ABSTRACT

Hard turning has been in use for some time to achieve close dimensional tolerances to eliminate time consuming and costly grinding operations. The most widely used cutting tools for finish machining of hardened steels under dry cutting conditions are the ceramics and PcBN cutting tools.

The purpose of this study was to investigate the machinability of hardened martensitic AISI 440 B stainless steel (HRC 42-44) using commercially available cutting tools: alumina based ceramic and PcBN, by hard turning under different machining conditions, by providing an in-depth understanding of wear mechanisms of these cutting tools. The study also developed a serrated chip formation mechanism of the workpiece and provided a deep understanding of the chemical interaction between workpiece and cBN cutting tools, through microstructural analysis of the adhered layer on the worn cutting tool.

Experimental studies on the effects of cutting parameters on the tool wear mechanism, cutting forces; surface roughness, dimensional accuracy, and chip formation mechanism were investigated.

The characterization of the workpiece, cutting tools, chips and wear scars on the cutting tools was performed using an X-ray diffractometer, and optical, scanning and transmission electron microscopes, as well as an energy dispersive spectroscope (EDS).

The cutting speeds selected for testing the cutting tools were in the range of 100 m/min and 600 m/min, depending on the type of parameter investigated. Two depths of cut, 0.1and 0.2 mm, and three feed rates, 0.05, 0.1 and 0.15 rev/min, were selected for the experiments.

Experimental results showed that the flank wear in the PcBN cutting tool is lower than that of the mixed alumina, with PcBN showing better wear resistance at all cutting conditions (about five times longer in some instances). Apart from the cutting speed, the feed rate was found as a parameter that directly influences the flank wear rate of the cutting tool.

The wear mechanism for the ceramic cutting tool is predominantly abrasive wear, and for PcBN tools it was adhesive wear and abrasive wear. The abrasive wear was caused by hard carbide particles in the workpiece material resulting in grooves formed on the flank face. There was formation of a transferred layer followed by plastic deformation of the workpiece material on the rake face of the PcBN tool when cutting at low cutting speed and feed rate. At much higher cutting speeds, some form of chemical wear preceded by adhesion and abrasion was the main tool wear resulting from the chemical affinity between the PcBN tool and the workpiece.

Better surface finish (Ra) was recorded for mixed ceramics but with deteriorating surface topography. The increase in the cutting speed results for improvement in the surface finish produced by both cutting tools was investigated. The final part, using the PcBN cutting tool, produced better dimensional accuracy resulting from its better wear resistance at the flank face. The results also show that good dimensional accuracy can be achieved with cBN tools using a CNC machine with high static and dimensional stiffness coupled with high precision hard turning.

The influence of cutting conditions on the chip formation showed production of continuous chip at a cutting speed of 100 m/min and segmented chip at higher cutting speeds above 200 m/min by both cutting tools. The increasing cutting speed affects the formation of shear localised chips with rapid increase in shear strain rate and degree of segmentation at cutting speeds higher than 200 m/min. The microstructure of the chip produced shows the distinct carbide grain in the martensite of the work material with intense shear localisation in the primary deformation zone of the cutting tool and formation of white layer in the secondary deformation zone.

The microstructure of the crater of the worn PcBN cutting tool at cutting speeds of 100 m/min and 600 m/min were studied in detail. A situ lift-out technique, in a Focused Ion Beam/SEM instrument, was used to produce thin foil specimens, which were taken out of the crater face of the PcBN tool and observed using SEM and TEM. The SEM and TEM study showed evidence of chemical interaction between the work material and the PcBN tool. Fe from the work material was found in the vicinity of TiC and AlB grains of the PcBN tool, with TiC having greater affinity for Fe. Oxidation of the elements was common in all Fe-rich areas. The microstructure of the worn PcBN cutting tool at the cutting speed of 600 m/min showed deeper penetration of Cr and Fe into the cBN tool, which was not easily detected by SEM at the cutting speed of 100 m/min.

The hard turning operations using the PcBN cutting tool for substituting traditional machining operations was successfully performed in the industrial environment. The overall surface finish and dimensional accuracy generated during the application of CBN-100 for machining within the industrial environment on specified mass produced shape showed a component acceptable tolerance range with good surface finish similar to that of the grinding operation.