpiece-chip system.

Significant research has been published in relation to the use of AE signal for monitoring machining process in recent years. A number of models of AE in metal cutting have been developed following the basic assumption that either the energy content of the AE signal is proportional to the work rate of plastic deformation [8–10] or the frequency content of the AE signal is related to the dislocation velocity and glide distance [11]. During machining process, the generation of AE signals includes the form of continuous and burst ones. The continuous AE signals are regarded as low frequency and low amplitude elastic waves generated by plastic deformation of chip and workpiece material, friction between tool-chip interface and friction between tool-workpiece interface. The burst AE signals are regarded as high amplitude and high fre-

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http://dx.doi.org/10.1016/j.jmapro.2017.04.003
1526-6125/

quency elastic waves that occur during chip collision and fracture, or tool chipping within the machining process. The primary deformation zone is regarded as the largest source contributing up to 75% of detectable AE energies [5]. Variations of count rate, root mean square (RMS) values, and spectral analysis have been commonly used to analyze the AE signals detected from the deformation zones. Diei and Dornfeld [12] researched the fundamental nature of high frequency AE signals generated during the complete breakage of cutting tools, and they had proposed a quantitative model relating the peak AE RMS voltage to both the fractured area and the res ultant cutting force at fracture. Guo and Schwach [13] developed a real-time AE based fatigue testing system to study the white layer effect on component life in rolling contact. They found that AE parameters such as energy, RMS, and amplitude were more sensitive to fatigue crack initiation and propagation compared with AE count rate in rolling contact. Pawade and Joshi [14] assessed the surface integrity of Inconel 718 in high speed turning using the energy, number of counts, and amplitude of the AE signals. They concluded that AE signals with fewer perturbations in the energy and counts profiles indicate a better-quality surface with the least alterations. The investigation of Bhuiyan et al. [15] has shown that the AE signals can effectively respond to different occurrences in turning process including tool wear and surface roughness, which can help to monitor the tool state without process interruption. Some other researchers also utilized AE signals to examine material mechanical properties [16], material damage [17] and coating adhesion strength [18], etc.

As the AE generation originates due to the material deformation process, it has also been used to study the chip formation mechanism in machining process. Barry and Byrne [19] presented that the energy of the AE signal in machining of hardened steel is up to two orders of magnitude greater than that in the machining of softer pearlitic steels. They found that this is a result of the transition from continuous to serrated chip formation. Specifically, the periodic and rapid release of elastic strain energy during catastrophic failure for serrated chips causes this phenomenon. Mian et al. [20] researched the chip morphologies in combination with signal processing technique, which revealed the feasibility of AE sensoring as a technique for material-dependent chip form detection in micro cutting. Prakash et al. [3] used AE signal to investigate the effects of tool wear on chip morphology and chip formation mechanism in micro end milling of aluminum alloy. They concluded that low frequency and low amplitude AE signals correspond to the formation of tight curl chips, while high frequency and high amplitude AE signals correspond to the formation of elemental/short comma chips. Lee et al. [21] categorized various sources of AE generation for different chip formation mechanisms according to the material removal volume. With the undeformed chip thickness decreasing from the level of millimeter to nanometer, the frequency of AE signals increases dramatically.

Although a great deal of work has been done by previous researchers to investigate the application of AE signal in machining process, the intrinsic relationship between the chip morphology and AE signal characteristic is still unclear. With the cutting speed increasing from low to very high, the chip morphology evolves from continuous to serrated, and then further to fragmented when the cutting speed exceeds a critical value [22]. The variation of AE signal with different kinds of chips, especially the serrated and fragmented chips generated in high speed machining, should be revealed further. In addition, the dependence of AE signal on the cutting energy consumption has been rarely researched although it has been recognized that the AE generation has direct relationship with the energy release during machining process.

Based on the research gap, the outline of this paper is formulated as following (as Fig. 1 shows). This paper aims to investigate the chip formation process during high speed machining using AE signal analysis. Firstly, orthogonal cutting experiments under various cutting speeds ranging from low to very high are conducted, during which the chips with different morphologies are produced. Secondly, the AE signals detected under different chip formations are analyzed with the methods of time and frequency domain analyses, through which the relationship between the AE signal and chip morphology is developed. Meanwhile, the models of cutting energy consumption under different chips formations are developed. Then the dependence of AE signals on cutting energy consumption can be revealed. The chip morphology, AE signal and cutting energy are affected by the cutting parameters and workpiece materials as Fig. 1 shows, and the researched cutting parameter refers to cutting speed alone in this paper.

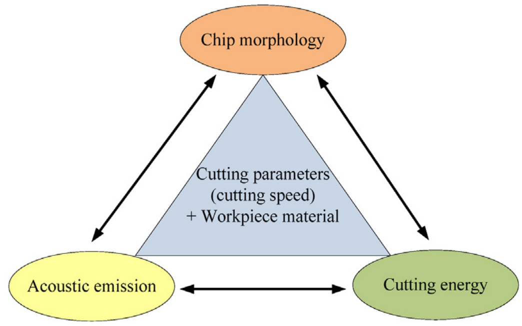

Fig. 1. Research outline of this paper.

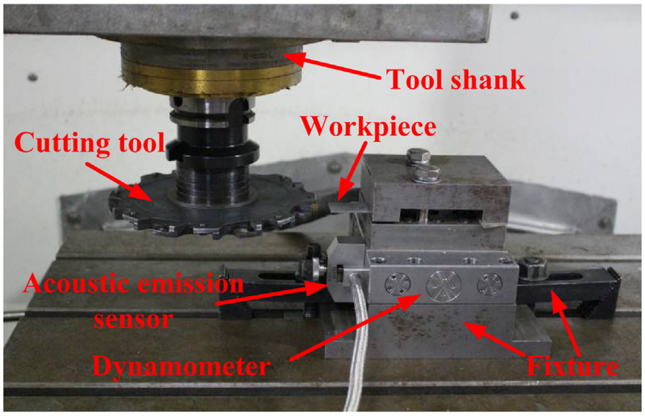

Fig. 2. Experimental setup for orthogonal metal cutting.

2. Experimental procedure

Fig. 2 shows the experimental setup for orthogonal cutting. The experiments were carried out on SMTCL VMC0540d high speed milling machine, whose maximum spindle speed is 30000 r/min. The Kennametal 4.96164-210 90°SN slot milling cutter with diameter of 160 mm is used and the width of workpiece is 20 mm. Because the cutter diameter is much larger than the workpiece width, the directions of cutting force and thrust force can be regarded as approximately invariable. The insert used is SNHX12L5PZTNGP with coated carbide (KC725 M) and its rake angle is 0°. There were two inserts installed symmetrically on the cutting tool one time during cutting experiments. The workpiece was machined at the cutting speeds ranging from 50 m/min to 8000 m/min and the feed rate per tooth was fixed as 0.1 mm/z. The feed rate per tooth corresponds to the undeformed chip thickness in orthogonal cutting. After each cutting path was finished, the insert was replaced by a new one to eliminate the influence of tool wear on the experimental results. The axial cutting width was 2.0 mm and the cutting condi-