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THE INFLUENCE OF TOOL WEAR ON CUTTING PROCESS DYNAMICS AND CHIP FORMATION MECHANISM

Abstract:
The paper presents the survey of the experimental research of the chip forming mechanisms and chip types dependant on the tool wear process in turning. Based on the experimental research, the influence of tool wear on morphology and microstructural alterations in a chip has been analysed. Relating to tool wear, the modification in chip structure and the character of vibrations appearing in certain size of the medium-width band for tool wear and chip segments formation mechanism significant for cutting conditions definition have been monitored. The research in the paper aims at contributing to better understanding of mechanism, feature and chip lamella formation depending on the size of tool wear medium-width band in turning.

Keywords:
Vibrations, Tool wear, Signal processing

INTRODUCTION

In order to achieve satisfactory tool existence in modern production conditions, the research does not aim only to increase tool cutting characteristics in high temperatures in order to examine resistance to increased temperature and wearing. Understanding the correlation between chip formation mechanism and tool wear in the process of cutting hard and improved materials has an important role in revealing the friction influence at critical point during the cutting process, as well as in determining optimal cutting conditions. Generally, in conventional (slower) cutting speed the dominant wearing mechanism includes abrasive and adhesive wear, and in higher speed the diffusion and oxidation influences have a dominant role in tool wear appearance. Kopač and al. [1] emphasised that cutting in lower temperatures produces high pressure resulting in welding which in turn leads to layers on the cutting edge, while the increased cutting temperature due to high cutting speed increases the oxidation process distribution onto larger tool surface. Diffusion process, appearing between the chip and the tool rake face, results in crater wear, while the oxidation reaction to the environment produces alterations on the cutting edge [1]. In the conditions of high-speed machining, with high cutting speed and supplementary movements speed, at the contact points between the tool and the chip, there appears material merge in certain zones on the tool face, which can seize the entire surface, considering their large contact area and fast spreading. In this case, it would be hard for the coolants and lubricants to reach to the tool/chip *contact area. Increase in sliding, i.e. friction coefficient reduction at tool/chip contact area can be solved by applying certain coat types [2]. The aim of the paper is to present the influence of tool wear onto chip formation mechanism, i.e. to examine the measure in which tool wear development affects the chip formation and type.*

CHIP FORMATION DEPENDANCE ON THE DEGREE OF TOOL WEAR

In the several last decades, even the entire century, the studies on the chip formation process have been performed, though the problem has remained in the centre of attention. Chip shape emerging during turning can be classified as continual, discontinual, continual with wrinkled edges, sheared and segmented (continual with periodical variations in thickness) [4]. Generally, the chip formed in cutting hard and improved materials is in most cases continual with wrinkled edges and sheared. Currently, there are two theories in available literature data which define the origin and formation of sawtooth chip (with wrinkled edges). One theory is the "theory of fracture" and cracks, by which the appearance of a chip happens with the appearance of a crack on the free surface of the workpiece which is then quickly distributed to the tool cutting edge up to the certain length when the crack halts due to strong plastic deformations in the material influenced by cutting tool high pressure. The segment, chip lamella, occurring between the tool rake face and the chip, advances forward in the tool movement direction, while the material in the region beneath plastic deformation of the initial crack is expanded along the tool rake face in order to form the sawtooth chip type [1, 3, 4, 5]. The second theory of shearing occurrence in the primary cutting zone is the "adiabatic theory of chip formation", which states that thermoplastic material instability occurs inside the primary shear zone and it is the basis for material deformation mechanism appearing due to heat softening, so the material lamellae shear due to forces occurring with thermoplastic material strengthening outside the zone, as a consequence of high material strain in the shear zone [4, 5]. Adiabatic shearing can precede the occurrence of the initial crack and its expansion inside the non-cracked area of the primary shear zone, depending on the cutting conditions. Barry and Gerard [4] have examined the chip formation mechanisms in steel machining and concluded that the instability inside the primary shear zone during sawtooth chip formation is initiated by the adiabatic chip formation theory, with the dominance of the shearing stresses and their expansion towards the free area of the workpiece. Deformations of the upper region in the primary zone close to the chip free surface are the consequence of the both theories, "theory of fracture" and "adiabatic theory", depending on the cutting conditions. Hard conditions in material processing, like high stiffness material cutting using high cutting speed, cause material degradation by chip appearance of the so-called "ductile" fracture influenced by high plastic deformations. The increase in workpiece material hardness, cutting speed, cutting depth (non-deformed chip thickness) and tool wear band width, as well as negative value of the rake face angle, can result in the occurrence of the chip with sawtooth segments [1]. The research has shown that the deformed segment on the chip cross section area decreases with the cutting speed increase.

Cutting tool vibrations during machining appear due to friction on face and rear tool surface, wear on tool cutting edge, and corrugated (non-cylindrical) cutting, and they are also connected to the shearing gear wheels in the kinematical machine chain. The research has shown that the largest source of lathe knife vibrations in stable machining mostly occurs due to the friction between the tool rear and the workpiece. Basic tool vibration frequency is the resonant system frequency caused by friction on the cutting edge. Vibration acceleration is the best possible measure for the vibrations appearing in high frequencies. Considering that the cutting tool vibrations are in fact high frequency vibrations (i.e. above 1 kHz), tool accelerations have been selected as a parameter for tool wear monitoring [3].

EXPERIMENTAL RESULTS SURVEY

Segmentation of the Sawtooth Chip

Experimental research presented in the paper offers a clear insight into the basis of metallurgical instability responsible for the appearance of the sawtooth chip lamella on the free surface. Figure 1 shows a microscopic view of the chip occurring in the machining of the low alloy carbon steel, thermally processed to the hardness of 45 HRC with a cutting speed of 200 m/min. It can be clearly observed that the lamella gear teeth in the cutting process are a cyclic process starting from the initial segment having considerate alterations due to physical tool action (or deformation due to high pressure of the tool tip). Likewise, grain elongations in the material structure, which, due to large elongation and stress, compress into the line extended from the primary shear zone, are visible on the cross section of the occurring chip, as in Figure 1. That such a shape is not a result of the sliding friction on the fracture segment is evident from the fact that the fracture force is maximal on the sliding area [4]. Instead of expanding the fracture crack downwards through the primary shear zone, the occurring deformation band is localized as a band formed due to adiabatic material sliding. This conclusion is based on the fact that its thickness is connected to the tool type, i.e. tool geometry and features, which assumes the appearance of shearing due to the influence of the cutting force and the expansion of the initial crack towards the tool cutting edge. The lack of the visible shear in the upper region of the material primary shear zone reveals that there is a deformation and stress decrease due to the influence of the thermal strengthening of the basic material, i.e. due to the machining material condition.

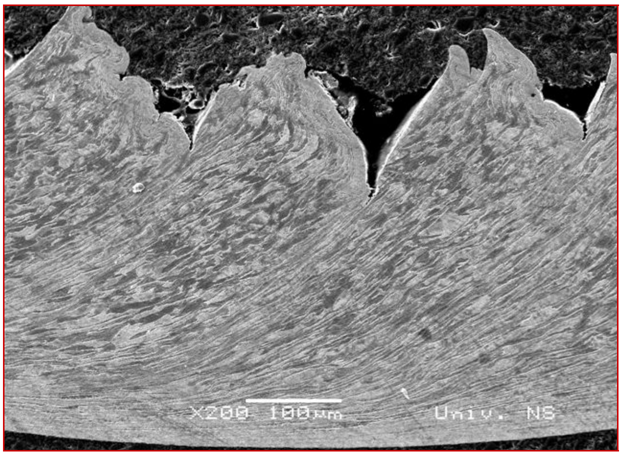

Fig. 1 Sawtooth chip segmentation

The band next to the chip edge in the contact with the tool shows shearing along the sample edge which is formed within the secondary cutting zone. The remaining traces of the elongated material structure grains are formed within the primary zone; however, it is evident that every appearance of cracks and initial chip segments in the basic shear zone forms a discrete segment. For the conditions in which the sample in Figure 1 is formed, the decrease in the improvement and the expansion of the initial crack in the lower segment of the primary shear zone (where lamella shearing localisation occurs) is observed. Within the observed chip segment, two chip formation segments can be identified in the primary shear zone in the formation of the lamella teeth of the sawtooth chip, which can be attributed to the sharp cutting conditions, and which can be observed through the longer time spent on the material removal and higher cutting speed due to thermal improvement of the material, as seen in Figure 2.

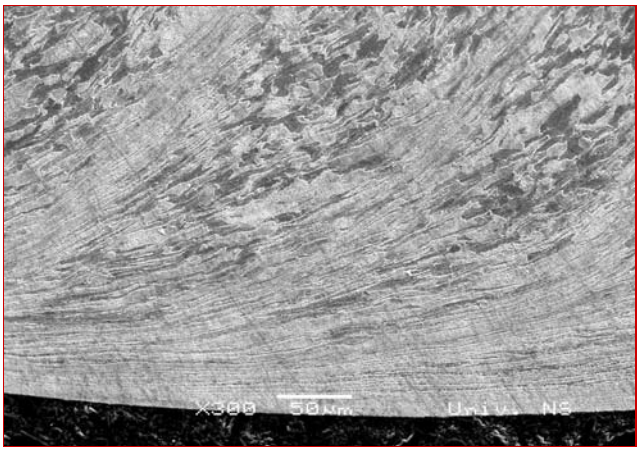

Fig. 2 The outlook of the zones of deformed and non-deformed material in chip formation

Segmentation of the Quazi Continual Chip Type

It is known that quazi continual chip type introduces obvious proofs for the occurrence of the lamella shearing in the primary cutting zone on the free surface, though, observed on the frequency scale, the frequency is for a size rate smaller than in the situation when sawtooth chip is formed [4]. A more significant difference in the nature of defining lamella shearing in the quazi continual and sawtooth chips is the relation between the distance of the cutting front D shown in Figure 1 and the d shown in Figure 3 on the undeformed chip thickness (cutting depth). On the free surface of the continual chip, the distance between the cutting front lamellae (equivalent to the lamella thickness) is largely independent of the undeformed chip thickness, *and it is usually from 7 to 12 μm. Sawtooth chip, i.e. the distance between lamellae is similar in its size as the undeformed chip thickness and it is generally within the 50% of that thickness.*

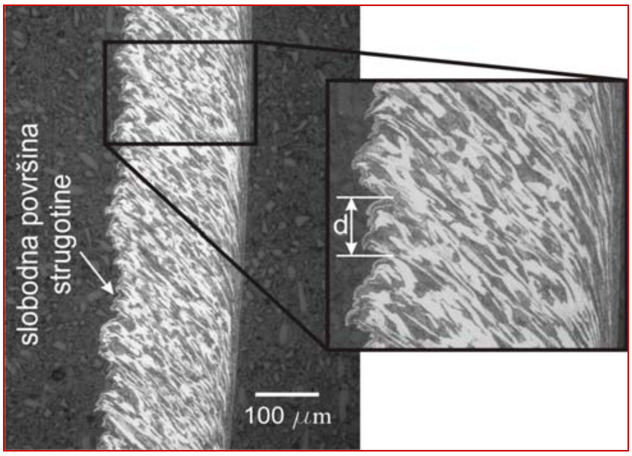

Fig. 3 Quazi-continual type of the occurring chip

Tool Rake Face Wear

The development of wearing on the tool rake face appears approximately only after 1/3 of the standard time in tool work after chip lamella breaks into the tool insert, after which it begins to grow progressively. Progressive wear development is connected to the temperature growth and friction on the rake face, and, as already stated, the insertion of the chip segment into the tool insert, thus removing the chemically less stable titanium nitrite together with the chip. The formed crater damages the cutting edge and in relation to the increased temperature leads to breakage and fracture of the tool insert tip.
The crater increase on the tool rake face has a very significant influence on the chip segment formation mechanism, as well as on the segmentation frequency and chip type. Crater wear is directly linked to the main initial structure in lamella formation which always aims to have a character of the continual uninterrupted chips. Chip interior in excessively growing crater formation leads to the beginning of the inlayer formation on the tool cutting edge. The sight of the chip free surface formed with the tool with the developed crater on the tool rake face and creation of the layers on the tool cutting edge is presented in Figure 4.
Localisation of the shearing within the basic and medium zone in chip formation appears as a key phenomenon controlling the wear progression, static cutting force and vibrations occurring in the cutting process.

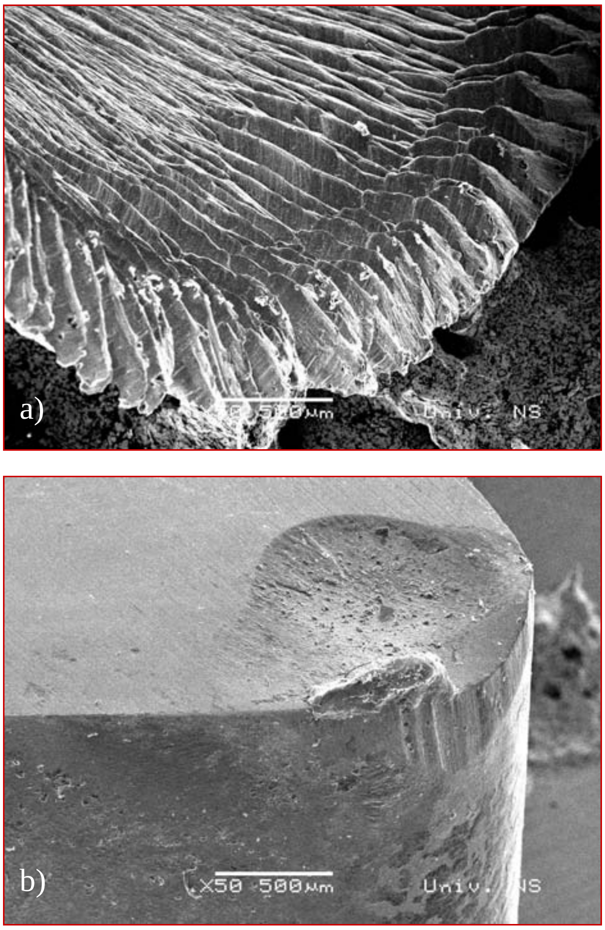

Fig. 4 Presentation of the a) chip free surface and b) rake face with the development of the crater wear on the cutting edge

The alteration in the chip shape caused by the alteration in the cutting wedge geometry leads to the alteration in lamella segmentation which then reflects the increase in signal content in high-frequency spectre segment. The alteration in the crater wear directly influences the chip type, which is in any case directly linked to the alterations in lamella formation and segmentation, which can be directly observed on the chip free surface.
Observing the lamella segmentation alteration, as well as the alteration in tool cutting geometry due to tool wear increase, Figures 5 and 6 present a comparative presentation of the time window of the recorded signal and microscopic shot of the cross section of the formed chip during the machining with the new tool and the tool with the certain degree of wear.

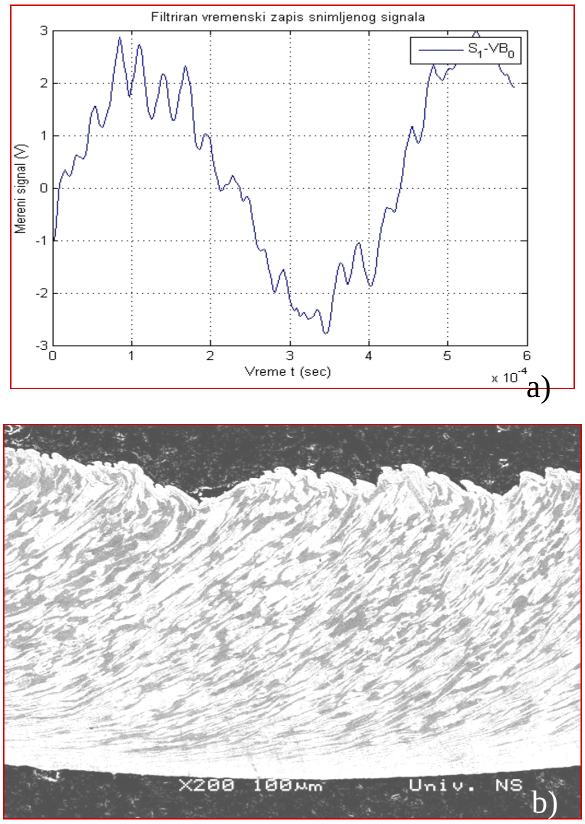

Fig. 5 Display of the vibration signal time window, a) cross section of the occurring chip, b) new insert

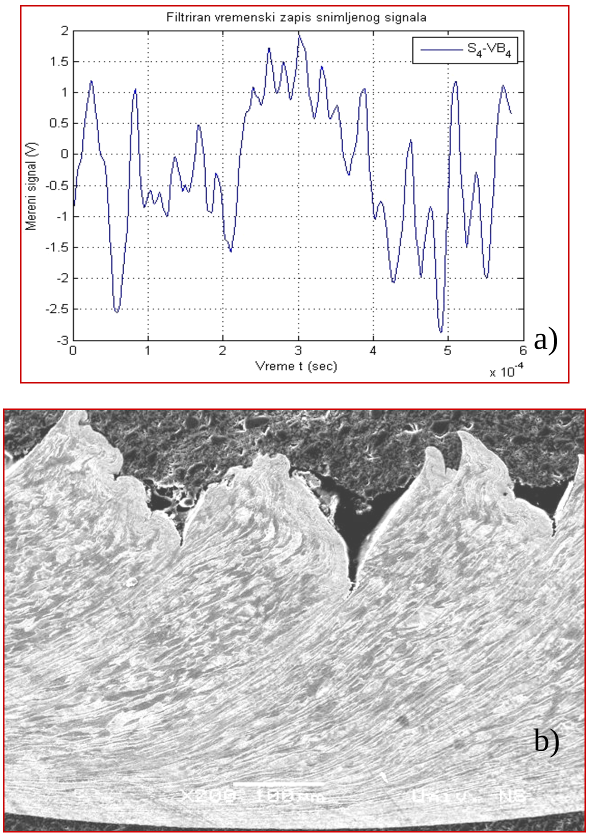

Fig. 6 Display of the vibration signal time window, a) cross section of the occurring chip, b) wear band 1mm

CONCLUSION

Considering the previous research, it can be concluded that the time limited observation of the vibration signal spectre presents "deviations" caused by the alternation in energy content due to the alternations of the chip segmentation type and features. The observed continual vibration signal measured on the lathe knife presents significant differences. Time limited short-term events appearing in the machining process can be identified by extracting significant parameters by the application of the appropriate methods for signal processing utilized to perform characteristic extractions from the basic signal content.

Identification of the tool rake face wear based on the alterations in the macroscopic and microscopic chip features is possible with the utilization of the adequate methods and techniques for vibration signal processing.

Common causes for the formation of statistic and frequently dependent characteristics for cutting processes are in correlation with the chip segmentation type and the development of the tool crater wear.

However, one should bear in mind that the wear process is performed simultaneously on both face and rear tool surface and hence the wearing process cannot be observed separately. Based on the trend of the growth of these influences on the amplitude and the signal spectre, identified influences will serve to recognize tool wear condition and classification. Vibration signal content is in any case directly dependant on the concrete cutting conditions, i.e. machining parameters.

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