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Experimental estimation of chip shrinkage under cup-tip cutting with straight and radius cutters

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Abstract. In the given work we present the results of experimental estimation of chip shrinkage under turning with straight and radius cutters for two schemes of cutting: “direct” and “reverse”. Ratios of thickening, broadening and longitudinal shrinkage of the chip were established as shrinkage parameters. The given paper presents the graphic charts showing dependences of shrinkage upon cutting depth, supply and cutting edge inclination which indicate the deformations taking place in the cutting area when cutting with cup-tip cutters. The authors show the significant difference in the character and degree of chip shrinkage when working according to various schemes of cutting.

1. Introduction

Monitoring of the chip formation process is a convenient means of monitoring the machining process [1-6] as the chip allows making conclusions about such parameters as stability of chip formation, temperature and deformation in the cutting area. To determine the temperature in the area of tool-workpiece contact the experts estimate the oxidizing colors of the chip and to estimate the deformation they study the chip shrinkage [5, 6]. Such approach allows fast estimation of the processes taking place in the cutting area

It is traditional to estimate the chip shrinkage along longitudinal and transverse directions. In the first case the longitudinal shrinkage is estimated as ratio of chip length to the cutting length and in the second transverse shrinkage (in terms of thickness and width) is estimated as ratio of thickness and width of chip to thickness and width of the cross-section of the cut layer of material.

Cutting with cup-tip cutters is a promising method of mechanical cutting of bodies of rotation. Its characteristics were studied by the authors of works [7-13] where they established that the given method is characterized by high productivity, accuracy and quality of machined surface. But the influence of cutting conditions, tool geometry and form upon the deformations of the cut layer of material is not studied enough. Due to the given fact the aim of this work is experimental estimation of dependences of chip shrinkage when the chip is produced by cutting with straight and radius cup-tip cutters, upon the cutting conditions (supply and depth) and cutting edge inclination.

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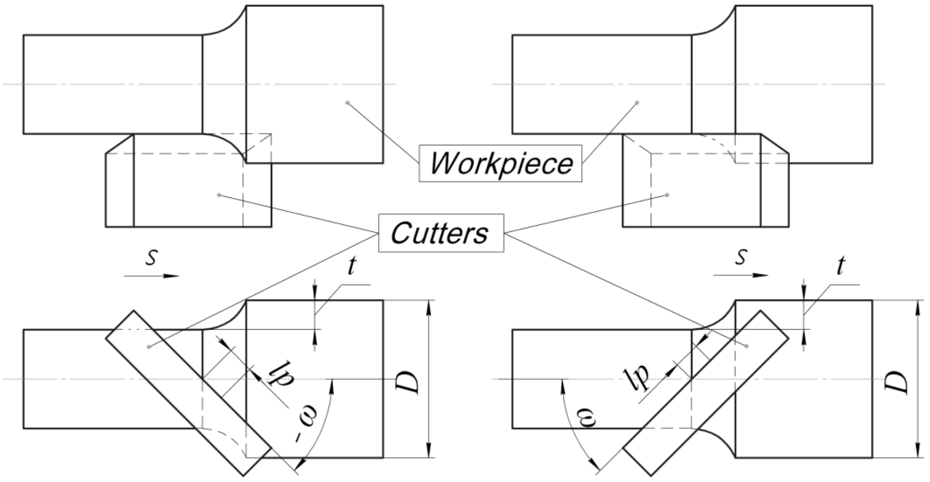
2. Research method

The study was completed for cutting according two schemes (Figure 1): “direct” – the operating area of the cutting edge (lp) is below the axis of the workpiece rotation (see Fig 1a) and “reverse” – lp is above the axis of the workpiece rotation. The material of the workpieces is 45 steel.



a) b)

Figure 1. “Direct” (a) and “reverse” (b) schemes of cutting with radius cutters

For the experiments we used cup-tip cutters with straight and radius cutting edges (Figure 2) equipped with carbide triangle blades. The blades were sharpened along top and face surfaces.

Works [14, 15] noted that an important characteristic of cutting with cup-tip cutters is negative clearance angle under a certain combination of cutting edge geometry, parameters of tool setting and cutting conditions with consideration to the chosen scheme of cutting (“direct” or “reverse”, see Fig. 1). Basing on this fact and according to the method presented in the work [14] the values of the tool clearance angle were estimated, values which ensure operability of the tool within the studied range of supply, cutting depth and cutting edge inclination for the considered diameter of the workpiece. Basing on the said above we obtained the value of clearance angle $\alpha_и$=7,5° for the “direct” scheme and $\alpha_и$=25° for the “reverse”. The value of the face angle for all blades is $\gamma_и$=0°.

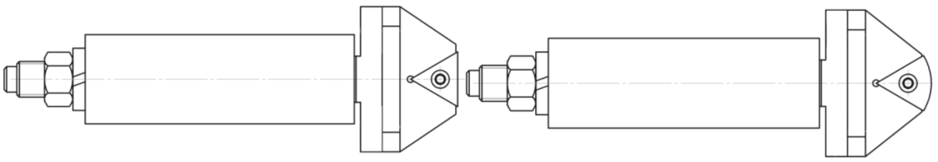


Figure 2. Cup-tip cutters with straight and radius blade

To estimate the longitudinal shrinkage of the chip we applied the gravimetric method [5]:

$$\xi_L = \frac{G}{L_1 \cdot \rho \cdot S}$$

where G – weight of the chip;

L_1 – length of the chip;

ρ – density of the machined material;

S – cross-section of the cut layer of the material.

The weighing machine ADAM HCB 302 with the accuracy of up to 0.01 was used to estimate the weight of the chip and its square s was estimated according to the data provided in works [16, 17].

Transverse chip deformation was found according to the well-known formulas [5]:

1) ratio of the chip thickening –

where a – maximum cross-section thickness of the cut layer; a1 – chip thickness.

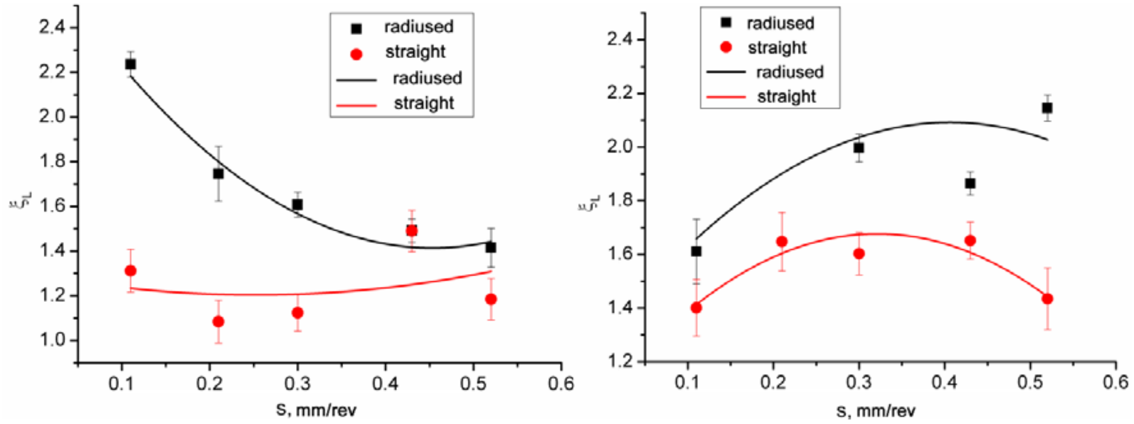
2) chip broadening ratio –

where b – maximum cross-section thickness of the cut layer; b1 – width of the chip.

Thickness and width of the chip were estimated by the microphotographs of chip cross-section obtained with the microscope LabotMet-1.

3. Main results and discussions

In the given part we present the dependences of chip shrinkage ratios ξ_L, ξ_a, ξ_b upon the cutting depth, supply and cutting edge inclination obtained when considering "direct" and "reverse" schemes of cutting. Figures 3-5 show the dependences for the longitudinal chip shrinkage.



a) b)

Figure 3. Dependence of chip longitudinal shrinkage changing upon the supply for "reverse" (a) and "direct" (b) schemes of cutting: t=0.3mm, D=38mm

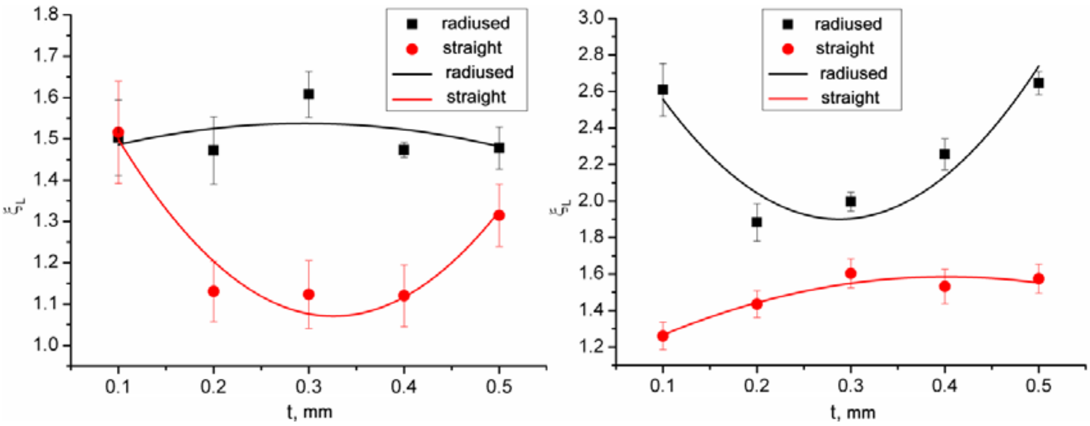


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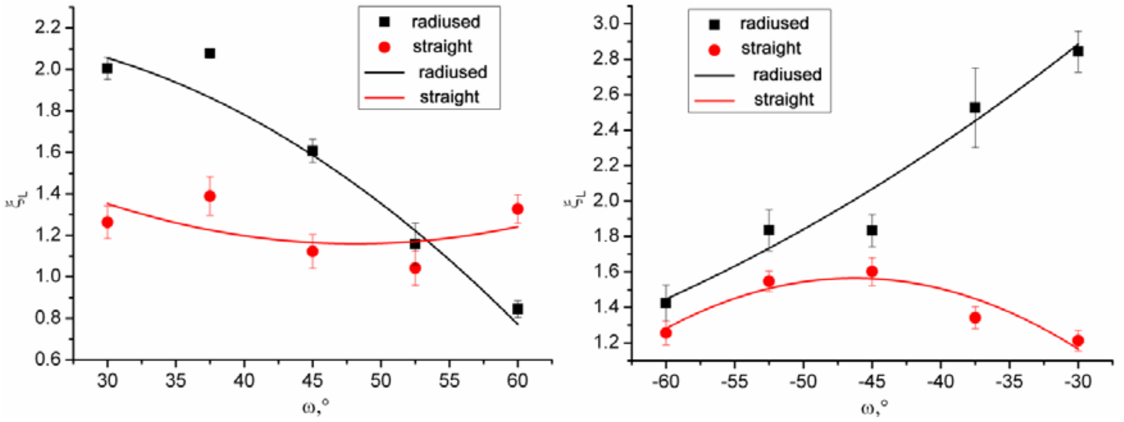
Figure 4. Dependence of chip longitudinal shrinkage changing upon the cutting depth for "reverse" (a) and "direct" (b) schemes of cutting: s=0.3mm/rev, D=38mm,

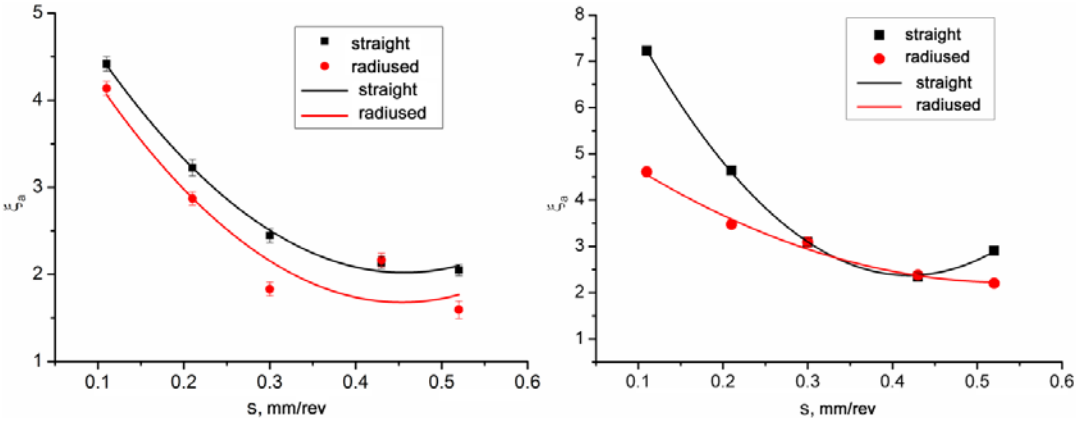


a) b)

Figure 5. Dependence of chip longitudinal shrinkage changing upon the cutting edge inclination for "reverse" (a) and "direct" (b) schemes of cutting: t=0.3mm, s=0.3mm/rev, D=38mm

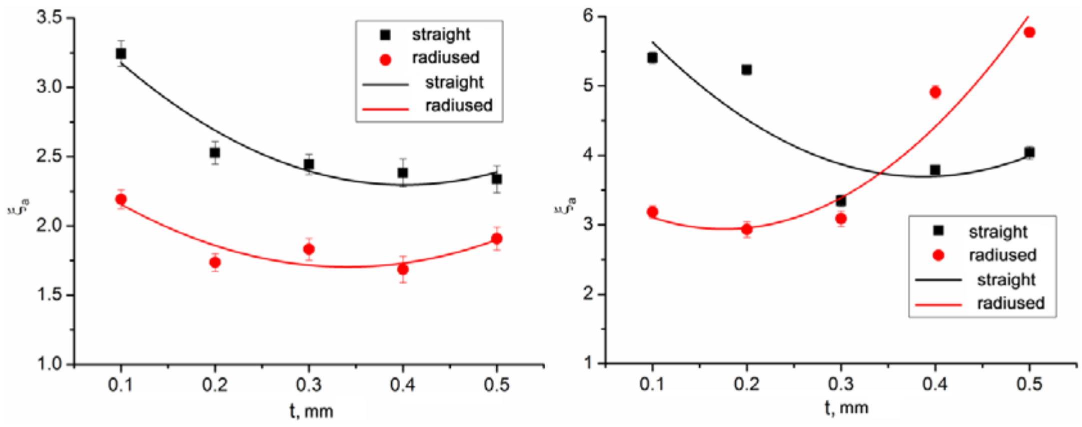
The obtained graphic charts allow making a number of conclusions. First, in most considered cases cutting with straight cutters is characterized by less longitudinal shrinkage in comparison to cutting completed with straight cutters. Second, the dependences of the longitudinal shrinkage for the considered schemes of cutting and cutting edge forms have different character. In separate cases we observe extremum, smooth function increase and decrease, but also, for a number of graphic charts we do not observe any obvious influence, for example: $\xi_L=f(\omega)$, $\xi_L=f(t)$ for the radius cutter and "reverse" scheme, . $\xi_L=f(s)$ for the straight cutter and "direct" scheme. Such differences in the character of dependences can occur due to the significant change of the cutting edge geometry and parameters of the cut layer influenced by the considered parameters (t, s, ω) and the chosen scheme of cutting. The last, in its turn, leads to the transformation of the workpiece material deformation and friction in the contact area conditions.

Figures 6-8 show the dependences for the chip thickening ratio ξ_a.



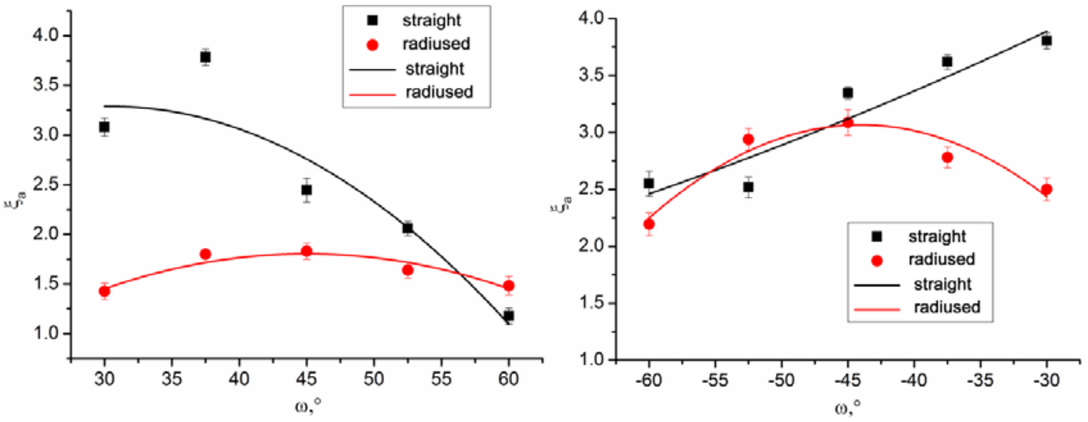
a) b)

Figure 6. Changing of the chip thickening ratio dependence upon the supply for "reverse" (a) and "direct" (b) schemes of cutting: t=0.3mm, D=38mm



a) b)

Figure 7. Changing of the chip thickening ratio dependence upon the cutting depth for “reverse” (a) and “direct” (b) schemes of cutting: s=0.3mm/rev, D=38mm



a) b)

Figure 8. Changing of the chip thickening ratio dependence upon the supply for “reverse” (a) and “direct” (b) schemes of cutting: t=0.3mm,s=0.3mm/rev, D=38mm

The data on the influence of the cutting conditions and the cutting edge inclination upon the thickening ratio ξ_a (see Fig. 6-8) prove its more expressed character than the data on longitudinal shrinkage (see Fig. 3-5). For the considered schemes of cutting and tool cutting edges the change of supply produces a similar effect upon ratio ξ_a: with the growth of s up to 0.4 mm/rev transverse shrinkage decreases and goes over the minimum with further increase.

In the case of “reverse” scheme of cutting for the considered tools changing the cutting depth has a similar effect upon ratio ξ_a, but its numerical value for the radius cutting edge is approximately by 1.5 times smaller than that for the straight cutting edge. In the case of “direct” scheme of cutting dependence $\xi_a=f(t)$ for the considered cutting edges is different.

With increase of cutting edge inclination for “direct” and “reverse” schemes ξ_a decreases for the straight cutting edge and for the radius one the dependence has an extremum under $\omega=45^0$.

In general chip thickening when cutting with straight cutters is larger than that when working with radius ones. Supposedly, it is associated with the fact that when cutting with straight cutters under the considered conditions the thickness of the cut layer is significantly smaller than that for radius cutters and its value approaches the corner radius of the tool. As a result of cutting a thin layer of material by the radius part of the cutting edge the material in front of the cutting edge is pressed and the thickness of the chip increases. This process (pressing of material) also contributes to the growth of ξ_a under small values of cutting depth and supply characterized by little thickness of the cut layer.

It is also worth mentioning that chip broadening when cutting according to the “direct” schemes has smaller values and this fact can be associated with the conditions of chip flowing along the front surface of the tool. Due to the fact that under working according to the “reverse” scheme the chip flows towards the previously machined surface the amount of obstructions for the chip flow is less in comparison to the “direct” scheme when the chip flows towards the surface to be machined and the pressing of material in front of the tool is larger.

Figures 9-11 show the dependences for chip broadening ratio ξ_b.

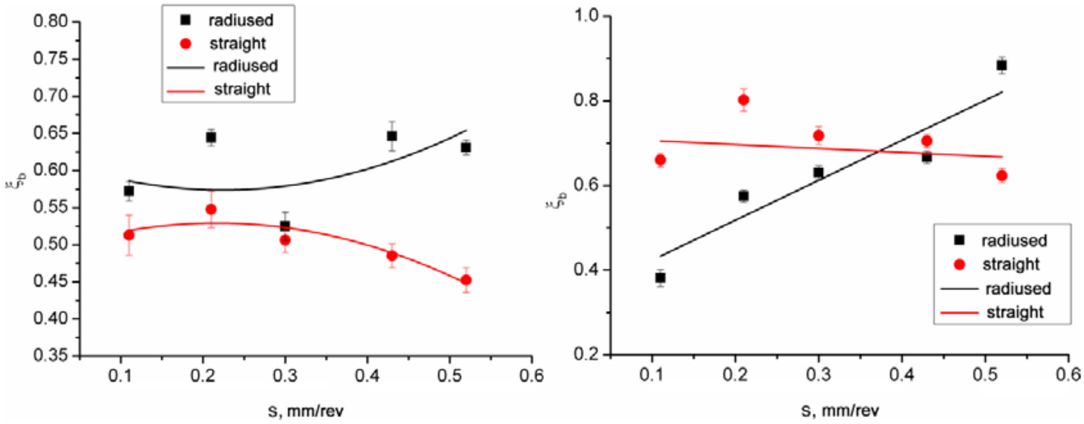


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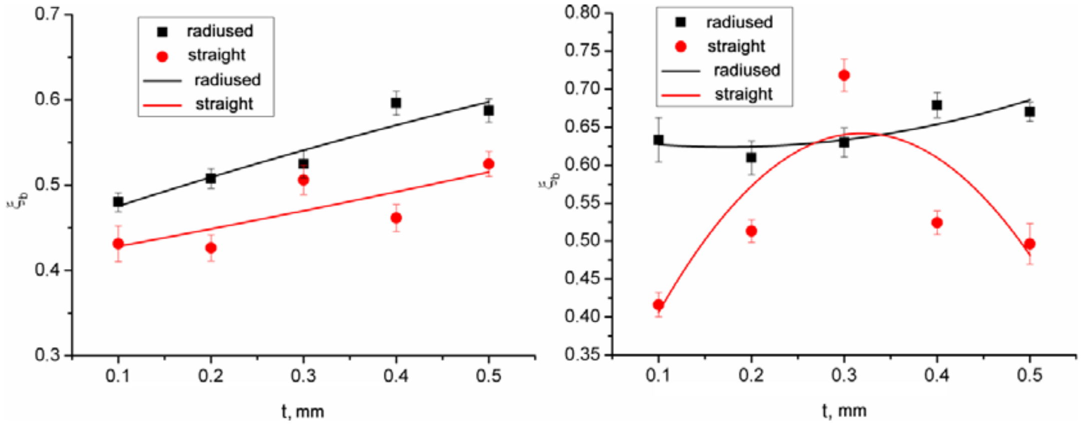
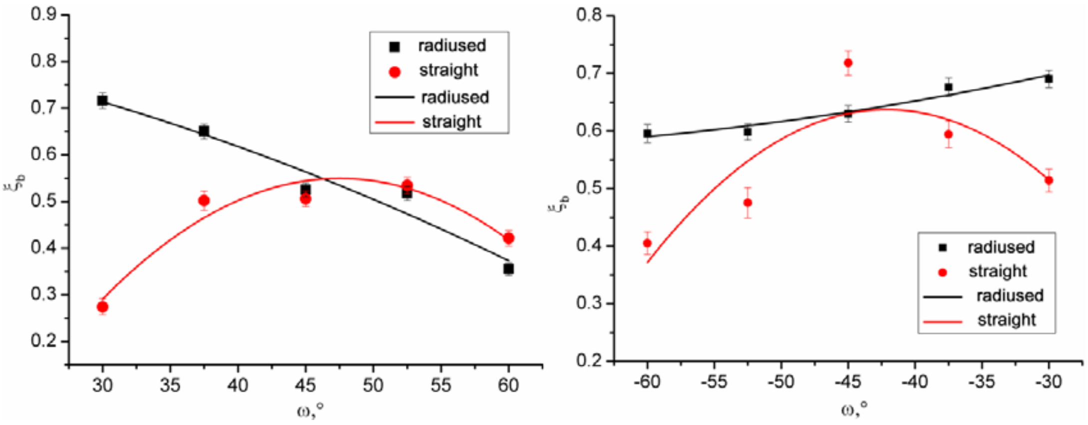
Figure 9. Changing of the chip broadening ratio dependence upon the supply for “reverse” (a) and “direct” (b) schemes of cutting: t=0.3mm, D=38mm



a) b)

Figure 10. Changing of the chip broadening ratio dependence upon the supply for “reverse” (a) and “direct” (b) schemes of cutting: s=0.3mm/rev, D=38mm



a) b)

Figure 11. Changing of the chip broadening ratio dependence upon the supply for “reverse” (a) and “direct” (b) schemes of cutting: t=0.3mm,s=0.3mm/rev, D=38mm

The obtained data on ξ_b under the considered values of cutting conditions and cutting edge inclination prove that in most cases ξ_b is smaller when cutting with radius cutters than when cutting with straight ones. At the same time in a number of cases there isn’t any obvious dependence of ξ_b upon the considered parameters, for example, for the straight cutter $\xi_b = f(t)$ – for the “direct” scheme of cutting and $\xi_b = f(s)$ – for the “reverse” scheme of cutting, for the radius cutter $\xi_b = f(s)$ – for the “direct” scheme. Dependence $\xi_b = f(\omega)$ for the radius cutters has an extremum under ω being about 45^0, and for the straight cutters ξ_b increases almosr linearly with the growth of cutting edge inclination.

4. Conclusion

Basing on the obtained data we can make the following conclusions:

1) An important characteristic of cutting with cup-tip tools is value $\xi_a > 1$, $\xi_b < 1$, while under traditional cutting with single-point cutters their values are usually $\xi_a < 1$, $\xi_b > 1$ [4-6]. First, it is conditioned by the thickness of the cut layer which is many times smaller for cup-tip tools than for the single-point ones. Under the little thickness of the cut layer the workpiece material is pressed against the front part of the tool which results in forming chip with larger thickness. Second, the thickness is additionally influenced by kinematic and geometric characteristics of cup-tip cutting which supposes pressing the workpiece material against the inclined front surface of the tool leading to overlying layers lapping the underlying ones. as a result the chip becomes thicker and narrower.

2) Difference in the obtained dependences is associated with the change in the cutting edge geometry and parameters of the cut layer cross-section which will be different in terms of value and character for the straight and radius cutters, besides the geometry parameters demonstrate extra change with transition from the “direct” to the “reverse” scheme of cutting. The previously completed studies show that geometry change (front angle of the tool and cutting edge inclination) have a significant influence upon the conditions of cut material deformation [18, 19].

3) Absence in some cases of obvious dependence of chip shrinkage upon cutting depth, supply, cutting edge inclination results from the change of not only deformation processes and heat generated as a result but also from the size of contact areas which will significantly vary according to the considered parameters. As a result the amount of heat generated in the process of friction will produce additional effect upon the processes in the cutting area.

4) Transverse shrinkage when cutting with radius cutters is smaller than that when working with the straight ones, while the longitudinal is larger. It is conditioned by smaller thickness of the cut layer when cutting with straight cutters. Thus, the process of cutting with straight cutters can be described as the process characterized by pressing of material which leads to strong deformation of the cut layer and changing of the cutting edge geometry.

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