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Structural Changes of Surface Layers of Hard Turned Parts by Wiper and Conventional Geometry

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Authors' contributions

This work was carried out in collaboration between all authors. Authors MS and MN designed the study, performed the experimental part and author MK managed the measurement and analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this paper is to achieve information about surface and sub-surface layers after hard turning by mixed ceramic tool with different geometry – Wiper and conventional and to compare achieved results to find out advantages of its use. Second aim is to obtain graphs of the influence of the tool wear on the surface structural changes.

Study Design: The experiment on hard turning was carried out with differently shaped mixed ceramic tools.

Place and Duration of Study: Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology, Institute of Production Technologies and Institute of Materials Science, between November 2013 and May 2014.

Methodology: In the case of cutting tool wear and structural changes measurement this experiment was carried out on two different workpiece sizes – 1.125 mm long cylinder to achieve cutting tool wear, 2. 10 mm long rings for structural changes. Microscopy for cutting tool wear measurement and X – ray diffraction for structural changes measurement was used. Cutting tool wear was represented by VB parameter and structural changes were represented by structural

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phase content, crystallites and lattice.

Results: Information about structural phase contents was achieved. There are some differences between surface and sub-surface layers after hard turning by mixed ceramic tool. Surface layer consists of more austenite phase than sub-surface layers. But there were not very big differences between used cutting tool geometry and its influence on the cutting tool wear. Both geometries were used more than 40 minutes till the flank wear parameter VB reached to 0.25 mm. The thickness of the surface heat influenced layer depends on the cutting tool wear and it is influenced by the cutting tool geometry – application of the Wiper geometry leads to thinner “white layer”.

Conclusion: It is very important to take into consideration cutting tool geometry when dealing with surface integrity after hard turning. But all achieved results depend on the used cutting parameters, cutting tool material, workpiece material, cutting force components, machine stiffness in specific experiments.

Keywords: Hard turning; wiper and conventional geometry; structural changes; austenite; martensite.

1. INTRODUCTION

Hard machining is a recent technology that can be defined as the operation of a work piece that has a hardness value typically in the 45-70 HRC range, using directly tools with geometrically defined cutting edges. Hard machining presents several advantages when compared with the traditional methodology based on finish-grinding operations after heat treatment of workpieces [1].

Specific problem of hard machining is a white layer formation. The austenite temperature of the workpiece material in the contact zone is reached during extremely short time of approximately 0. 1 ms and structural changes must be expected [2].

According to [3] white layers consist of over 60% of austenite, which is non-etching white component in contrast to the dark martensite scoring. Due to this fact, it is suggested [4] that the term “white layer” is misleading and it is proposed to distinguish two groups of this structure´s appearance in micrographs.

Many different authors deal with machining of hard materials with different cutting materials and measurement of surface integrity – especially 2D and 3D surface roughness parameters [5], tool flank wear of ceramic wiper inserts represented by VB parameter [6], using ANOVA analysis for evaluation of the influence of the cutting tool shape on the achieved surface roughness parameters [7].

Those publications demonstrate the impact and significance of use of wiper cutting tool geometry in hard turning when dealing with surface roughness, cutting tool wear, cutting force components. This article deals with different subjects of use of differently shaped cutting tool in relation to surface structure.

2. EXPERIMENTAL INVESTIGATION

During the experiment, samples of 100Cr6 (Table 1 Chemical composition) with Rockwell hardness 60±1 HRC were turned by the mixed ceramic cutting tool (Al_2O_3 + TiC) with two different geometries – Wiper and conventional made by Sandvik Coromant.

Cutting conditions used in this experiment were established in accordance with the manufacturer's recommendations:

- cutting speed v_c = 100 m/min,
- depth of cut a_p = 0.25 mm,
- feed f = 0.3 mm/ rev.

Structural changes of surface layers were observed depending on tool wear. Experiment was performed as follows – 10 times continuous turning of the workpiece with a length of 125 mm by the sharp, subsequently turning of short rings (Fig. 1) – measurement of the cutting tool wear – repeating hard turning until the cutting tool chipping (Fig. 2).

Fig. 1. Samples used for experiment

Those rings were used for structural changes measurement, which was carried out on the multipurpose x-ray diffractometer PANalytical Empyrean with X-ray ceramic lamp as a source of CoK$\alpha_{1,2}$ characteristic radiation. Parallel beam optics was used at primary beam arm in grazing incidence (GI) geometry coupled with diffracted beam collimated using 0.27° parallel plate collimator and scintillation detector. Soller slit and fixed primary divergence slit was used when θ-2θ geometry (GONIO) was applied. In this case however, fixed antiscatter slit and Pixcel3D detector was installed on diffracted beam arm. A sample was placed at a Chi-Phi-Z stage and aligned with respect to the incident beam using a dial indicator to correct for z axis off-set. Collected diffraction data were analysed using PANalytical X-Pert High Score Plus in order to determine present phases at the diffractogram. Quantitative phase analysis, crystallite size as well as microstrain determination were carried out using the Rietveld full pattern method implemented in the computer program MAUD [8]. Determination of a crystallite size is based on a well-known Scherrer formula which requires determination of diffraction peak broadening and calibration of the instrumental broadening. The MAUD, i.e. the Rietveld method calculates this value for each resolved peak using non-linear leas-square method fitted into the Caglioti formula. In order to determine instrumental broadening the coarse grained stress-free annealed Al_2O_3 was measured and the full pattern was refined in the MAUD. All parameters of Caglioti formula were refined and remained fixed for subsequent refinement of experimental patterns of samples after machining. Due to high precision the Al_2O_3 lattice parameter is determined further instrumental dependent parameter, 0°2 Theta off-set, was also refined. The measurement parameters as well as refinement strategy were kept constant for all samples.

3. RESULTS AND DISCUSSION

Achieved results lead to confirmation of the theoretical knowledge of the influence of the cutting time on the tool life (Fig. 4). The critical value of VB (flank wear) was determined as 0.25 mm. Tool wear is a time dependent process. As cutting proceeds, the amount of tool wear increases gradually. But tool wear must not be allowed to go beyond a certain limit in order to avoid tool failure. The most important wear type from the process point of view is the flank wear, therefore the parameter which has to be controlled is the width of flank wear land, VB [9].

There are pictures of critical value of tool wear for conventional and Wiper inserts in the Fig. 3.

There is a chart of the influence of the cutting time on the tool wear represented by the VB criterion (flank wear). Use of Wiper geometry in hard turning in comparison to conventional geometry did not demonstrate differences in tool life. There was an assumption that Wiper geometry will be worn faster because of its longer minor cutting edge, higher temperatures caused by the longer contact zone between workpiece surface and cutting tool. It was not confirmed. This may be due the fact that cutting tool life is inversely proportional to the cutting conditions, which were the same for both geometries in this experiment.

Table 1. Chemical composition of workpiece material

100Cr6	Cr	C	Si	Mn	P	S	Ni	Cu	Mo
Wt (%)	0,98 – 1,05	1,40 – 1,65	0,15 – 0,35	0,25 – 0,45	≤ 0,027	≤ 0,02	0,23	≤ 0,25	≤ 0,1

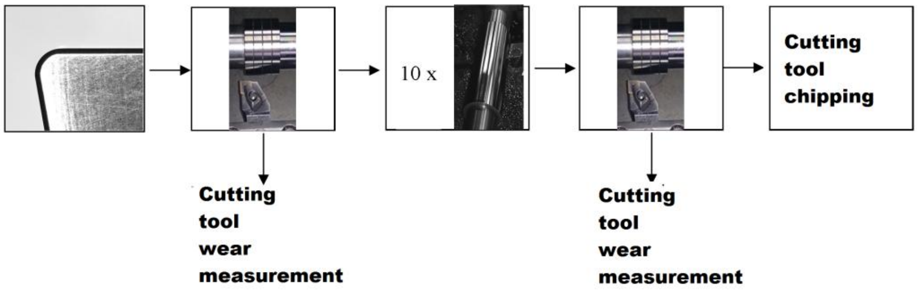

Fig. 2. Plan of experiment

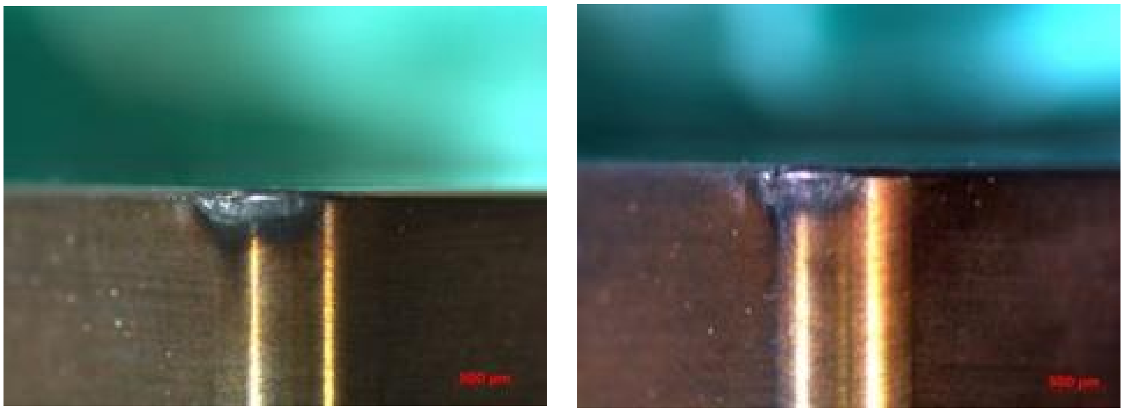

Fig. 3. Pictures of critical value of tool wear for Wiper (left) and conventional (right) inserts

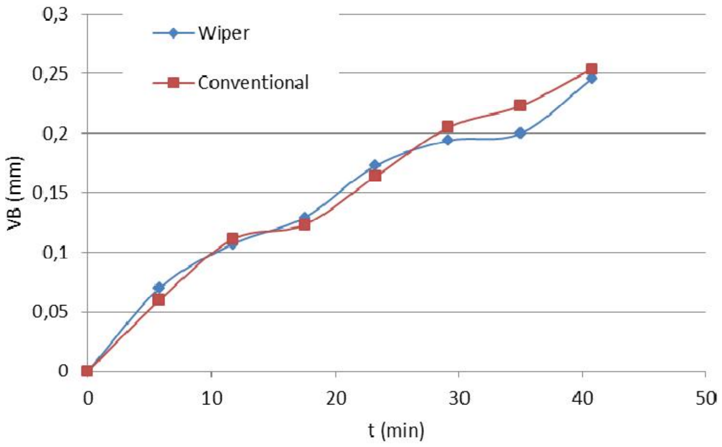

Fig. 4. Graph of the cutting tool wear dependency on cutting time

Surface structural changes were monitored as well. It was represented by measuring of the phase composition, elongation (lattice) and crystallites. Two different measuring techniques were used. GONIO, which provides information about the material in deeper subsurface layers and GI, which is used for evaluation of the surface layer (in our case about 1 μm).

The basic aspect of surface integrity in hard turning is rapid heating of the surface layers and consequently it´s fast cooling. It is very similar process as quenching, except that in hard turning is heating only a thin surface layer and the heat is removed with cold core.

Today we know that the temperature in hard turning normally exceeds the austenitizing temperature. When the surface is cooling from this temperature, this sharp decrease below the recrystallization temperature could lead to the secondary hardening, ie creating the martensitic structure with some austenite content. Austenite structure is subsequently blocked by martensite needles that are generated when cooling as it was mentioned before.

It appears that the proportion of austenite in the structure depends on the size of the flank wear, represented by the VB parameter (Fig. 5). Larger VB leads to higher temperature in the contact zone between the workpiece and the tool and higher temperatures penetrate deeper in the machined sub-surface. Significantly it is seen at small tilts (GI method), because the thickness of the white layer is smaller than the penetration depth of the X-ray method GONIO.

In this thin surface layer is increasingly blocked residual austenite, because of the increasing effect of cooling speed – it is seen when using both geometries. The GONIO method doesn´t significantly expressed this fact.

It is obvious, that using Wiper geometry the cutting edge is in the contact with machined surface two or more times. When using conventional geometry and higher feeds the surface state is determined by the size of the contact zone and cutting conditions. Machined surface gets again into the contact with minor cutting edge of Wiper cutting tool and the cooling process is interrupted (decelerated). The result is a smaller austenite content in the surface – it is visible in the GI method, but even more the phenomenon is manifested in the case of GONIO techniques. It appears that this effect rather affects deeper layers below the surface in the range of X-ray penetration depth (GONIO) and less it occurs in layers close to the surface.

For the highest wear value (ie after about 40 minutes of cut) is the difference between the cutting tools not so much caused by the geometry, but it has to do with the fact that as the cutting edge of conventional geometry remains intact, there the Wiper geometry occurred cutting edge fracture. Although the fracture leads to the optical VB increase, but the real contact zone, which is responsible for the surface integrity is smaller – partially removed by the refraction and therefore the austenite content decreases instead of its increase.

In addition to structural analysis, the crystallite size was evaluated (Fig. 6).

Crystallite size is also controlled by a cooling speed – the higher, the smaller the crystallite size – in our case it is the dominant effect considering the observed effect. Graphs in the Fig. 5 also show that the crystallite size is smaller close to the surface (up to 1 μm) then in the deeper layers, what is shown by the differences between the GI and GONIO method, in particular using the Wiper geometry.

When using Wiper geometry the cooling speed is lower therefore the crystallites size is mostly greater in comparison to conventional geometry. Further, it is shown that minor cutting edge of Wiper geometry by its repeated loading of the surface leads to the stable crystallites size and thus with every flank wear value it doesn´t change in contrast to the conventional geometry, where differences are more pronounced.

A lower cooling speed has also impact in the case of the elongation evaluation (Fig. 7). The state of workpiece between surface and deeper sub-surface layers is more balanced after use of

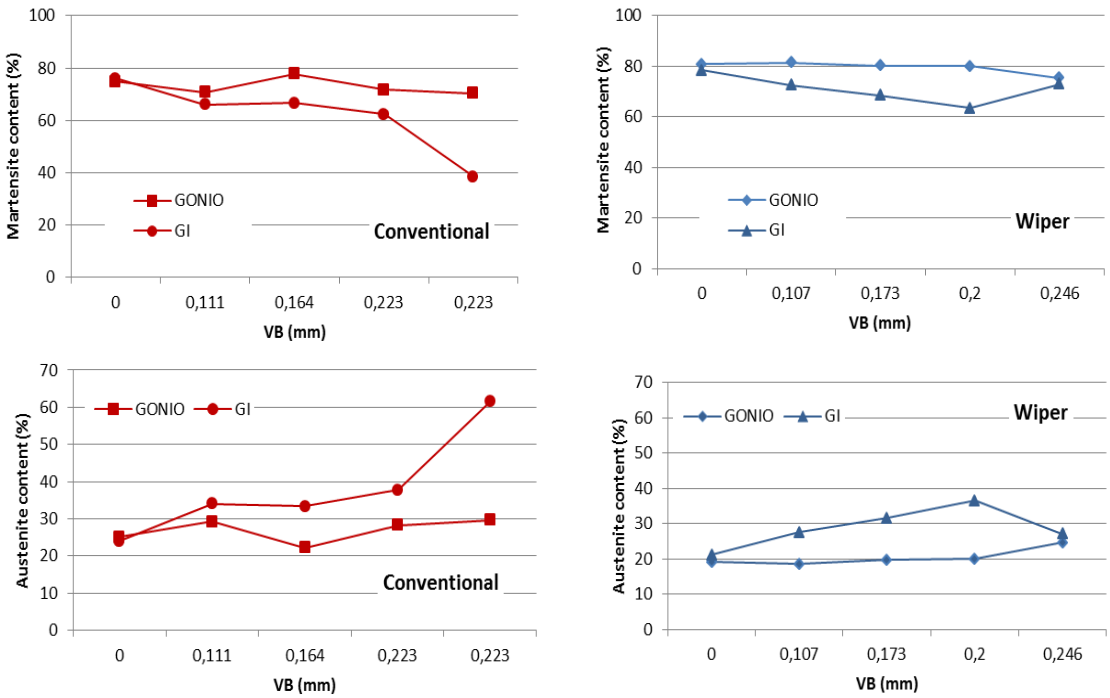

Fig. 5. Structural changes in dependency with flank wear VB (GI – surface layer, GONIO – sub-surface layer)

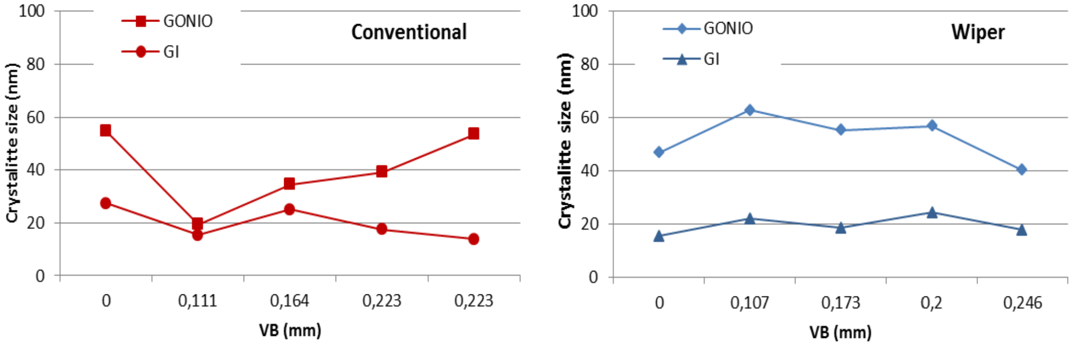

Fig. 6. Crystallite size influenced by the flank wear VB

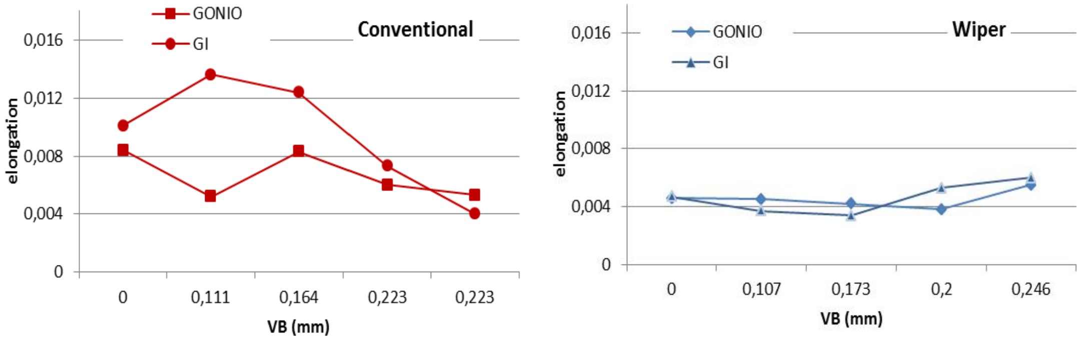

Fig. 7. Influence of the flank wear on the elongation

Wiper geometry, what is indicated by the elongation values, which are lower for Wiper geometry and stable for every VB values in contrast to the conventional geometry.

Comprehensively described experiment shows that the Wiper geometry - thus prolonged minor cutting edge, which partially suppresses the effect of hardening and partially eliminates the effect of the sharp heating when passing through the VB, what reduces differences between the surface and sub-surface layers. These surfaces are better in terms of functionality after using Wiper geometry. Use of conventional geometry provides greater voltage and structural gradient compared to Wiper geometry and thus Wiper geometry leads to attainment of better surface functional properties.

4. CONCLUSION

The structural analysis showed differences between conventional and Wiper geometry in terms of content of ferrite and austenite in the surface and subsurface layers. The content of austenite in the surface layer (about 1 µm) after use of conventional geometry is increasing according to the wear. At a greater distance from the surface are obtained lower austenite contents.

Use of Wiper geometry leads to achievement of lower percentage of austenite and it is not significantly climbing with the tool wear. It is caused by the prolonged minor cutting edge, which doesn´t allow a quick heating and subsequent fast cooling. On the contrary, longer contact between the workpiece and cutting tool restricts quick surface cooling. Measured elongation is talking about a more balanced state between the surface and sub-surface layers achieved by hard turning with Wiper geometry.

Crystallite size has stable values when using Wiper geometry with development of wear and this experimental study has also shown that the greater the workpiece temperature, the smaller crystallite sizes.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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