Surface Integrity of Hard Turned Surfaces on AISI 52100

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Abstract

Hard turning has over the last decades become as a complementary and also in some cases an alternative process to grinding. Desired surface integrities can be achieved at the same time as hard turning offers dry cutting possibilities and have a greater flexibility for complex geometries than grinding. By correct selection of process parameters and right tools (inserts) surface roughness values down to Ra=0.1µm can be obtained. The flexibility of the process allows a tailor made and a unique surface integrity for a specific application regarding i.e. residual stresses and surface topography. It is shown that different cutting parameters are resulting in quite different levels of residual stresses both on the outmost layer of the surface as well as the subsurface. Deterioration of the cutting tool due to different wear mechanisms during machining is unavoidable and has a great influence on the material.

1 Introduction

The aim of this investigation is to increase the understanding of the influence of the hard turning parameters on the surface integrity regarding the residual stresses, microstructure (white layer) and surface topography. The influence of cutting speed, flank wear, feed rate and rake angle on the residual stresses, surface roughness and white layer were studied by means of X-ray diffraction, scanning electron microscopy and interference microscopy. The hard turning tests were performed on AISI 52100 heat treated to either a bainitic or a martensitic microstructure with similar hardness.

2 Results

2.1 Residual Stress

It is shown that the residual stress profile curves can be controlled in order to customize the product surface integrity by proper selection of cutting data and tool parameters. Figure 1 shows typical stress pattern after different machining operations like grinding, hard turning and honing after Jacobson [1]. Generally, grinding gives compressive residual stresses on the surface while hard turning can result in tensile surface residual stresses. However, if further compressive residual stresses are required, honing can be used. The influence from the different cutting parameters on the surface integrity was thoroughly studied by Dahlman et al. [2] as well as Jacobson [1]. The surface residual stresses after hard turning are dependent on several parameters like the tool wear, cutting speed as well as the feed rate as shown in Figure 2 and Figure 3. Generally, the largest influence on the depth and level of compressive stresses has the tool rake angle, the feed rate and the flank wear.

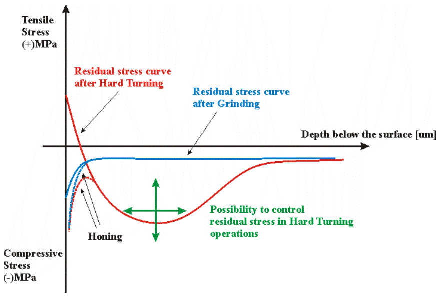

Figure 1: Typical residual stress profiles after hard turning, grinding and honing [1].

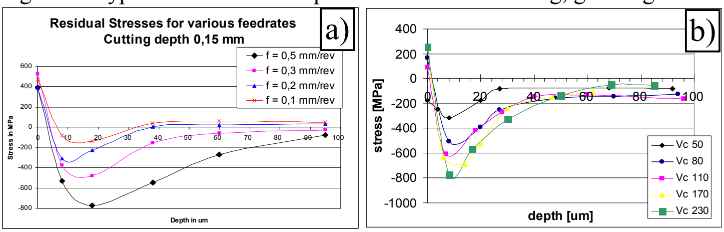

Figure 2: Illustration of the influence from a) the feed rate after Dahlman et al. [2] and b) cutting speed after Jacobson [3] on the residual stresses.

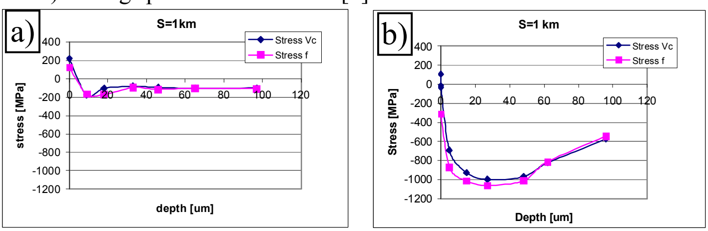

Figure 3: Influence of the rake angle on the residual stresses a)-6° and b) -61° after Dahlman et al. [2].

Using larger feed rate (Figure 2a), higher subsurface compressive stresses can be obtained while the cutting speed has a larger impact on the surface residual stresses

(Figure 2b). A larger negative rake angle will also introduce both higher near surface compressive residual stresses as well as larger penetration of the high compressive stresses as shown in Figure 3.

2.2 Microstructure and White Layer

The microstructure investigation showed that for new inserts only discontinuous white layer was found for the surfaces machined with highest cutting speed. While the surfaces machined with worn tools, independent on the cutting speeds contained continuous white layer. Initial TEM studies on the white layer created at the highest cutting speed with a worn tool were characterized by nano-sized grains ranging from a few nanometers up to few hundred nanometers. The white layer created during machining with lowest cutting speed (30 m/min) and worn insert, resulted in moderate surface residual stresses while increasing the cutting speed to 110 m/min or 260 m/min, the residual stresses were altered to high surface tensile residual stresses. No large difference in the white layer thicknesses (Figure 4a) or the residual stress pattern for the two different materials, bainitic and martensitic structures, could be seen with the exception for the surfaces machined with the lowest cutting speed.
Despite the fact that the formation of white layer is done under both high contact pressure (tool and workpiece) as well as high temperature (400-1100C) the (Fe,Cr)3C carbides were still present in the white layer as shown in Figure 4b.

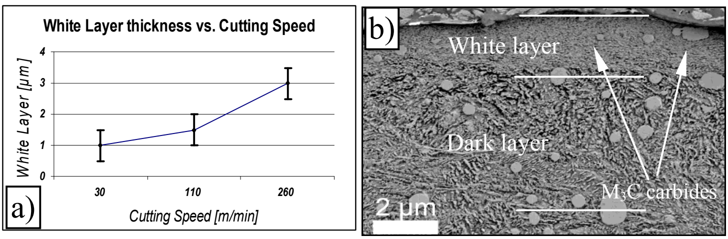

Figure 4: a) Influence from the cutting speed on the white layer thickness (V_B=0.17 mm). b) SEM image of the refined white layer structure, the dark layer and the $(Fe,Cr)_3C$ carbides in the microstructure.

2.3 Surface Topography

As shown previously by M. Jacobson et al. [3] the theoretically calculated surface roughness (Rt) does not correspond to the actual roughness obtained after experiments. Typical surfaces generated with a new and worn tools (Figure 5b and

5c) showing the change in the profile height due to the "Wiper effect" of the tool, Even though the surface roughness values are improved the surface residual stresses will shift from compressive to tensile with increased flank wear.

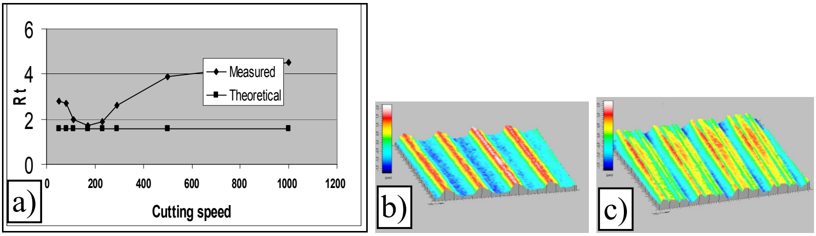

Figure 5: a) Comparison between measured and calculated profile height using a new tool [3]. 3D surfaces generated by b) a new tool and c) a worn tool.

3 Conclusions

It is shown that the surface integrity obtained after hard turning can be customized by a proper selection of process parameters like cutting speed, feed rate as well as by right selection of the tool geometry. Despite that hard turning can be optimized in such a way to obtain desired surface integrity, the extensive tool wear will result in undesirable subsurface microstructure alteration as well as high surface residual stresses. The selected cutting parameters and the wear of the tool resulting in the presence of the white layer and different residual stress state can be concluded as that the there is different mechanisms resulting in the formation of white layer.

References:

[1] M. Jacobson, "*Hard Turning of Bearing Steels – Controlling Residual Stress and Improving Fatigue Life*", Chalmers University of Technology, Göteborg, Sweden 2004, ISBN 91-7291-403-3

[2] P. Dahlman, F. Gunnberg and M. Jacobson, *The influence of rake angle cutting feed and cutting depth on residual stresses in hard turning*, J MATER PROCESS TECH, 2004;**147**/2:181–184

[3] M. Jacobson, P. Dahlman and F. Gunnberg, *Cutting Speed Influence on Surface Integrity of Hard Turned SKF 827B Steel,* J MATER PROCESS TECH, 2002;**128**/1-3:318–323