

Some Aspects of Plastic Strain in Chip Creation

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The article presents an experimental method of tracking deformation domains in the formation of shavings in machining of metal materials. The methodologies of the study of the mechanism of plastic deformation in the zone of chip forming used hitherto were based on the observation of quasi-static states obtained by stopping the process of cutting. The methodology shown here rests in a dynamical study of the movement of grains or groups of grains in the area of chip forming. In the course of machining, the path of the movement of the particle is being recorded. This part of the movement of the particle is being recorded. This part enables us to judge of the speed and the acceleration of the movement and draw some conclusions as to the course of the phenomena of the plastic deformation of the material in front of the cutting edge of the tool.

Keywords: machining, plastic deformation, chip forming

1 Introduction

When turning metals, the process of chip creation belongs among complex heterogeneous deformation and destruction processes. The approaches to the definition of chip creation mechanism have so far been based on geometric models. Some authors have preferred deformation and shearing processes in a plane (Time, Merchant, Brix, Glebov, Usačev), some of them a volume developed under tool cutting edge (Okoshi – Hitani, Palmer – Oxley, Zorev, Johnson). Loladze has been the one to approach the reality of cutting process when he defined cutting process as cut material in plastic state flowing around the cutting wedge [8].

To explain the essence of chip creation processes, metallographic – fractographic approach, which has been presented in several works [7], [11], seems to be important. The basics of the experiment has been laid in immediate interruption of the process with minimal influence on geometric processes of chip creation [13]. The materials obtained in such a way undergo metallographic and fractographic analysis on the base of recent physical and metallurgical knowledge. The influence of the tool on cut material evokes force effect which can be principally characterised as a force of normal chip pressure on tool face F_n and friction force F_t , which has influence on the area of contact of the tool with creating chip (Fig.1). These elements summarise into the resulting force F , which has a point of action approximately in the center of the contact of the chip with tool face. Resulting force evokes a reaction with opposite sign F' in cut material, which works in the middle of abscissa considered to be the interface between basic material and creating chip. Material deformation resistance creates physical basis of this force. Force F' can be divided into the element F'_t , which represents shear deformation resistance in the interface plane. Structural analysis shows that there occur high degrees of shear deformation within interface plane which is shown in the creation of deformation texture.

Another element is force F'_n , which is responsible for the measure of breaking of the elements of creating chip

parallelly with the tool face. From the viewpoint of machine coordinate system, force F' divides orthogonally into elements F'_y and F'_z . Other parameters presented in Fig. 1 correspond with common symbolics presented in literature [1], [2], [5], [19].

Scheme of chip creation with the division of forces according to Fig.1 is based on literary knowledge and measurements which prefer turning as stable process. The point of action of cutting force is situated into the center of abscissa of the contact of the chip with tool face AT . The point of action of the forces of cutting resistance is in the center of the abscissa AM (idealised border of plastic deformation).

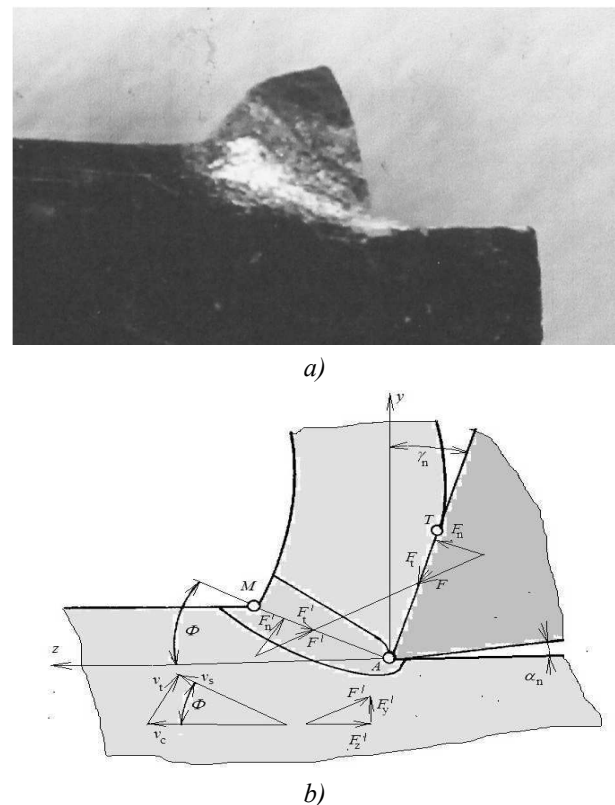


Fig. 1 Visualization of the chip formation zone (a) and scheme of chip creation with force ratios for free cut (b)

2 Methodology of experiments

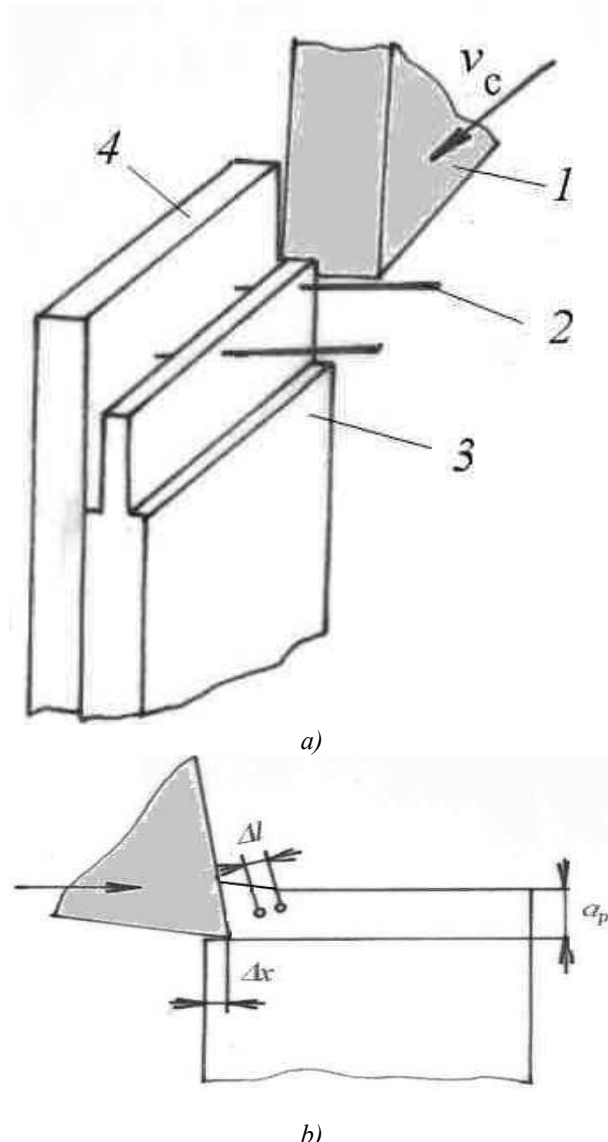


Fig. 2 Adjustment of workpiece to observe the movement of material particles into the chip. 1 – tool cutting wedge, 2- needle, 3 - workpiece, 4 – registration plate made of plastic material

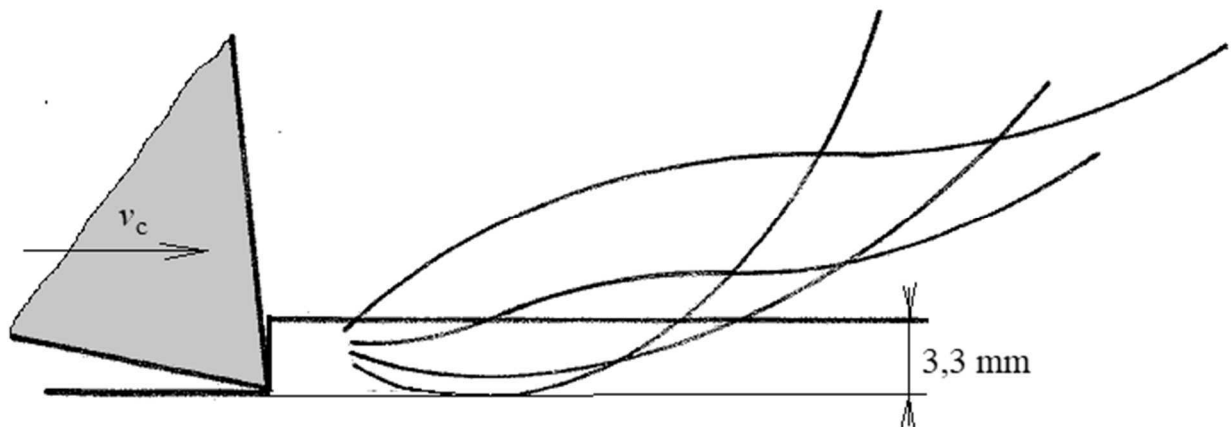
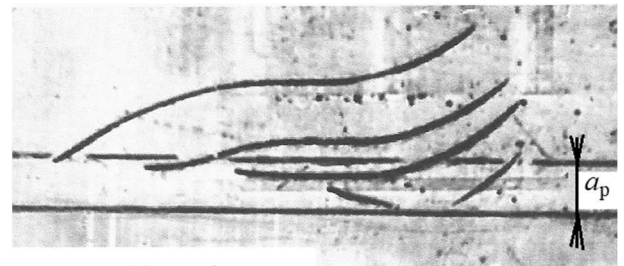


Fig. 4 View of curves drawn by needles, corresponding with the position of chip elements

When observing the changes of these characteristics of the process depending on cutting force, it is necessary to observe the movement of material elementary particles into the chip. Following experiment has been realised for this purpose.

A model of a workpiece 3 has been made of lead sample (Fig. 2) into which steel needles 2 have been inserted, ending on the polished wall of a lead plate 4.

When the tool passes and the chip is being created, the tips of needles would draw the courses of different chip elements. The photography of the course of obtained curves is shown in Fig. 3.



$v_c = 11 \text{ m.min}$
 $a_p = 3,5 \text{ mm}$

Fig. 3 Photography of the record of the material elements course during the shift into the chip

After obtained curves are shifted under each other, there is created a course of element movement in different positions of the thickness of cut-off layer.

Corresponding course is shown in Fig. 4. The curves correspond with the case when the tool and chip are in move and the workpiece is static. This corresponds with slotting. It can be seen that the lines of element movement interlap. The points close to the position of machines area perform a more complex movement, first they decrease and then shift into the chip. Upper points leave freely. It can be realistically supposed that the movement of actual grains, at realistic thicknesses of cut-off layer, will be realized similarly.

Lead samples have been used in modelling the process, which enables to freely increase the thickness of cut-off layer. In Fig. 5 there is a visualization of the course of points located in different positions of the cut-off layer. The case is opposite – the workpiece is moving and the tool is static (planing). It means, movement of points against the workpiece is modelled. It can be seen that different points approach the tool face and they get the direction of chip leaving after the chip leaves contact with the tool face.

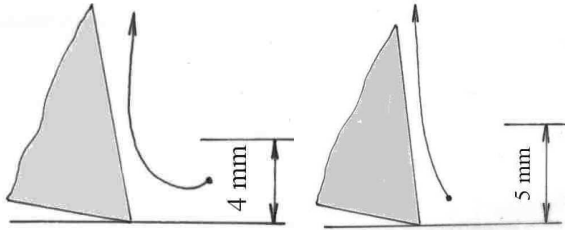


Fig. 5 Modelling of points movement in the cut-off layer against the tool

Presented methodology enables to determine speed and acceleration of observed points. After certain shift of the tool (micrometric screw of machine support) by the same value Δx , needle position is recorded. The distance of side punctures determines the shift of element in the chip. In Fig. 6 there is a view of registration plate with punctures determining different positions of observed element.

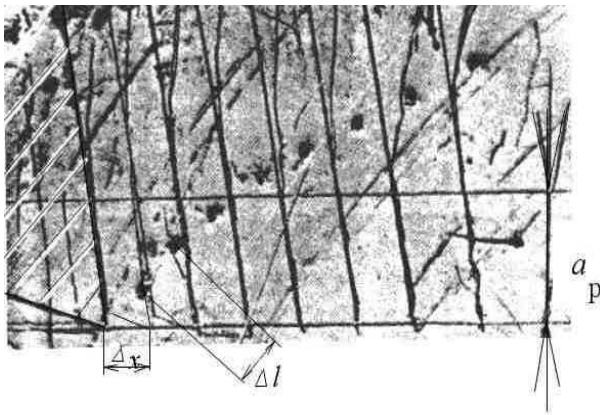


Fig. 6 View of different element positions when the tool inserts into the workpiece

3 Analysis of movement kinematics in plastic field

Speed of element movement is evaluated as a ration of such found course Δl during the same time τ_1

$$v = \frac{\Delta l}{\tau_1} \quad (1)$$

In Fig. 7 there is a course of such found speed of element movement in the chip.

It can be seen that the speed sharply grows to maximum value from the zero tool position and next stabilizes at the speed which corresponds with the speed of chip

movement v_t .

Similarly, acceleration can be determined by fraction of speed and time of tool shift by Δx :

$$a = \frac{v}{\tau_1} \quad (2)$$

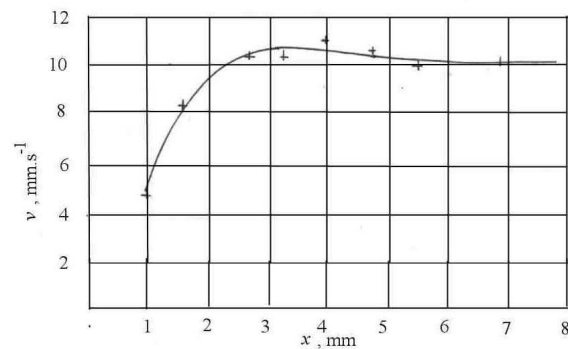


Fig. 7 Course of speed of element movement in chip

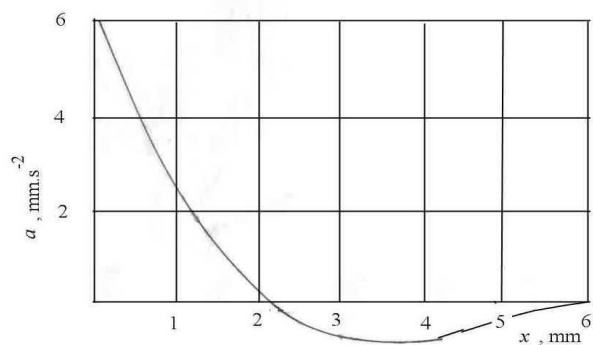


Fig. 8 Course of acceleration of movement of element during shifting into the chip

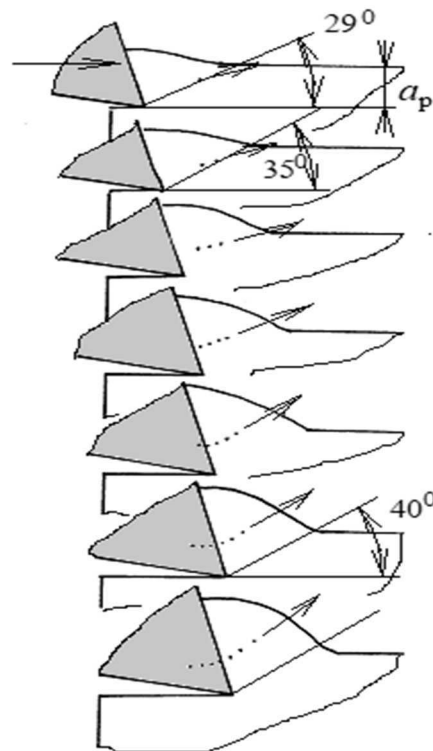


Fig. 9 Change of needle position (chip element) when tool enters the mesh

In Fig. 8 there is a diagramme of the acceleration of element. It can be seen that maximum acceleration is at the beginning of the movement. It decreases gradually and reaches zero value when the element shifts from plastic zone into the chip.

By gradual insertion of the cutting wedge into the mesh, also the change of element orientation and the size of angle of the border of plastic deformation ϕ can be identified. In Fig. 9 there is a principle of relocation of observed point in the chip when the workpiece is static and the tool is moving.

It can be seen that the angle of plastic deformation

continually grows and the direction of the movement of observed element actually copies the angle of chip texture.

4 Zone of plastic deformation

Let us observe the mechanism of initial plastic deformation in cutting zone, i.e. in front of the tool cutting edge. In Fig. 10 there is a metallographic V-cut of the area of chip creation obtained by interruption of the cutting process at cutting speed 100 m.min^{-1} . A fortified phase with the width 0.2 mm , the same as the thickness of the cut-off layer, is created on the tool face.

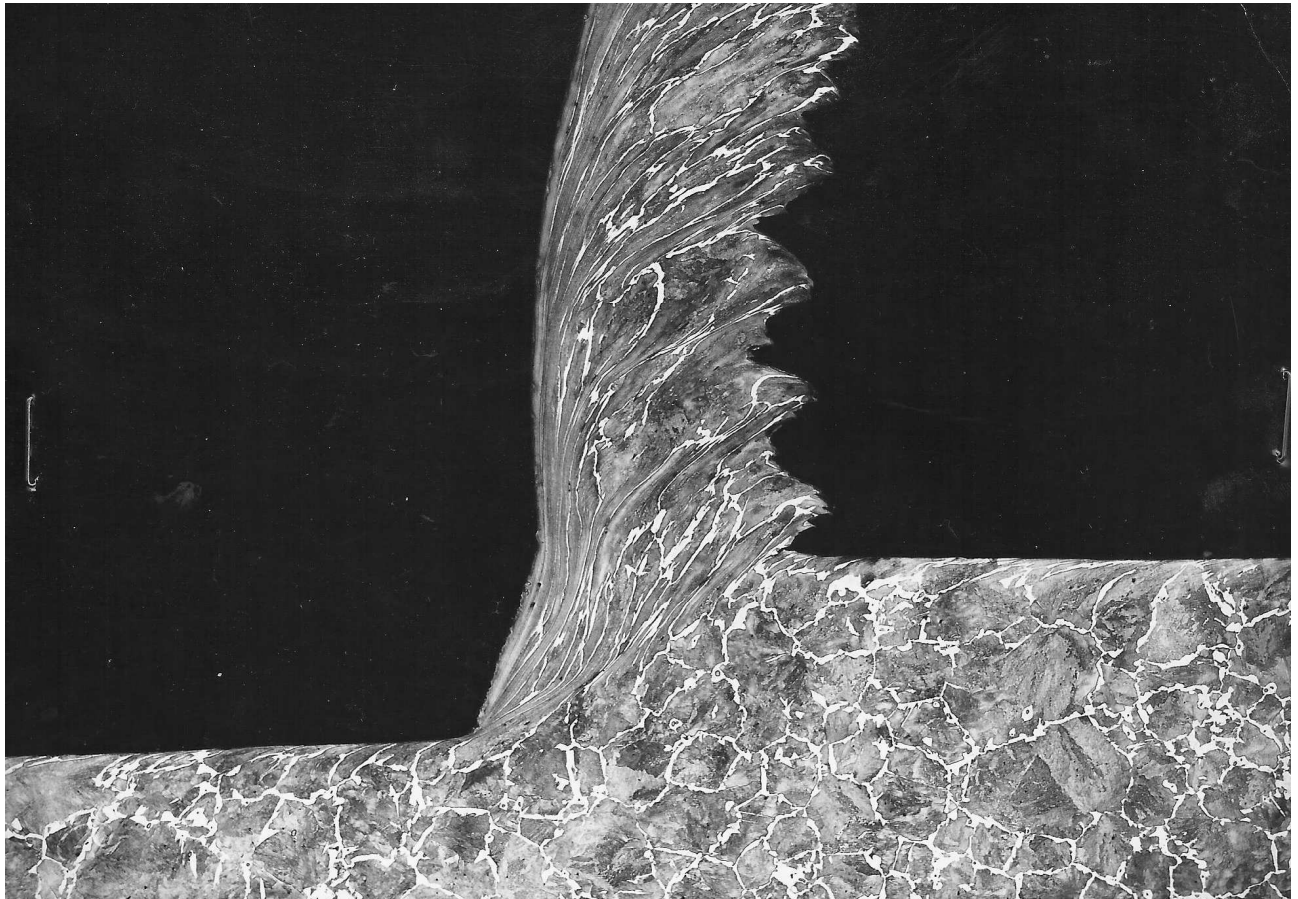


Fig. 10 Photography of metallographic V-cut of "chip root". workpiece: steel C45; $h = f = 0.2 \text{ mm}$, $v_c = 100 \text{ m.min}^{-1}$

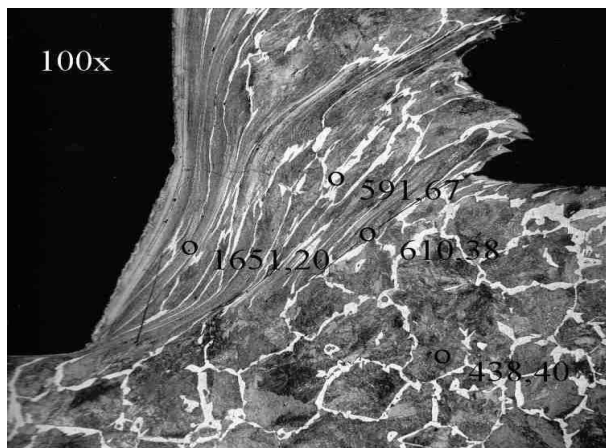


Fig. 11 Enlarged area in front of cutting wedge from Fig. 10 with data about microhardness HV_{20}

It can be seen that there occurs prolonging of grains into the shape of fibres. Deformation in chip does not have the same intensity. Deformation periodicity, which leads to the "saw-like" profile of back chip side is shown. Tearing of highly deformed grains occurs in front of the cutting edge. A detail characterizing the chip being separated of the observed steel is shown in Fig. 11. As it follows the figure, considerable (four-times greater) increase of material hardness occurs in the stalled layer in front of the cutting wedge. This is a proof of considerable fortification. This means that after taking away the chip, this layer takes over the function of the cutting wedge. Given layer seems like a plastic one at high deformation in the deformation field. Shears in the chip have periodical character. Their frequency mainly depends on cutting speed and tool geometry. In the shear zone, there occurs higher fortification than in the center of chip element.

5 Conclusion

The border of plastic deformation is actually not linear, but bent towards the workpiece. It is necessary to realise two facts:

- In the process of plastic deformation, there is an effect of thermal deformation, which compensates for the effect of deformation fortification. There are adiabatic deformation conditions.
- Measurement of microhardness has been performed after cooling of the sample, after finishing the process. During actual process of chip creation, whole area is in plastic state with different deformation intensity.

Observing mechanism of chip creation is important considering a possibility of tool geometry optimisation, decreasing energetic demandingness of chip creation and quality of machined surface.

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