POLISH ACADEMY OF SCIENCES - MATERIALS SCIENCE COMMITTEE
SILESIAN UNIVERSITY OF TECHNOLOGY OF GLIWICE
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ASSOCIATION OF ALUMNI OF SILESIAN UNIVERSITY OF TECHNOLOGY

Conference Proceedings

11th INTERNATIONAL SCIENTIFIC CONFERENCE
ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

# A contribution to the understanding of chip formation mechanism in high-speed cutting of hardened steel

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The chip-formation mechanism analysis is an effective tool for deeper understanding of cutting process. During conventional and high-speed milling of the hardened tool steel (X63CrMoV51), with cutting speed range from 50 to 1500 m/min, different mechanisms of chip-formation appear. The analysis covered the chip segmentation frequency, chip shape and dimensions, and also the size of deformed and un-deformed parts of chip segments. The results show that there exists a close relationship among these chip parameters, especially in the region of high-speed machining.

## 1. INTRODUCTION

Investigations of machining of hardened steel have recently attracted a great deal of attention. This is related to the fact that high-speed technologies enable the machining of workpieces in their hardened state with a good surface quality and dimension accuracy. Therefore these processes have considerable advantages compared to the traditional machining technologies which include machining processes from rough machining of material in softened state, semi-finishing, hardening and finishing.

The newest investigations in this segment of processes are focused on the four characteristic directions: mechanisms of tool wear [1], quality of surface finish [2], mechanisms of chip formations [3], and problems of machining of materials in their hardened state (hard machining) [4]. All these researches are mainly focused on the one common goal, to establish the possibilities of optimal use of the high-speed machining in practical applications. One of the most important tasks, therefore, is to establish the regime of the cutting speeds that correspond to the level when the process enters into the high-speed range.

In the paper some results of the investigation of the cutting speed influence into the strain-hardening rate and chip formation process are presented. Findings are obtained on basis of the micro-graphical analysis and measurement of chip micro-hardness (some of them were already discussed, see e.g. [5]). Also, the some particularities referred to the chip segmentation frequency and shape and dimensions of the chip segments are discussed.

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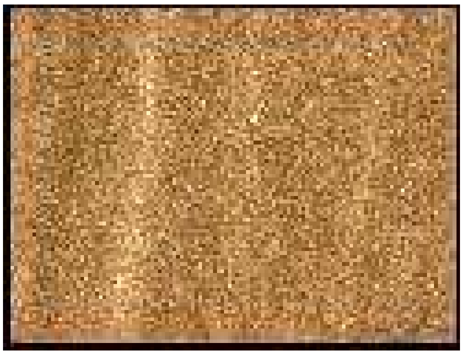
* Authors participate in the CEEPUS No PL-013/02-03 project headed by Prof. L.A. Dobrzański.

## 2. EXPERIMENTAL WORK

The experimental work has been carried out at the Faculty of Mechanical Engineering, University of Ljubljana. The machining was conducted on the milling machine, type Moriseiki-Frontier. The machining conditions were as follows: cutter diameter D = 80 mm, depth of cut d = 2mm, tooth feed $f_z$ = 0.1 mm, cutter type SUM-UFO-4000, cutting insert SFKN 12T3 A2TN - AC230, $\gamma = 27^o$, $\lambda = -7^o$, $\chi = 45^o$. Steel was machined at the cutting speeds at speeds 50, 150, 300 and 1500 m/min.

The chemical composition and microstructure of the investigated steel grade X63CrMoV51 is presented in Figure 1. The microstructure of the steel in tempered state (629 HV) consists of martensite with the characteristic eutectoid carbides and some retained austenite due to “yielding” after quenching.



| Chemical composition [ %] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| C | Si | Mn | P | S | Cr | Mo | V | Cu | Al |
| 0.62 | 1.0 | 0.59 | 0.017 | 0.004 | 5.46 | 1.21 | 0.46 | 0.26 | 0.028 |

Fig. 1. Microstructure and chemical composition of the investigated steel

## 3. RESULTS AND DISCUSSION

All the experimental results have been presented in Figure 2 in the form of a diagram of the micro-hardness and cutting speed magnitude; the diagram is illustrated by the microstructures of the chip shape produced. On the left hand side the figure presents the microphotographs of the initial microstructure for the steel at the tempered state 629 HV-52 HRC).

When the cutting speed is $v_c$ = 50 m/min, the microstructure of the material belongs to the classical type of deformation with uniformly elongated grains, but with the appearance of the white layer on the inner side of the chip, which is the consequence of the thermal softening of the material. The average measured microhardness is 660 HV, which in relation to the initial value (629 HV) gives a low level of strain hardening.

In machining at a speed of $v_c$ = 150 mpmin, the chip is segmented and has a typical saw-tooth shape. Clearly visible is a white layer both on the inner side of the chip and also between the segments. Therefore, the appearance of the thermal softening and deformation mechanism occurred. The average measured micro-hardness value of the white layer is 756 HV.

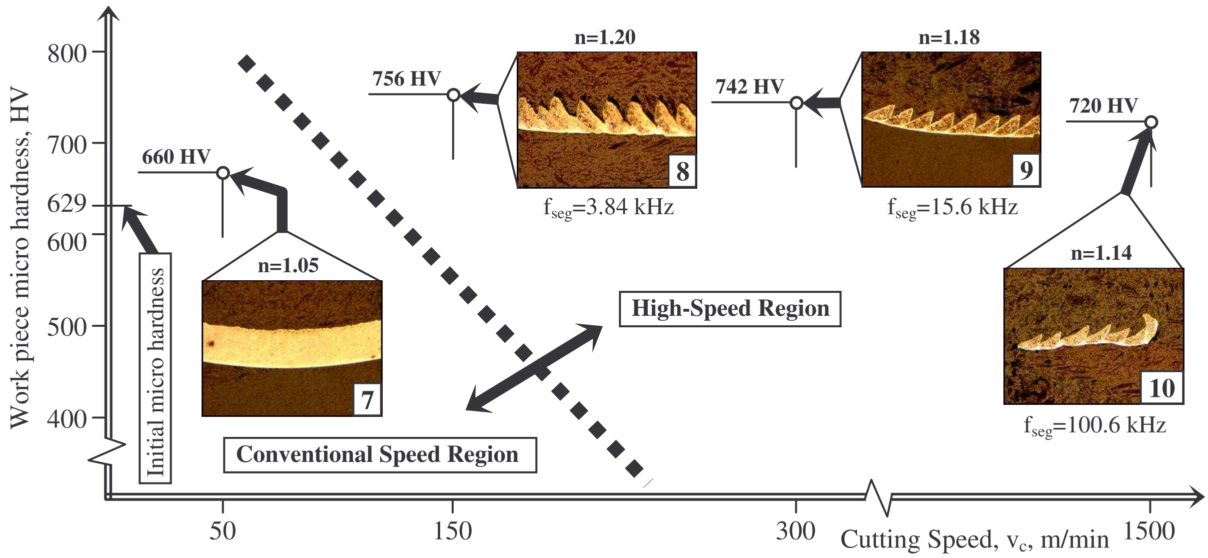



Fig. 2. Chip morphology obtained in conventional and high-speed region

However, on the inner (non-deformed) part of the chip segments the average micro-hardness is only 632 HV, which shows as a complete non-deformed structure in relation to the initial state of the workpiece materials. Approximately 62% of the chip segment cross-section area is deformed. The frequency of the chip segmentation is about 3,84 kHz.

On the basis of the above findings it can be concluded that the machining with this speed is already in the range in which we can make conclusions related to the high-speed machining.

In machining at a speed of $v_c$ = 300 m/min the chip is even more highly segmented, with lower thickness and with the segments of lower dimensions in comparison with the previous speed. At the same time the thickness of the white layer is lower and its average measured micro-hardness is 742 HV. On the inner part of the segment the average micro-hardness is 640 HV. In this case, approximately 40% of the chip segment cross-section area is deformed, and the frequency of the chip segmentation is about 15.6 kHz.

In cutting with the speed of $v_c$ = 1500 m/min the chip shape is heavily segmented with an even lower thickness and magnitude of the segments. Moreover, the thickness of the white layer is lower compared to the machining with lower speeds; its average micro-hardness is 720 HV. On the inner part of the segments the average micro-hardness is 618 HV. Finally, approximately 33% of the chip segment cross-section area is deformed, and the frequency of the chip segmentation is about 100.6 kHz.

The resulting diagram, presented in Fig. 3 shows the relationship between the frequency of chip segmentation and the relative magnitude of the cross-section area of the chip segment deformed part. The proportionality between these parameters and the cutting speed is obvious from the particular diagram.

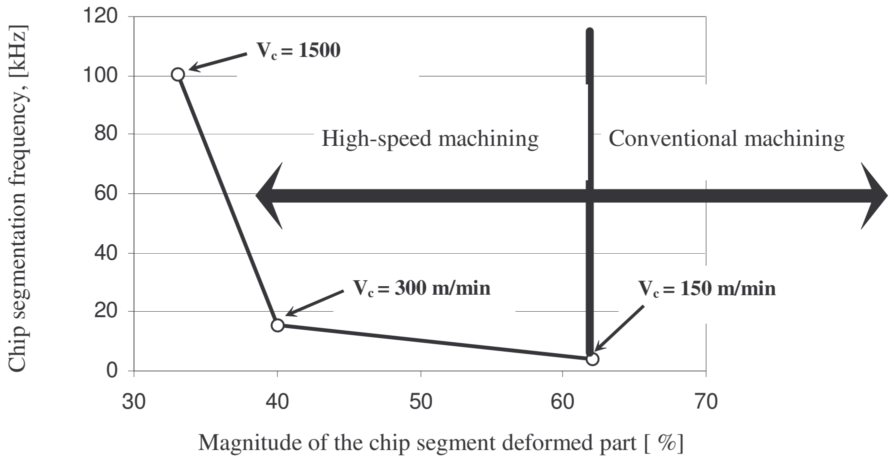



Fig. 3. Frequency of chip segmentation and magnitude of cross-section area.

## 4. CONCLUSION

In the paper the experimental investigations of the chip shape and measurement of the chip micro-hardness serve as a basis for the analysis of the process of plastic deformation in machining of the steel X63CrMoV51 at the tempered conditions. In relation to the results obtained some main conclusions can be defined:

1. On the basis of the chip shape evaluation obtained during the machining of the investigated steel the high-speed machining appears with the cutting speeds above 150 m/min.
2. With the increasing of the cutting speed the chip segmentation frequency also increases while the chip thickness and magnitude of chip segments decrease. At the same time, the magnitude of the deformed part of the chip segment decrease.
3. As cutting speed increases, the material thermal softening during the process of plastic deformation becomes greater, while the part of chip segment cross-section area, which is exposed to the influence of thermal softening, becomes lower (white layer),
4. As chip segmentation frequency increases, the deformed part of chip segment cross-section area decreases.

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