Surface Integrity and Machineability in Intermittent Hard Turning

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Despite the large amount of research on hard turning, there are few results on intermittent hard turning. In this paper, the feasibility of internal intermittent hard turning has been investigated. First, the cutting tools with different cubic boron nitride (CBN) contents were evaluated, based on machineability: tool wear, surface roughness, and cutting forces. In the case of intermittent turning, low CBN content tools had better machineability than high CBN content tools. The depth of the machining damaged layer and the magnitude and distribution of residual stress were evaluated. The experimental results showed that intermittent hard turning can produce surface integrity which is good enough for replacing the grinding process.

Keywords: CBN Tool; Hard turning; Intermittent; Machineability; Surface integrity

1. Introduction

Hard turning has been considered in the area of agile and lean manufacturing environments for the last few decades. The main purpose of hard turning is to replace finishing processes such as grinding. In hard turning, the part is finished in a highly tempered or hardened state with geometrically defined cutting tools [1–3]. This offers many possible benefits over a grinding process, such as lower equipment cost, shorter set-up time, reduced number of process steps, and better surface integrity.

Hard turning has become possible because of the development of new cutting materials. Alumina-based ceramics reinforced with titanium carbide (Al2O3/TiC) are suitable for hard machining, particularly in continuous cutting. Cubic boron nitride (CBN) tools are known to be good for interrupted cutting, because of their superior fracture toughness [4,5].

In order to gain acceptance as an equivalent of the grinding process, hard turning must be able to satisfy the high quality requirements of the workpiece concerning form and size accuracy, surface finish, and surface integrity. These are mainly determined by the following conditions: machining parameters, tool materials, cutting edge geometry, properties of the machine tools, and the geometric shape of the workpiece [3,6].

In the case of continuous turning, many results have been published on tool wear and/or surface integrity [7–10]. However, there are limited results for intermittent hard turning, even though the need for it has increased [11]. A general candidate for hard turning is a ball bush, as shown in Fig. 1, where grooves are to be machined in the internal surface. Conventionally, these grooves are ground by an internal grinding machine. We must replace the machining process with hard turning. In this case, tool wear or chipping, machineability and surface integrity may pose problems owing to the high cutting temperature and the impact of the cutting force.

The objective of this research is to investigate the feasibility of using CBN tool materials for internal intermittent hard turning and to investigate factors affecting machineability and surface integrity. For this purpose, different kinds of CBN content tool were evaluated with regard to machineability, i.e. tool wear, surface roughness, and cutting forces. In the case of intermittent cutting, we found that the low CBN content tool is better for machineability than the high CBN content tool. Finally, we tested surface integrity by measuring the depth of the machining damaged layer and the magnitude and distribution of the residual stress. From this experiment, we concluded that surface integrity is good enough for replacing the grinding process except for the geometric accuracy related to the clamping problem of the tube.

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Fig. 1. Schematic diagram of a ball bush.
2. The Experimental Procedure

In this work, the workpiece is a ball bush that contains internal grooves, as shown in Fig. 1. The ball bush was made from bearing steel (AISI52100) and was heat-treated and the hardness was around HRC60. Three cutting tools with different contents of CBN were selected for comparison as follows: BN250 (60% CBN/H11001TiN), BNX4 (70% CBN/H11001TiN), and BN100 (80% CBN/TiN) from the SUMITIMO Company. The nose radius of the cutting tool is 0.8 mm, the chamfer width 0.1 mm, and the chamfer angle 30°. These geometric dimensions were selected because they were shown to improve the anti-chipping performance for interrupted cutting [11].

Cutting tests were carried out on a CNC lathe (Pro-6, Daewoo) as shown in Fig. 2, and the cutting force changes due to the cutting conditions and the progress of tool wear were measured by a tool dynamometer (Type 9257, Kistler), on which the internal cutting tool holder was fixed. The tool life was judged by either the occurrence of tool chipping or the length of the flank tool wear. In intermittent hard turning, tool chipping is important for tool breakage and the surface accuracy of the workpiece, even when the tool chipping is not large. Tool flank wear was measured by a tool microscope (TM301, Mitutoyo) according to the ISO specification for every 1 km of cutting length. Simultaneously, average surface roughness (Ra) was measured by a surface roughness tester (Surf test 301, Mitutoyo) with a cut-off length of 0.25 mm, and was averaged for three points on the workpiece surface. Also, an energy dispersive X-ray spectrometer (EDX) analysis was carried out to analyse the tool wear mechanism in the intermittent hard turning.

In the case of intermittent cutting, the impact force may affect the surface integrity, which can make the surface integrity different from that in piece face that in continuous hard turning. In this regard, the depth of the machining damaged layer and the magnitude and distribution of the residual stress were evaluated. First, factors such as machining parameters and tool wear affecting the damaged layer were investigated. To do this, samples were prepared using a wire-EDM (electro discharge machining), as shown in Fig. 3. Samples were mounted on epoxy and were polished, and etched with 2% nital. Then, the machining damaged layers were measured using a metallurgical microscope (Axiotech) and pictures were taken. The magnitude and distribution of residual stress in the damaged layer was measured using the X-ray diffraction (XRD) method, and measurements were taken from the surface into the workpiece every 10 μm. The workpiece was machined in 10 μm steps by electro-chemical grinding. The residual stress was measured using an X-ray diffractometer, and the calculation method was 2π/λsinθ [12–14].

3. Machineability

3.1 Cutting Force

Figure 4 shows the trends of the cutting forces with respect to different cutting conditions. The thrust cutting force (radial component) is dominant, as it is in continuous hard turning. That is, the impact force does not influence the cutting force pattern in intermittent hard turning. The cutting force decreased slightly with the increase of cutting velocity. The variation of the feedrate and the depth of cut affect the cutting force greatly. In particular, the effect of the depth of cut is most significant.

The cutting force components were affected, along with the progress of tool wear. A significant increase of thrust cutting force could be observed, as shown in Fig. 5, with the increase of cutting length, owing to tool wear. This is due to the increased contact area between the workpiece and the land of the tool flank wear. This phenomenon is more severe than when machining an external surface, since the contact area is