THERMAL-MECHANICAL MODEL OF SHEAR INSTABILITY DURING CUTTING

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ABSTRACT

Machining of metals belongs to the group of complicated dynamic and stochastic process, where are missing the perfect informations about the mechanism of chip creation and about the phenomena which it accompany. The reason is in random state of characteristics. The solution of these processes requires the scientific approach to the behaviour of material during cutting , which is performed under extreme loading conditions. There are elaborated different theories about the chip creation, which are directed to the shape of chip. The chips are classified as continuous or cyclic, where the mechanism of the last type is explained as catastrophic thermal-plastic shear which is caused by the instability of strain in the zone of cutting.
In the contribution there are introduced criteria for shear instability during cutting and there are analysed the conditions for determination of the start of shear localisation. The obtained results can be used for determination of dynamic properties of materials under high rates of strain.

KEYWORDS

Cutting, Shear instability, strain localisation.

INTRODUCTION

In the framework of scientific discipline Engineering technology it is necessary to solve a large rang of problems, as the quality of produced components, reliability of construction, co operation on the development of new materials, similar as increasing of their functional properties.

The increasing requirements on the material properties due to the more difficult conditions of their loading and exploitation, require the perfect understanding and knowledge of all relations between the structure and behaviour of these materials during their loading

The development of production technology is in close connection with development and knowledge of machining technology. The most widespread mechanism, which is used during machining, is the mechanism of elastic - plastic strain, which expressively influences the result of machining, it means the chip creation and the properties of subsurface layer, which arises during removing of material allowance

The process of strain is accompany by a row of phenomena, which it influence and can be realised as stable or unstable. The basic parameters which influence this process are the cutting velocity. and cutting forces . Different approach to the solution of cutting problems can be in the fact, that it does not take into the consideration, that during cutting there are changed the mechanical properties of material to be machined. These properties are namely influenced by the stresses, strain and temperature and all these facts has to be consider when analysing the shape and process of chip formation under normal and especially under very high rates of strain.

To understand the degradation of ductile materials is strongly connected with the knowledge of laws influencing the strain. As the most important is the question of strain hardening and structure changes which are caused, equally the localisation of strain. Quantitative theories of all these phenomena are till now not satisfactory formulated

CRITERIA OF SHEAR INSTABILITY

Classical model of shear instability during cutting was elaborated by RECHT,1964 [1] and he introduced that catastrophic shear arises in the zone of primary plastic deformation in such a case, when the temperature changes in this zone have higher influence than the effect of strain hardening .On the rise of plastic instability which comes into the shear localisation exist also other opinions, which say, that to the lowering of shear strength can come also without the effect of thermal softening, as result of micro cracks arising in the primary zone of deformation. In this way comes to the reduction of real area which is exposed to the stress {Walker,Shaw,1969}[2].Komaduri and Brown,1972[3], Shaw and Vyas 1993[7] have applied this mechanism when machining with low cutting velocities. This model appears to be useful for explanation of cyclic chip creation during machining of titanium and its alloys, where this type of chip is created already from the lowest velocities. On the mechanism which can be used for evaluation of shear instability takes into the consideration the structure transformation which set in transformation of austenite to martensite {Lamaire, Beckhofen,1972}[8].

In this contribution there is performed the analysis of chip creation during machining of different materials and there are used two methods for determination of start of shear instability .The first method is a metallographical one , where the evaluation of shape chip is done on the micro section grindings. The second method is the determination of relation between the shear stress and cutting velocity. By this procedure it was possible to determine the areas of shear instability when machining the normalised materials and materials heat treated and tempered and simultaneously to predict the origin of shear instability.

MODEL OF SHEAR INSTABILITY DURING CUTTING

The proper knowledge about thermal plastic instability were obtained on the base of experiments performed on the selected kinds of steels, which were annealed and tempered. The were evaluated 21 samples of steel which were annealed and 15 samples of steel which were heat treated. In the fig. 1 are introduced the micro section grindings of steel 17 720.1 chips. Theoretical basis for evaluation of individual values is in the fact, that the properties of material are changed within the cutting conditions when it comes to the strain hardening . During the tests evaluation was followed also the frequency of chip creation. This was determined by means of chip velocity along the tool face v_t and the average distance of picks of chip thickness a_p {Fig.2}

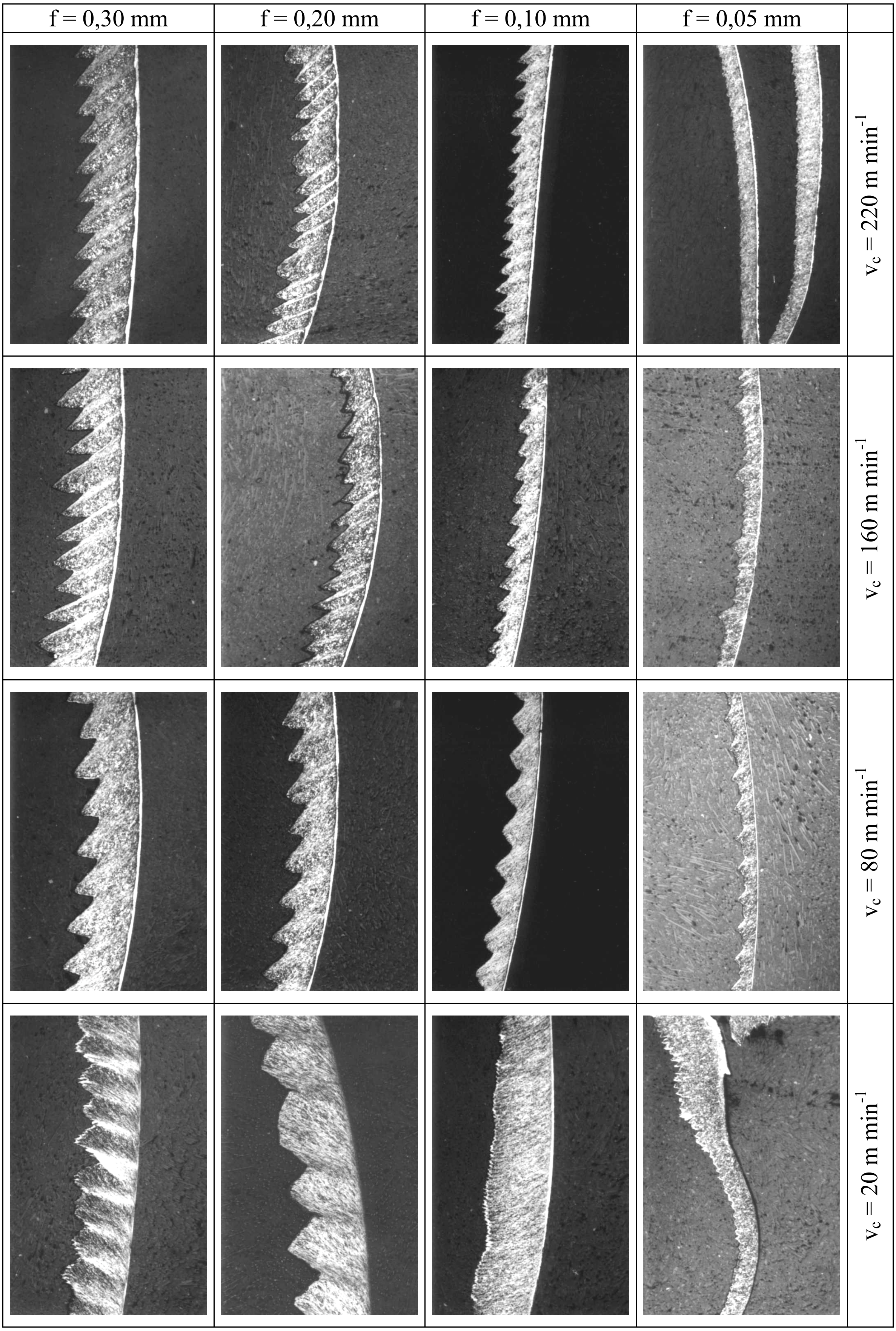

Fig.1 Chip shapes after machining of steel 16 720 by different cutting conditions

$$\overline{FC} = \frac{v_t}{a_p} \qquad [kHz],$$

where

$$v_t = \frac{v_c \,.\, \sin\phi}{\cos(\phi - \gamma_0)} \qquad [\ m\ .\ min^{-1}\ ],$$

v_c – cutting speed [m . min^{-1}]
ϕ - angle of the plane of maximum shear stress
γ_0 – orthogonal rake angel

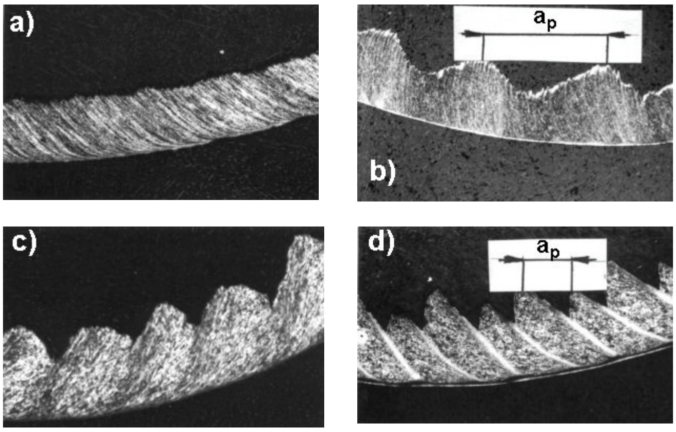

Fig.2 Shapes of individual kinds of chips
a) continuous chip, b) wavy chip, c) elementary chip, d) saw-tooth chip

Micro sections grindings in fig.1 and 2 demonstrate, that the localisation of shear deformation arises between the individual chip segments and material between them is not deformed and has the same structure as basic material. The important finding is the determination of the area of cyclic chip creation. On the start of chip segmentation has the expressive influence also the size of chip (Fig.3 and 4). This fact was not predicted by the classical model of adiabatic shear.

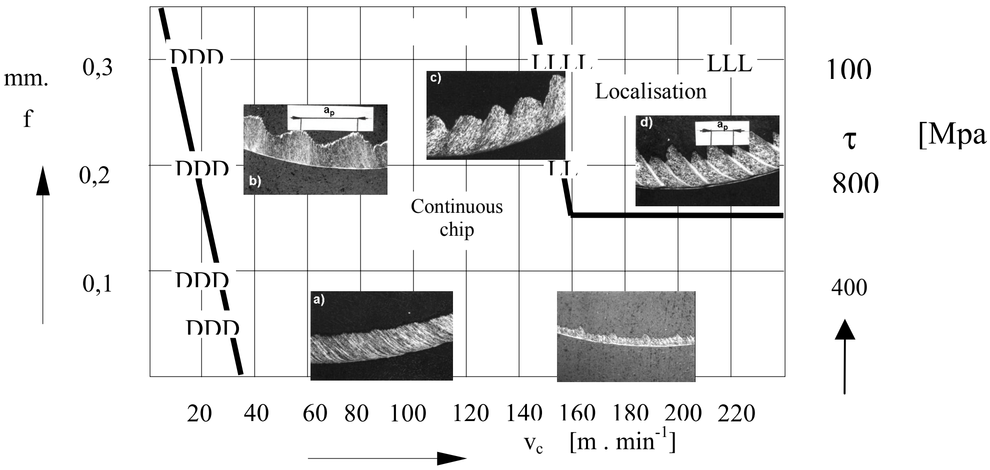

Fig.3 Marking of the zones of chip creation during machining annealed steels

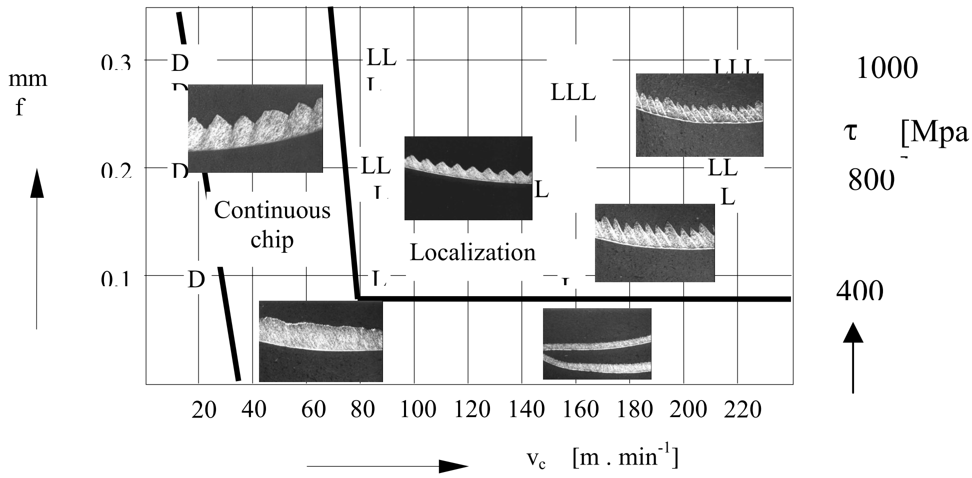

Fig.4 Marking of the zones of chip creation during machining of heat treated steels

During cutting there comes first to the compression of material in the front of the tool and the cutting wedge causes stress field. Generally it is considered, that it exists the curve along which are the existing stresses as maximum. When the stress along this curve reaches the yield strength, the plastic shear causes as further response the further local material compression (Fig.5)

Fig.5 Crack creation in front of tool wedge and its propagation

The second possibility for evaluation of shear instability is the determination of shear stress and its relation to the cutting conditions. After the evaluation of the tests was concluded, that shear stress is changed in relation to the rate of strain and that it exists a certain maximum of the curve represented this dependence. This maximum corresponds to the critical velocity of the start of shear deformation instability (fig.6).

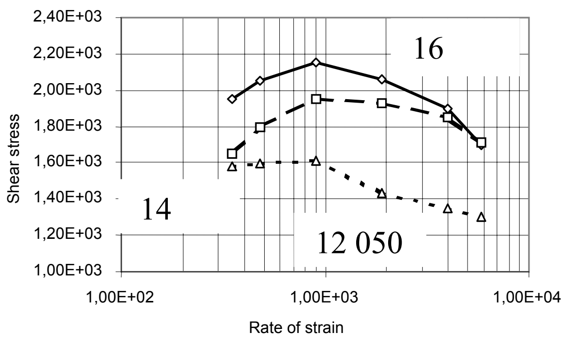

Fig.6 Changes of shear stress in relation to the rate of strain during machining of different steels

The calculation of shear stress was done on the base of cutting forces measurement. The calculations were realised according to the own program, which enables to calculate both shear stress and the dynamic yield limit strength under high rates of strain.
During testing were observed the conditions of creation and propagation of crack before the point of cutting tool when cutting the carbon steel, hardened bearing steel and titanium alloy (Fig.7,8,9)

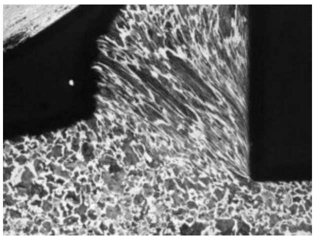

Fig.7 Carbon steel 12 050.1

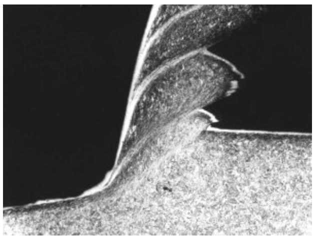

Fig. 8 Hardened bearing steel 14 109

Fig.9 Titanium alloy Ti6Al4V

The most important factor controlling the deformation is the orientation of grains with respect to the plane of maximum shear stress. It was demonstrated, (Black,1970) [10] that under the conditions of micro cutting, the material is separated in individual elements – lamellas. This lamella chip structure is orientated perpendicular to the main motion of cutting and the shear bands are very narrow. The thickness of lamellas is the function of the size of removed material layer, of rate of strain and is in range from 2 to 6 μm.
For demonstration of introduced mechanism were done the pictures of chips surface after machining of the tested steels when changing the cutting speed.(Fig.10)

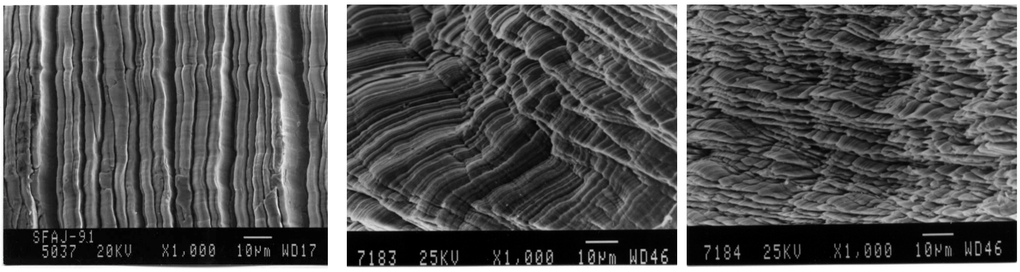

Fig.10 Lamellar structure of chip steel 14 331

This lamellar structure can not be changed with the saw tooth shaped hip. The mechanism of plastic deformation when are created the individual lamellas are reflected into the micro geometry of machined surface and can be very well evaluated from the roots of the chips.(Fig.5).
The values of lamellas thickness can be used for evaluation of deformation behaviour of material under high rates of strain. The planes in which the lamellas are created, are the planes of maximum stress concentration. The values of lamellas thickness are important also for calculation of rate of strain during cutting. The program prepared for calculation of basic cutting parameters and dynamic material properties under high rates of strain enables also the calculation of lamellas thickness in the relation to the cutting conditions. The calculations which were done correspond with the results obtained on the electron microscope. For the tested material the thickness of lamellas was in the range 3 up to 6 μm when cutting with high velocities and in the range 7 up to 12 μm when cutting with low velocities.

DISCUSION

The simplified model of shear instability during cutting gives the possibility to appreciate the conditions under which is created the cyclic type of chip and enables also to determine the critical cutting velocity, which corresponds to the changes of shear stress. It is visible, that the plastic deformation instability is beside the cutting speed influenced also by the chip size- Also the environmental influences and the changes of material properties have the influence on the shear instability during cutting.. Localisation of plastic deformation appears after the loss of plastic deformation stability and becomes evident that it is concentrated into the bands, which can be evaluated on the micro section grinds. An other conception of cyclic chip creation consider that the crack initiates on the free surface of the workpiece and propagates again the tool point (Shaw,Vyas,1998) [7]. It means that under these conditions no adiabatic shear. To this opinion should correspond the results of chip creation during cutting titanium and its alloys (Fig.9) When the deformation velocity is high enough, it can happen, that in the zone of chip formation takes place the transformation into autenite . On the micro section grinds appears white layers, which are created by non tempered martensite and residual autenite . Because the temperature in the zone of cutting must not reach the temperature of transformation values, this effect can be explained so, that for the transition was used beside the thermal energy also the energy mechanical.

CONCLUSIONS

In the contribution was pointed out to the problems of shear instability during cutting of metals. For the evaluation of this effect were used two methods. The metallographic method and the method of shear stress measurement.
Cyclic chip as the result of plastic instability is created due to the localization of plastic deformation and its course is changed with the cutting speed, with the size of the chip and with the kind of machined material.
On the base of performed tests was elaborated the simple model of the start of localization during cutting of steels which were normalized and heat treated. Both methods which were used for evaluation of this effect demonstrated to be sufficient for representation of material behaviour during cutting.. The evaluation of changed values during testing can be used also for determination of dynamic material properties under high rates of strain.

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