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Technical Paper

Influence of cutting edge geometry on tool wear performance in interrupted hard turning

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ABSTRACT

Turning of hardened steels with interrupted surfaces presents some restrictions, due to the fact that the tools usually used have little resistance against the typical loads of interrupted cutting. In order to reduce tool wear, an appropriate combination of tool material and cutting edge preparation must be chosen. With the goal of finding a proper edge geometry, the paper investigates the influence of customized cutting edge geometries on tool wear performance of CBN tools in interrupted hard turning. Regarding tool flank wear, results showed that a single chamfered cutting edge is the most appropriate, since it reinforces the cutting edge without excessively increasing mechanical and thermal loads. The main wear mechanism observed for all micro geometries corresponds to attrition.

1. Introduction

Some of the advantages of using turning instead of grinding for the finish machining of hardened steel surfaces are: high flexibility, the ability to cut complex surfaces with a single machine setup, cost of the process and the possibility of machining without cutting fluid [1]. Otherwise, turning of hardened steels with interrupted surfaces presents some restrictions, due to the fact that the tools usually used for this purpose are brittle, and therefore, have only little resistance against the typical shocks of interrupted cutting. However, a very large number of industrial parts present some kind of interruption on their surfaces, which made the study of turning of interrupted surfaces of hardened steels very important [2].

One difference between continuous and interrupted cutting is that the latter, during engagement, does not have the thermal softening effect from the shear zone. This results in higher initial cutting forces. The mechanical impact due to such a rather sudden rise of the cutting forces induces transient vibration [3].

The interrupted cutting process has three characteristic features: tool entry into the workpiece, tool exit and cyclic loading and unloading accompanied by cyclic heating and cooling. The relative importance of these depends on the dimensions of the cut, the cutting speed, the heating time/cooling time, the workpiece and tool materials, the shape of the tool and the geometry of the entry and exit [4].

According to Pekelharing [4], tool entry, formerly considered to be the major danger point, is only a jump in the cutting force from zero to its normal value. This could be dangerous at the beginning of the cut, since the main cutting force is supported by only a narrow strip of the rake face. The same author affirms that the tool exit can be even more important regarding tool life due to a “negative shear zone” formed at the exit of the workpiece. He explains that the usual shear zone with a positive shear angle stops functioning when a negative shear zone occurs. The positive shear zone exists with a positive normal pressure, i.e. with compressive stress normal to the shear movement. The negative shear zone lacks this pressure or has to work under tensile stress and fails to maintain continuity. Before the pressure between the rake face and the chip falls to zero the total pressure is concentrated near the edge on a narrow strip with a width of about one-third of the thickness of the cut. This stress reversal can lead to tool failure. In their investigations Ghani et al. [5] verified that the stress reversal is stimulated by higher cutting velocities.

Alternating heating and cooling cycles, which cause high temperature gradients, also have to be considered in interrupted cutting. It has been known that thermal stresses due to cyclic temperature gradients, called “thermal shock”, are the main mechanism of thermal cracking, a detrimental phenomenon to tool life. However, in interrupted cutting, cutting temperature variations also depend on cut and non-cut durations. Thus, it is possible that cutting tools may not reach saturated temperatures, as in continuous cutting, for a shorter cut period, and similarly, may relax to

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lower temperatures for a longer non-cut period, and therefore, restore hardness and other properties [3].

In order to reduce the influence of such wear causes and increase tool life, CBN has been widely used in interrupted cutting of hardened steels, because of its high hardness, high thermal conductivity and low thermal expansion coefficient. Tools with high CBN content are usually recommended for turning of hardened steels with interrupted surfaces due to their higher hardness and toughness in comparison to low CBN content tools [1].

Chou and Evans [3] suggest that greater hardness and fracture toughness of high CBN content tools result in better wear resistance to mechanical impact. However, the metallic binder (cobalt or aluminum) in such tools accelerates tool wear at high cutting speeds due to its affinity with workpiece materials. Godoy and Diniz [6] analyzed the wear mechanisms of high content CBN tools in interrupted cutting and observed that attrition with pulled out particles was the main wear mechanism. They suggest that, when removed from the tool, these particles probably cause abrasion mainly when chip thickness is small and cutting pressure is high. Moreover, they affirm that attrition may have been favored by the presumably low cohesion between CBN and the binder material. Differently, the application of low CBN content inserts in interrupted hard turning by Pavel et al. [7] led to notch wear and small chipping of the cutting edge. The authors attributed the wear pattern to the thermal and mechanical shocks produced by the interruptions.

A reduction of tool wear in interrupted hard turning can also be reached by a suitable preparation of the cutting edge. According to Pekelharing [4], a chamfered or rounded edge can postpone or eliminate tool failure, but the feed force of a well-chamfered cutting tool may be two or three times higher than that of an otherwise identical sharp tool and correspondingly the rate of flank wear may also be much higher. This means that the chamfer must be optimized so that just enough protection is obtained. Results from Dokainish et al. [8] indicate that for the cases in which the thickness of the cut is small compared to the chamfer width, the magnitude of the shear stresses near the cutting edge increases significantly when the chamfer angle is increased from 5° to 20°.

Diniz and Oliveira [1] demonstrated that the interaction between cutting edge geometry and tool material has a significant influence on the tool life. They observed that tools with edge rounding exhibited longer lives when a high CBN content tool was used, and chamfered tools had longer lives when a low CBN content tool was used. Edge rounding makes the edge more rigid and resistant to chipping and breakage. On the other hand, it causes a greater chip deformation due to the lower rake angle, especially when a small chip thickness is used.

Considering that an appropriate combination of tool material and cutting edge preparation can decrease tool wear, this paper proposes investigating the tool wear performance of customized cutting edge geometries, prepared in CBN inserts by grinding, in interrupted hard turning. The investigation of the use of such micro geometries in this process is motivated by the improvement of tool life obtained by these edge geometries in continuous hard turning in comparison to inserts prepared with single chamfers [9].

2. Material and methods

The applied inserts have the specification SNMA120408 and eight CBN corners brazed on a cemented carbide substrate of grade K10-20. The CBN part is composed of 90% CBN, and TiCN and Co as bond materials. CBN grain size is approximately 4 μm and its Vickers Hardness is of 36.4 ± 0.48 GPa. The inserts are ground (grinding of flank faces and edge preparation) in a five-axis grinding machine type Wendt WAC 715 Centro with a maximum rotation of the grinding wheel of 1625 rpm and a maximum spindle power of 3 kW. A diamond grinding wheel with grain size D15, concentration C120 and vitrified bonding is used with the following parameters: axial feed rate v_{fa} = 4 mm/min, rotational speed of the insert to grind corner radius v_R = 2778°/min, and cutting speed v_c = 20 m/s. In order to avoid wheel clogging and profile wear, the grinding wheel is continuously dressed with a dressing roll Al_2O_3 220 mesh and an axial dressing feed rate v_{fad} = 1 μm/s.

Cutting edges of CBN inserts are prepared with the method developed in Denkena et al. [10]. Here, the general edge roundings are discretized by several chamfers. Chamfers are characterized by chamfer width and angle, while edge roundings are characterized by the cutting edge section at the rake face S_γ and the cutting edge section at the flank face S_α. The form factor $K = S_\gamma/S_\alpha$ defines the tendency of the cutting edge to the rake ($K > 1$) or to the flank face ($K < 1$). In case of a symmetric rounding ($K = 1$), the edge radius r_β will be used instead of S_γ and S_α. Five sorts of micro geometry are tested in interrupted hard turning (Fig. 1): sharp edge, single chamfer (chamfer width b = 100 μm and chamfer angle $\gamma = 26°$), asymmetric rounding K = 2.0 (S_γ = 100 μm, S_α = 50 μm), symmetric rounding K = 1.0 (r_β = 50 μm) and asymmetric rounding K = 0.5 (S_γ = 50 μm, S_α = 100 μm). All edge roundings are discretized by three chamfers, which are shown in Fig. 1. A Mahr Perthometer is used for obtaining the profile of the ground micro geometries. The characteristic geometric values have been determined by the profile plots and the standard deviations are under 10%.

Turning tests are conducted in a Gildemeister CNC lathe type MD10S, which has a maximum rotational speed of 10,000 rpm and maximum power of 50 kW. Cutting speed v_c = 200 m/min, feed rate f = 0.05 mm/rev and depth of cut a_p = 0.05 mm are kept constant. Cylinders of 16MnCrS5 steel with hardness 60 ± 2 HRC and length 200 mm are turned without cutting fluid. The interruptions consist of two longitudinal rectangular channels (depth = 1 mm (for maximum diameter), width = 8 mm) with an offset of 180° in tangential direction (Fig. 2). During the tests, the diameter of the cylinders is allowed to vary from 65 mm to 62 mm, so that the variation of the impact frequency due to the interruptions is lower than 5% and does not affect the results.

Maximum tool flank wear is controlled through a digital microscope Keyence VHX-600 and pictures of the tool wear are recorded through a scanning electron microscope Zeiss EVO 60 at the end of the tests. The tool life tests are carried out up to a length of 800 mm (approximately 16 min). Aiming to investigate the influence of micro geometry on the process forces without considering tool wear, these are measured in a cutting time of 2 min. Cutting, feed and passive forces are acquired by a Kistler three-component-dynamometer type 9129AA linked to a Kistler charge amplifier type 5015. An acquisition rate of 2500 Hz and a low pass filter with cutting frequency of 1000 Hz are applied. For calculating average force values, only workpiece full parts are considered, while interrupted parts are neglected.

Turning tests were repeated in order to ensure the reliability of the obtained results.

3. Results and discussion

Since the effect of different edge geometries on tool performance is addressed in this paper, it is appropriate to define the edge sharpness. According to Stepien [11], the edge sharpness strongly depends on the geometrical characteristics of the edge, as well as the tool and work materials and the kinematics of the process. In accordance with Outeiro and Astakhov [12], considering the characteristics of machining processes, sharpness is a relative parameter, which depends on the ratio of the uncut chip thickness and the tool cutting edge radius (relative tool sharpness). Even if the tool cutting edge radius is small, it may have a significant