INFLUENCE OF CUTTING TOOL WEAR ON CONTACT STRESSES AND TEMPERATURE DISTRIBUTION IN TITANIUM ALLOY MACHINING

V. Kozlov[a], *J. Zhang*[b], *E. Letshiner*[c], *W. Zhao*[d]

National Research Tomsk Polytechnic University
[a] kozlov-viktor@bk.ru, [b]965075948@qq.com, [c] letshiner@bk.ru, [d] Zhaosaner110@gmail.com

Generally, the wear of cutting tool is estimated by the length of the wear on the flank h_f and with clearance angle α_h (ordinary $\alpha_h \approx 0$ °) which limits the wear for cemented carbide tool about 0.75 mm for a heavy cut in steel machining. The machining of titanium alloy parts causes very intensive wear on the flank due to very small heat conductivity of titanium alloys and h_f reaches 2.5…5 mm, and cutting edge rounding radius reaches ρ = 0.3…5 mm [1–3], but even with this big value, cutting tool is still capable of working, which is obscure.

The distribution of contact stresses has been received in free orthogonal turning a disk made from difficult-to-machine titanium alloy BT3-1 (Ti-6Al-3Mo-2Cr-0.3Si) with radial feed rate f by means of "sectional tool" method and by the method of variable flank wear length on the special four-component dynamometer for a sectional cutter [2]. Wear was simulated by a chamfer ground on a flank surface with a length h_f and with a clearance angle $\alpha_h = 0°$; for research of rounding influence – by artificial rounding of a cutting edge with the demanded radius ρ. Temperature distribution in a cutting wedge was received by painting a lateral surface of a cutter with a temperature sensitive paint [4] and by measuring the colour borders on the toolmaker's microscope after cutting. The focus of research was given to experimental research of contact stresses distribution over a flat section of an artificial flank-land, which was used to simulate flank wear.

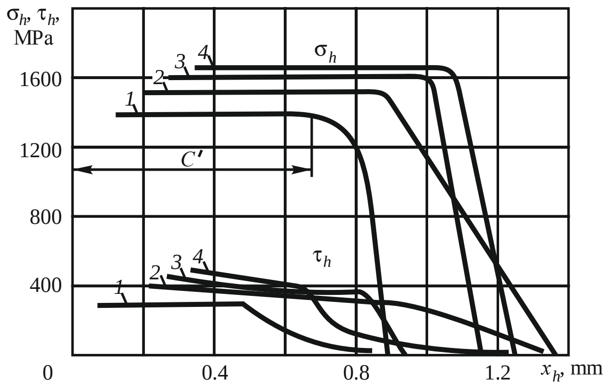

Fig. 1. Distribution of normal σ_h and tangential τ_h contact stresses (MPa) over the artificial wear flank land of the cutter in titanium alloy machining by a cutter with cutting edge rounding with radius ρ. BT3-1 – BK8, γ = 0º, α = 10º, α_h = 0º, V =1 m/s, f = 0.21 mm/r; 1 – ρ = 0.07 mm; 2 – ρ = 0.2 mm; 3 – ρ = 0.28 mm; 4 – ρ = 0.35 mm

Machining of titanium alloy BT3-1, which forms discontinuous chip, by a cutter without cutting edge rounding, shows the greatest value of the normal contact stress σ_{hmax} (σ_{hmax} = 3400–2200 MPa) near the cutting edge [2] due to the elastic recovery of the transient surface at the moment of chip elements separating from the workpiece [5], but then σ_h is dramatically reduced to 1100…500 MPa far from the cutting edge. This feature explains working capacity of very worn-out cutting tools in machining titanium alloys. Reduction of the normal contact stresses magnitude in three times far from the cutting edge may be due to the high value of contact temperature (Fig. 2) and contact layer softening [6].

Small value of shear contact stresses (τ_h = 800…700 MPa) and reducing far from the cutting edge (τ_h = 300…200 MPa) is explained also by the high value of contact temperature and contact layer softening.

Machining of titanium alloy BT3-1 by a cutter with a rounded cutting edge (Fig. 1) shows uniform pattern of normal contact stresses distribution and reduction of normal contact stresses almost in 2 times compared to cutting without cutting edge rounding. We explain this paradoxical phenomenon by formation of a seizure zone on the cutter face in the region of rounding, which reduces contact of the transient surface with the flank land. It is indirectly proved by the presence of the scratch marks on the rounded part, left during sharpening of the cutting tool. The uniform pattern of normal contact stresses distribution is observed also in brass machining by a cutter with a rounded cutting edge [2].

Temperature distribution in a cutting wedge is presented on the Figure 2. It is possible to mark the temperature rise to 1000 °C at essential wear on the flank surface. Such high value of temperature on contact areas causes reducing the strength of work material, and explains a small value of tangential contact stresses τ_h and reducing normal contact stresses σ_h far from the cutting edge (Fig. 1).

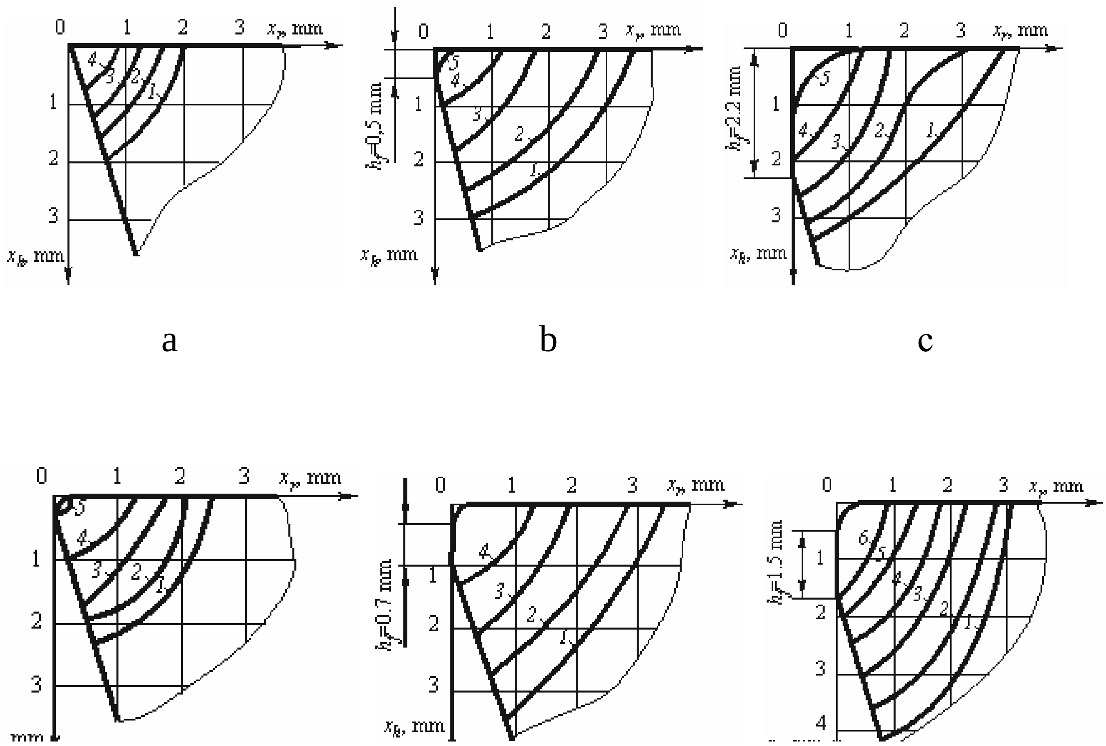

Fig. 2. Distribution of temperature in cutting wedge in titanium alloy machining. ВТ 3-1 – ВК8, γ=0°, α_h = 0°, v=1 m/s, f=0.21 mm/r, Ordinate – distance from the cutting edge on the surface of flank land x_h (mm), abscissa – distance from the cutting edge on the rake surface x (mm).
a – h_f = 0 mm, ρ = 0.002 mm; b – h_f = 0.5 mm, ρ = 0.002 mm; c – h_f = 2.2 mm, ρ = 0 mm;
d – h_f = 0 mm, ρ = 0.07 mm; e – h_f = 0.7 mm, ρ = 0.07 mm; f – h_f = 1.5 mm, ρ = 0.35 mm;
d – h_f = 0 mm, ρ = 0.07 mm; e – h_f = 0.7 mm, ρ = 0,07 mm; f – h_f = 1.5 mm, ρ = 0.35 mm;
1 – 500 °C; 2 – 600 °C; 3 – 700 °C; 4 – 800 °C; 5 – 900 °C; 6 – 1000 °C.

References

1. Narutaki N. et al. Study on machining of titanium alloys // CIRP Annals – Manufacturing Technology. – 1983. – Vol 32(1). – P. 65–69.
2. Kozlov V.N., Gerasimov A.B., Kim A.B. Distribution of contact loads over the flank-land of the cutter with a rounded cutting edge // IOP Conference Series: Materials Science and Engineering. – 2016. – Vol. 124. – P. 012–173.
3. Hu J., Chou Y. Characterizations of cutting tool flank wear-land contact // Wear. – 2007. – Vol. 263(7-12). – P. 1454–1458.
4. Lee J.J., Dutton J.C., Jacobi A.M. Application of temperature-sensitive paint for surface temperature measurement in heat transfer enhancement applications // Journal of Mechanical Science and Technology. – 2007. – Vol 21(8). – P. 1253–1262.
5. Kozlov V. Flank contact load distribution at cutting tool wear // Proceedings 7th International Forum on Strategic Technology, IFOST. – 2012. – Article number 6357713.
6. Wang B. et al. Investigations of yield stress, fracture toughness, and energy distribution in high speed orthogonal cutting // International Journal of Machine Tools & Manufacture. – 2013. – Vol. 73. – P. 1–8.