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Process controls for surface integrity generated by hard turning

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Abstract

An investigation was conducted on the evolution of the residual stresses and re-hardened white layer during finish hard turning. The residual stress pattern is dominated by changes in cutting forces resulting from tool wear. Increased flank wear accelerated normal sliding force generating tensile residual stress at the surface and reducing the magnitude of compressive stress below the surface. However, very high flank wear yielded maximum below-surface compressive residual stress. Increased tool wear beyond a critical value led to discontinuity in the relationship between normal and tangential forces. This paper proposes a new tool-life criterion for controlling surface integrity in finish hard turning.

Keywords: Hard turning, Surface integrity, Process control

1. Introduction

Finish hard turning has emerged as an alternative to grinding for the machining of hardened steels. Hard turning offers significant cost benefits because of its reduced capital investment, lower setup cost and lower tooling cost, which have rapidly expanded the process's applications. Hard turning has been found to induce compressive residual stresses at the surface. In addition, rolling contact fatigue tests have shown that hard turning provides equal - or in some cases, better - fatigue performance than grinding [1,2]. However, some challenges remain in using hard turning applications to completely finish precision components such as the functional surfaces of bearings.

The surface integrity generated by hard turning was found to depend largely on the tool's edge geometry [1,3,4]. Since tool wear affects the edge geometry, it can significantly change the properties of the hard turned surface. Previous investigations have reported that hard turning with worn tool can result in tensile residual stresses at the surface. Also, the depth of the white re-hardened layer was found to increase with tool wear [3-6]. Therefore, in order to control the functional performance of the surfaces produced by hard turning it is critical to understand the onset of white layer formation during the finish hard turning process.

The present finish hard turning investigation was undertaken to establish criteria for useful tool life that will result in appropriate surface integrity of the finished components. Experimental results are presented that show the effect of tool wear on the properties of hard turned surfaces. An analysis of these results indicates that, after certain levels of tool wear are reached, acceleration of normal force limits the useful life of the cutting tool in finish hard turning. Finally, a method to control the performance of the hard turning process by monitoring and detecting the change in normal force is discussed to define the useful tool life.

2. Experimental setup and results

Experiments were performed to monitor the change in cutting forces and characteristics of the hard turned surface with insert wear. These experiments were conducted on a CNC lathe using AISI 4319 and 52100 alloy steels hardened to 58-62 HRC. PCBN inserts (CBN particle size 3-5 µm, CBN content 45%-65%) with 0.4 mm nose radius, chamfer angle of 15°~ 25° and 5 µm edge honing were used. A cutting speed of 140 m/min with feed of 0.1mm/rev and depth of cut of 0.1 mm was used. A water soluble coolant with 4 bar pressure was used to control the bulk temperature of the work piece and assist in chip control. Cutting forces in the normal, tangential and axial directions were measured using a Kistler

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9121 dynamometer. The magnitude and change of cutting force in the axial direction was lowest and hence this data is not included. Residual stresses were measured using X ray diffraction method. Tool wear was measured on the machine using an optical microscope. Figure 1 shows the change in normal force F_n and tangential force F_t with tool flank wear.

Although both cutting forces increase with insert wear, the magnitude of change is different in each direction. Initially, normal force tends to increase with higher flank wear, but after a certain amount of flank wear the rate of change of normal force increases rapidly. The rate of increase of tangential force with flank wear is nearly constant. For the same set of experiments the rate of change of flank wear was observed to be almost linear with cutting time. The change in cutting forces was very similar for both the materials. It is important to note that these experiments were conducted using shorter cutting times to precisely monitor the evolution of flank wear and the resultant cutting forces. Also, efforts were focused on minimizing the error in the flank wear measurement by measuring the wear on the machine without removing the cutting tool. It is interesting to note that in both materials, normal force started rapidly increasing after about 0.1 mm of tool flank wear. Similar results showing a rapid increase in normal force with the progression of flank wear have been previously reported; even though these investigations did not focus on the discontinuity in normal force[3,7,8,9].

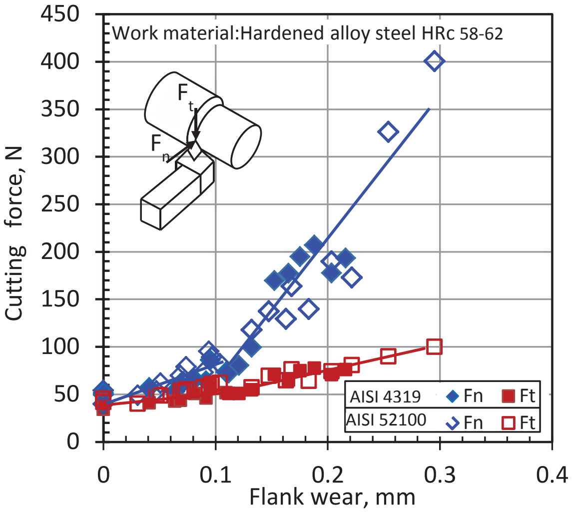

Figure 1: Cutting force vs flank wear

3. Surface integrity in hard turning

The effect of tool flank wear on circumferential residual stress is shown in Figures 2 and 3 for the AISI 4319 and AISI 52100 steel materials, respectively.

Independent of the surface stress condition prior to hard turning, a compressive residual stress was observed on the surface after hard turning with a new insert. However, as flank wear developed, tensile stress was observed at the surface. It is important to note that this tensile stress occurred only in the shallow region beneath the surface. Below a depth of about 0.025 mm the residual stress was compressive. The occurrence of higher tensile stress with the progression of flank wear indicates increased heat generation at the work tool interface. The depth of heat penetration to the workpiece was very shallow due to the small contact zone and short machining time; hence, the presence of tensile stress was limited only to very shallow depths near the surface. It is also interesting to note that very large flank wear generated deep compressive stresses in the work surface mainly due to the severe plastic deformation.

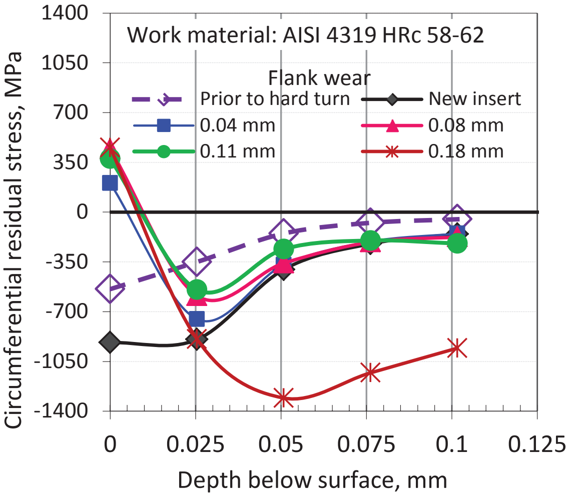

Figure 2: Residual stress vs flank wear AISI 4319

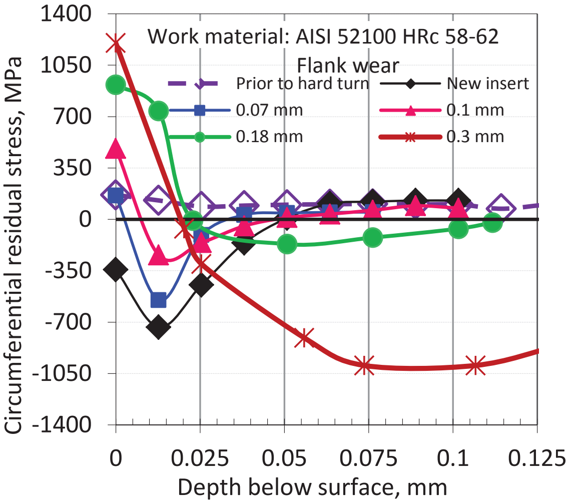

Figure 3: Residual stress vs flank wear AISI 52100

Figure 4 shows the microstructure of the hard turned surface at different values of flank wear. The formation of white layers on the hard turned surface is attributed to plastic deformation as well as thermal transformation of the work surface during the hard turning process [3,5]. The main objective of this investigation was identifying the onset of thermal transformation at the work surface. As seen in Figure 4, after about 0.1 mm of flank wear a white layer is observed on the surface; a dark layer was visible immediately under