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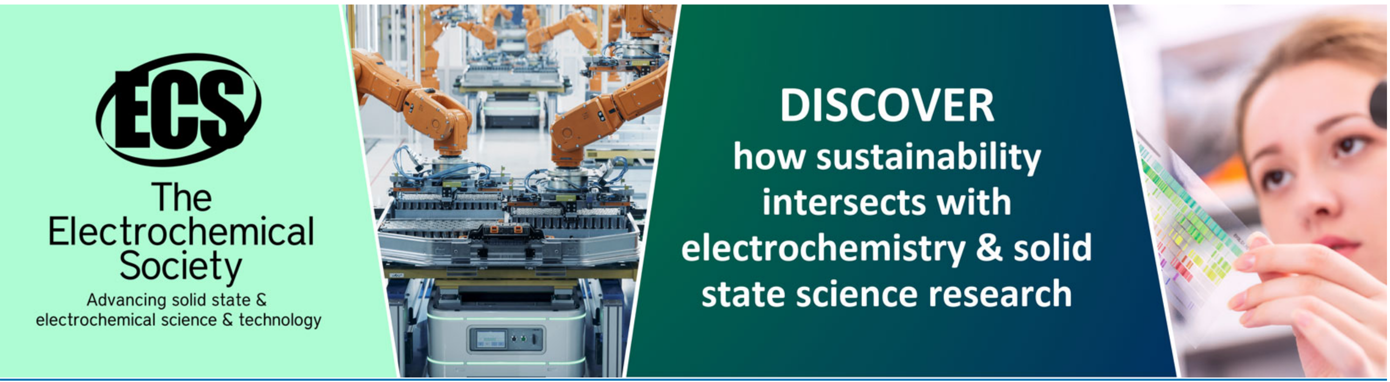

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Cutting Edge Geometry Effect on Plastic Deformation of Titanium Alloy

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Abstract. The paper presents experimental studies of OT4 titanium alloy machining with cutting edges of various geometry parameters. Experiments were performed at a low speed by the scheme of free cutting. Intensity of plastic shear strain was set for defining of cutting edge geometry effect on machining. Images of chip formed are shown. Estimation of strain magnitude was accomplished with digital image correlation method. Effect of rake angle and cutting edge angle has been studied. Depth of deformed layer and the area of the plastic strain is determine. Results showed that increasing the angle of the cutting edge inclination results in a change the mechanism of chip formation.

Introduction

Cutting_operation_for many years is one of the most effective ways of metal shaping. Complexity of the processes, occurring in the cutting zone, makes it difficult to study inter-coupling of various physical characteristics of cutting operations. Workpiece material strain is one of key physical components of cutting operations. The most common ways to examine cutting strains are micro-sections and use of a grade grid. These methods require fragments of the cutting zone with intact chips, which can be achieved by use special tools for momentary pause of the operation. The tool wear resistance, the performance and stability of the cutting process, the quality of the machined surface depend on the cutting edge geometry, the cutting conditions, the rigidity of the technological system and the materials of tool-workpiece pairs [1-8].

It is known that different materials and cutting conditions are characterized by different chip formation mechanism The copper chip forming is realized by continuous mechanism in a wide range of cutting conditions and the cutting edge geometry. The copper chip forming is realized by continuous mechanism in a wide range of cutting conditions and the cutting edge geometry.The element discontinuous and continuous chips can be made under machining titanium alloys.

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Application of digital image correlation (DIC) for cutting operation research is described in [9, 10]. DIC method summary consists in registering of cutting operation with a digital camera with simultaneous cutting zone highlighting with monochromatic laser. The laser light creates a contrasting image on the sample surface. Block-by-block search using correlation algorithms allows computing a vectorial field of displacements [11, 12].The main advantage of DIC is the ability to study operation recording, using different computation algorithms. In addition, DIC method does not require micro-sections and metallographic studies. Thus the complexity of experimental studies is significantly reduced.

We investigated the peculiarities of plastic deformation in polycrystalline copper cutting using tools with different rake angles and cutting edge inclination angles. The result revealed that the increase of the rake angle and the cutting edge inclination angle reduces the intensity of the plastic shear strain and sizes of plastic deformation area in chip formation zone [12].

The work's aim is the experimental research of the cutting edge geometry effects on the plastic deformation region formation in the OT4 titanium alloy samples.

Research method

This work is a continuation of a series of experimental studies of in-cut strain processes. In this paper we consider the effect of cutting edge geometry on plastic strain in the sample made of OT4 titanium alloy. Corrosion-resistant OT4 titanium alloy is used for manufacture of aircraft parts, operating at temperatures up to 350°C. OT4 relates to a Ti-Al-Mn system (Ti-4.2Al-1.6Mn) with pseudo α-structure and a small amount of β-phase stabilized with manganese.

Tool material is R6M5K5 (SKH 55). Cutting speed is limited to 13 mm/min, due to characteristics of recording equipment (video recording speed is 27 fps). Experiments were performed by the scheme of free cutting (see fig.1). While oblique cutting, incline plane of the cutting edge was out of sight of the camera.

In the study two sets of cutters were used. The first set, with the rake angles (γ) +4°, 0° and -4°, rear angle α=7.5°, cutting edge angle λ=0°. The second, with cutting edge angles 7.5°, 15°, 30° and 35° if α=7.5° and γ=15°.

Video recording was processed using special software developed in ISPMS SB RAS. Correlation analysis revealed a magnitude and direction of displacement of strained material. A schematic image of vectorial field of displacements is shown in Figure 1.

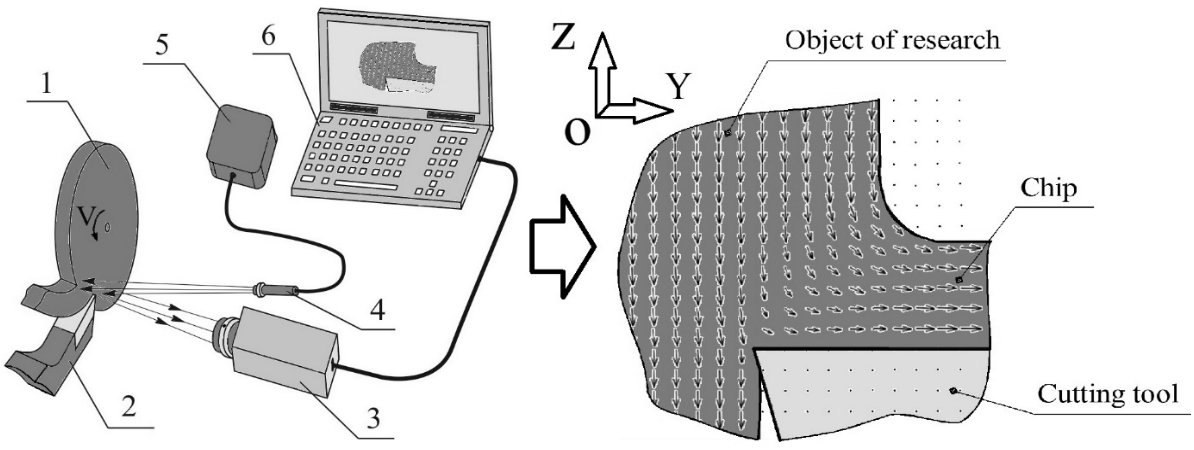

Figure 1. The experimental scheme and vectorial strain field in cutting zone

During experiments a side face of the sample was observed, therefore lateral strain was not determined. Further calculations were performed for plane-strain state. Further on computations were performed for plane-strain state. According to general concepts of the plastic strain theory [13] strain components can be determined by known displacements:

$$\varepsilon_z = \frac{\partial V_z}{\partial z};\ \varepsilon_y = \frac{\partial U_y}{\partial y};\ \gamma_{zy} = \frac{1}{2}\left(\frac{\partial V_z}{\partial y} + \frac{\partial U_y}{\partial z}\right). \quad (1)$$

where V_x is a displacement vector projection on vertical axis OZ,

V_y is a displacement vector projection on vertical axis OY.

Intensity of shear strain for plane-strain state [13]:

$$e_i = \sqrt{2}/3\sqrt{\left(\varepsilon_z - \varepsilon_y\right)^2 + \varepsilon_z^2 + \varepsilon_y^2 + \frac{3}{2}\cdot\gamma_{zy}^2}. \quad (2)$$

Computation by the formulas (1) - (2) gives value e_i matrix within a cutting zone with 0.12 mm pitch along axes OY and OZ.

Based on the data obtained, topograms with e_i-distribution were constructed in Mathcad. For illustrative purposes contours of a tool and a test sample are located on the topograms. Plastic strain area (s) and deformed layer depth (Δ) are defined as quantitative assessments of tool geometry effect on formation of plastic strain. Relative strain magnitude upwards of 0.01 is taken as a criterion of plastic strain. The values s and Δ are found by a graphic method considering a scale factor.

Results and discussions

Topograms of intensive plastic strain when cutting titanium alloy OT4 with a tool with rake angles +4°, 0° and -4°, if α=7.5°, λ=0° are shown in Figure 2. Schematic images of formed and detached chip elements are shown too. The greatest magnitude of e_i is observed at the tool top, in contact area of the tool clearance face with the sample and on the sample surface near the shearing range. In our researches formation of a narrow zone with great strain intensity is observed. This zone has form and arrangement similar to a conventional plane of share [6].

In this case, chips are formed elementally: by accumulation of strain in the material, with its localization in the narrow zone. When strain reaches a certain critical value, chip elements displace along the shearing range (see Fig. 1). Shearing begins from the tool top and progresses along the chain of zones with high values of e_i.

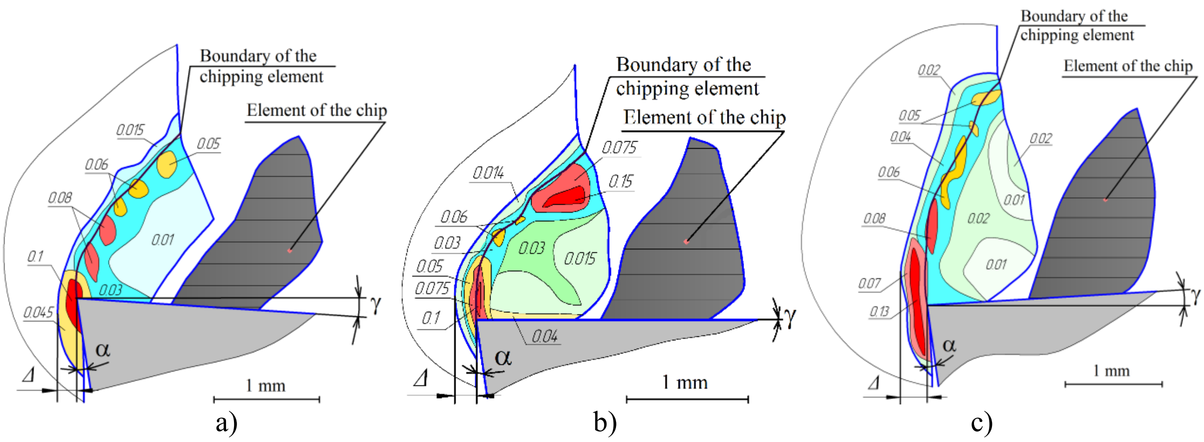

Figure 2. Intensity of plastic strain a) γ= +4°, b) γ=0°, c) γ= -4°

Figure 3 shows images of chip elements produced with cutting tool with angle γ = 0 °, obtained with a laser scanning microscope Olympus LEXT OLS 4100. The element has a shape similar to a

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triangle. The base is a flat, formed as a result of pressing of the front tool face on the metal. Compression of the material results in broadening of elements near the contact area of chips with the tool (see. Figure 3b), consistent with a high strain intensity e_i=0.04 near the front tool face (see Figure 2b).

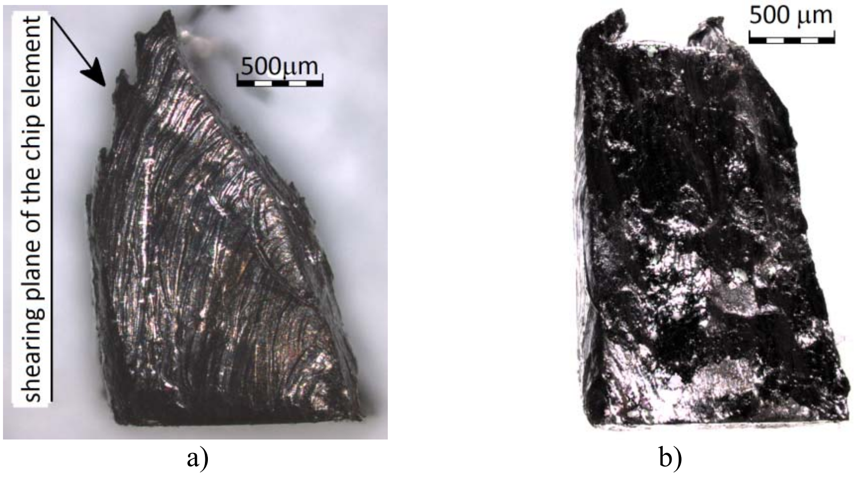

Figure 3. Image of elemental chips produced by cutting with angle γ = 0 °: a) lateral surface, b) shearing plane

Figure 4 shows the topograms of intensive plastic strain when cutting of OT4 titanium alloy with a tool with blade angles 7.5°; 15°; 30° and 35° if α=7.5° and γ=15°.

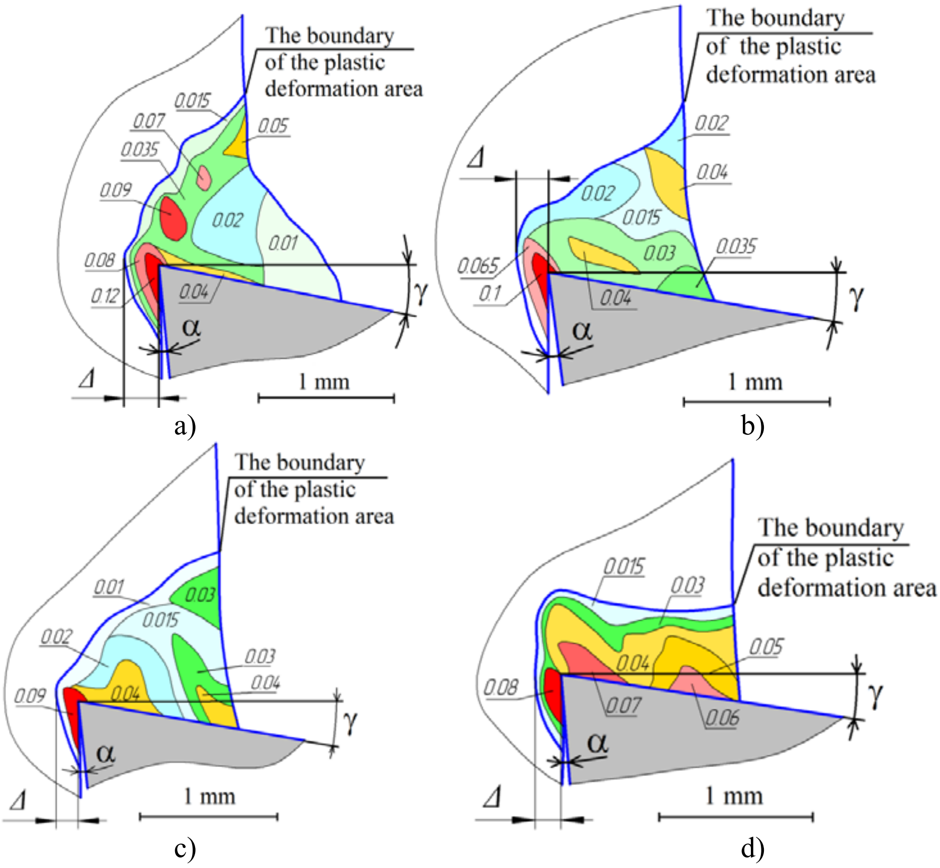

Figure 4. Intensity of plastic strain a) λ=7.5°, b) λ=15°, c) λ=30°, d) λ=35°

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Chips flowing from angled front face are formed as a continuous helical spiral. When cutting with a tool with angles λ (15°, 30° and 35°) chip formation represents a continuous flow, that is, a continuous plastic deformation of the sample material occurs without chipping and separation into elemental chips. When cutting with the angle λ=7.5° chips are formed as connected segments, without chipping.

The highest strain intensity when cutting with a tool with the angle λ=7.5° is localized within a narrow zone, the same is when cutting with tools with λ=0° if γ +4°, 0° and -4°. With increase λ angle strain is less localized. e_i value increases from the strain zone boundary to the front tool face. In all cases, larger e_i values are observed near the tool blade tip.

Figure 5 shows an image of a fragment of the helical chip produced by cutting with the angle λ=35°. Chips are undivided (without segments) in the form of helical spiral with a pitch of 3mm and a diameter of 4mm. Increasing of the blade angle changes shear direction due to additional shear in transverse direction. This is the main cause of chip twisting.

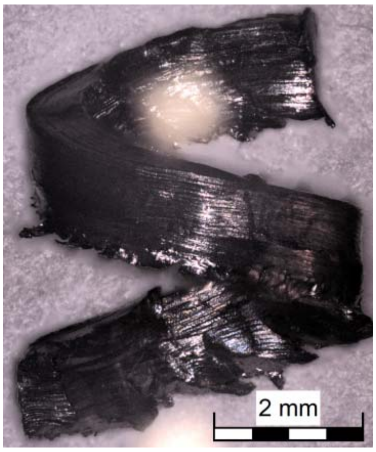

Figure 5. View of twisted chips resulting in cutting with angle λ=35°.

Figure 6 shows a curve of the area of plastic strain (s, mm2) and depth of the deformed layer (Δ, mm) for various values of the cutting edge angle (λ) and the rake angle (γ).

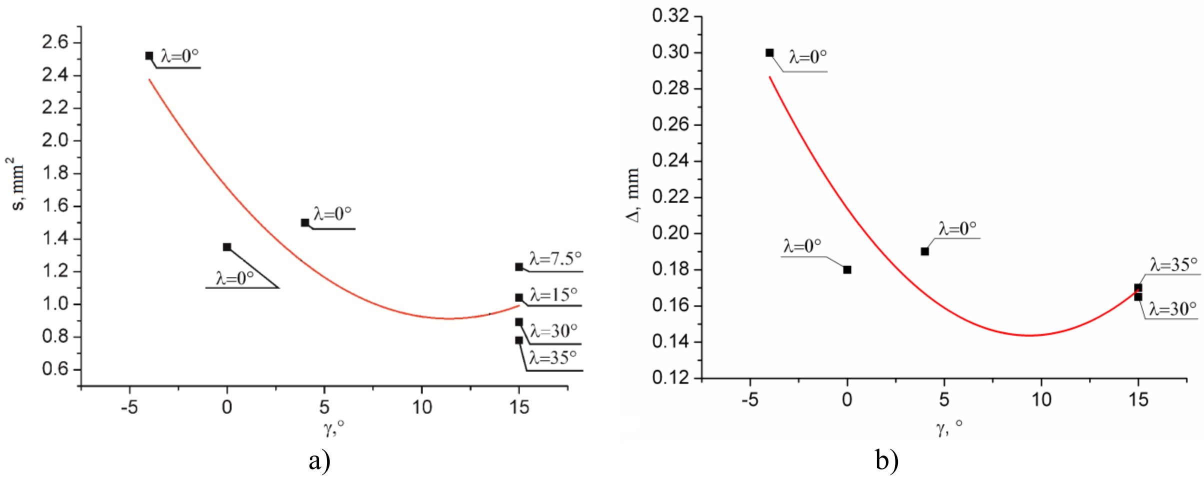

Figure 6. Effect of cutting edge geometry on plastic strain area (a) and depth of deformed layer (b)

According to the curve (see Figure 6a), plastic strain area decreases with increasing of the cutting edge angle and the rake angle of the tool. The depth of the deformed layer also decreases with increasing of the rake angle of the tool (see Figure 6b). Accordingly, a severity of strain effect exposure on the workpiece face layer decreases. In turn, this reduces strain hardening and residual stresses in the face layer.

Conclusion

The findings on the effects of tool geometry on plastic strain of OT4 titanium alloy make it possible to draw the following conclusions:

1) Cutting with the angle $\lambda = 0$ ° causes compression and shear of the material sample which occur in the plane ZOY (see Figure 2) Cutting edge angle increase changes strain state from flat to volumetric and chip formation from elemental to continuous.

2) Rake angle increase and cutting edge angle increase diminish the area of plastic strain.

3) Intensity of plastic shear strain e_i subsides with increase of the cutting edge angle and the rake angle of the tool.

4) With increase of angle λ, chip formation changes from elemental to continuous making cutting operation more stable.

5) With increase of angles γ and λ the depth of deformed layer diminishes which as well is a positive aspect of tool geometry effect on cutting operations.

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