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CALCULATION OF THE SHEARING ANGLES WHEN ORTOGONAL FREE TURNING WITH CUTTER OF A NEGATIVE RAKE ANGLE

The determination of shearing angle in process of free orthogonal cutting of low-plastic carbon-ferrous alloys is provided by analytic method based on mechanical resistance of material machined. There are numerous marks of steels deformation characteristics under the temperature of cutting as well as results of experimental turning analyzed. The method proposed enables to calculate shear angles, angles and coefficients of friction, as well as shrinkage of chip dependently of steel mark, relative elongation and relative constriction of steel deformed when turning under the proper cutting temperature.

***Key words**: shearing angle, acting angle, coefficient of friction, shrinkage of chip, steel mark, deformation characteristics.*

Depending on the plasticity of metal in processing, chip formation occurs in the plastic flow of metal in the area of cutting or breaking with the formation and the subsequent development of cracks and the following separation of elemental or step swarf, also known as chip [1, 2] .

Known methods of assessing the nature of the deformation in the area of cutting enable to solve efficiently the problem of stressed-strained state, however, is not always sufficient to fully reveal the physical nature of the phenomena and quantify the processes [3–5].

One of the basic provisions of the science about the cutting of metals is the dependence of the shrinks chip formation from the degree of deformation of material layer deformed. Long time shrinks chip is one of the basic characteristics that allow us to recognize the phenomenon in the area of cutting, make numerous calculations with its use [2].

However, it is well known that measurements of cutting length and width of the cut of chip, its weighting of the final calculations of the actual quantities and values of the shrinkage of chip related essential labor consuming, have significant error and extremely uncomfortable in practical application in industrial production.

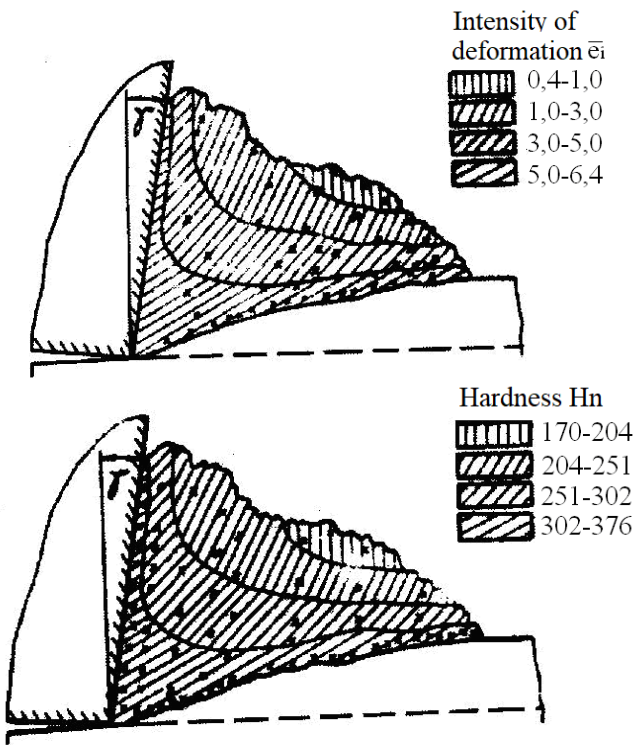
It is particularly difficult to get the values of the chip shrinkage in the formation of element and jointal types of chips, the total length of which is almost impossible to identify without error [1].

Using the generally known scheme of chip formation with one plane shear and knowing the area of contact of the rake surfaces of the cutting elements of the allowance that is to be removed, it is possible to provide a description of the contact phenomena in the area of chip formation and cutting force to calculate [3].

It is known [6], that separation of metal takes place in the area of cutting, where it received the terminal deformation, which is extreme, and if tension is equal to the boundary strength of consolidated metal.

In contact with the anterior surface of the cutter the stress in the chip will also reach their limit values. M.f. Polêtìka [7] believes that the chip is formed as a result of the birth and development of cracks in the close proximity to the cutting edge of the tool.

In Fig. 1 shows the microslice of the element of chip formation textured, the direction of which depends on the location in the area of cutting [8].



a *b*

Fig. 1. Microslice separated with the texture of shift [8]. Distribution of the intensity of deformation along the element of the chip (a) and of hardness on the element of chips (b)

The direction of the texture leads to the end of the plane, in which the metal is extremely hardened and subjected to displacement, which also separates chips from the main materìal allowance.

A subsequent contact interaction of chips with the rake surface of the cutter leads to additional heating of the chip due to its friction on the rake surface of the cutter and texture mild chip already formed not so much by the shear stress at the chip, but due to the contact friction with rake surface of the tool and the internal friction of chip [9].

There are several current models of the zone of deformation while turning, both with one and multiple planes, reflecting the process of chip formation, as a result of plastic shear strain in the area of the workpiece material.

Despite the fact that model with the developed area of deformation looks more realistic, analytical studies using models with one plane displacement look complete enough and when processing high speed turning become more acceptable. This is especially evident when handling sharp fragile and low plastic materials [1].

Depending on boundary values of the fluidity and strength of iron-carbon materials can be divided into high plastic when $\sigma_т(\sigma_{0,2})/\sigma_в$ = 0,45–0,55; plastic when $\sigma_т/\sigma_в$ = 0,55–0,70; low plastic, which have a ratio of $\sigma_т/\sigma_в$ = 0,70–0,90 and fragile that practically do not have turnover [10].

According to these indications, almost all hardened steel and malleable iron, chilled iron, high-strength alloy must be attributed to the low plastic materials.

When processing with tool of negative values the rake corners, which is typical for turning case hardened steels and cast irons with cutters of polycrystalline cubic boron nìtrid (PcBN), material in the zone of deformation is compressed and displaced in the chips [10].

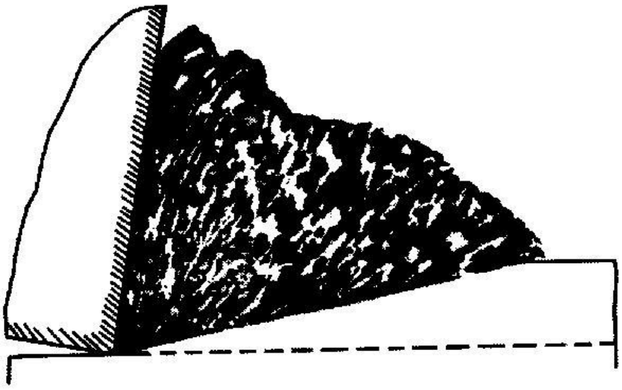


Fig. 2. Microsection with texture formed on steel Steel 45, V=60 m/min; S=0,59 mm/rev; t=1,5 mm [2]

Looks like with Fig. 2, chip texture is formed at an angle that does not meet neither the rake corner incisor, nor the angle position of the rakeier zone of chip formation [8].

Numerous microsections reveal that reveal the texture of the shear line, which goes to the chips as examined in the best way by M. M. Zorev [2].

Zone of deformation image, the angle of the texture of chip with the measured their values are shown in Fig. 3. where cutter with zero rake angle was used when processing carried out.

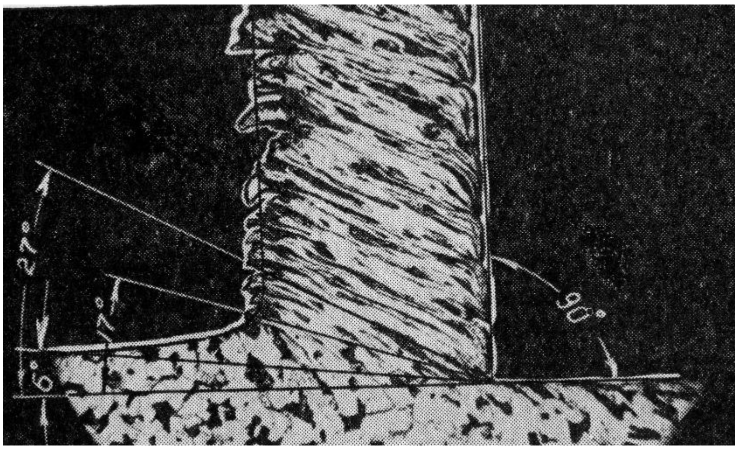


*Fig. 3. Image of borders of zone of deformation in chip formation and shear angle of the texture with a free rectangular cutting steel 20Г (*20G) *speeds V = 0,7 m/min, the thickness of the cut a = 0,065 mm* [2]

The sequence of the origin and formation of the element of chip when turning of steel 20G type was recorded using high-speed shooting with a frequency of 1500 frames per second, as it is shown in Fig. 4.

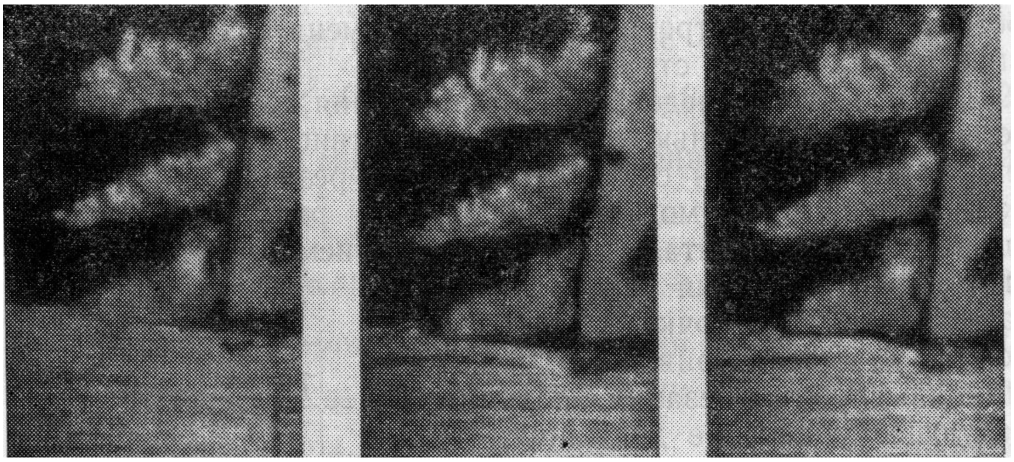


Fig. 4. Diagram of the formation of these chips, and textures with the frequency of high-speed shooting 1500 frames per second cold-drawn steel type 20Г (20G). The thickness of the cut-0,25 mm

High-speed footage of the shooting that the figure. 4 obtained in the rectangular free-cutting cold-drawn steel 20G type with a velocity of cutting 40 m/min. and the thickness of the cut of 0.25 mm. At the stage of the origin of the chip element in the material that separated the tekstue lines are visible and are more clearly observed in separate elements of chip.

In this case the direction of the offset lines is the same. As long as the normal tension in the elementary volume of material deformed, equilibrate tangent lines tension on the rake surface of the cutter, shift does not happen, material of allowance is plastically deformed and being forced out of the zone of deformation on the the rake surface of the cutter.

As soon as stresses reach the compression strength limits the destruction of its elemental space and then extension first on the plane, and then on the rake surface of the cutter take place.

As S. Silin rightly insists [12] the force of chip formation when turning initiates significant compression and elastic-plastic deformation of metal cut off with following plastic shifting (destruction of).

Consider the modified scheme to determine the ratios of shearing angle, cut thickness chip thickness and chip shrinkage, a proposed Merchant [1], and taking into account a negative rake angle, as shown in Fig. 5.

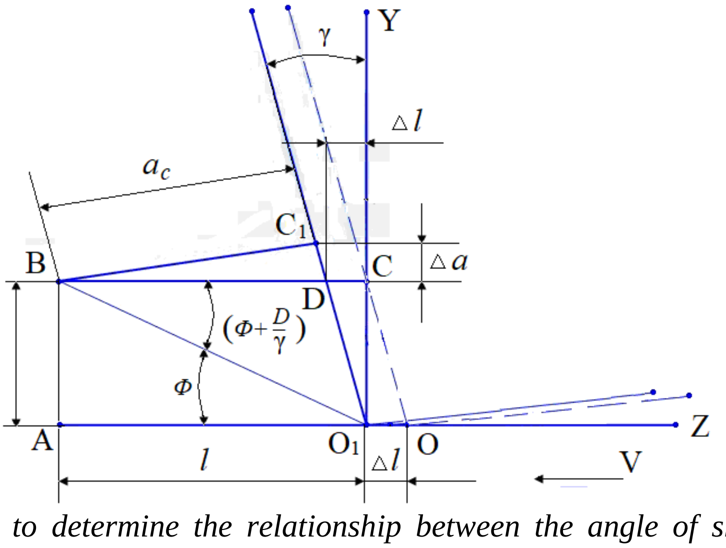


Fig. 5. The scheme to determine the relationship between the angle of shear, cut and chip thickness and chip shrinkage; Δa-metal deformation on the thickness of the cut, Δl-deformation of metal on the length of cut

Given the fact that the metal removed is that by not changing its density and missing side deformations on the width of cut, condition of continuity can be represented in equal volumes of the original before displacement and strain directly when the displacement of metal that process [13].

Provided the permanence of the width of the cut and the density of the material, the quadrangles OABC and O_1ABC_1 is to be equal. The area of quadrangle OABC will be:

$$S_{OABC} = a \cdot l + 0{,}5a \cdot \Delta l \tag{1}$$

The area of quadrangle O_1ABC_1 will be:

$$S_{O_1ABC_1} = S_{O_1ABC} + S_{DBC} - S_{DBC_1} \tag{2}$$

The area of the constituent rectangle and triangles will be:

$$S_{O_1ABC_1} = a \cdot l + \frac{0{,}5 \cdot \Delta a \cdot l \cdot \cos(\Phi + \gamma)}{\cos\gamma \cdot \cos\Phi} - 0{,}5a \cdot \Delta l \tag{3}$$

After shortage:

$$\frac{0{,}5l \cdot \Delta a \cdot \cos(\Phi + \gamma)}{\cos\Phi \cdot \cos\gamma} = 0 \tag{4}$$

After the cosìnuses sums of angles decomposition we get:

$$\frac{\sin\Phi \cdot \sin\gamma}{\cos\Phi \cdot \cos\gamma} = 1 \tag{5}$$

Or

$$tg\Phi = ctg\gamma \tag{6}$$

As shown on Fig. 7 and condition of continuity:

$$\frac{a}{l} = \frac{\Delta a}{\Delta l} = tg\Phi \tag{7}$$

With the resulting equation (6) reverse dependency between shear angle and negative rake angle indicates that the increase in the negative value of the rake angle leads to a decrease a shear angle, that is, if the material machined had to perfectly plastic properties and should be not friction on surfaces in contact with the cutter, then if there would be zero rake angle the deformation on the thickness of the cut would reach to infinity, and the strain on the thickness and length of the cutting area would be equal if the values of $\gamma = 45^0$.

However, constructive and tool materials are not perfect, and have certain properties that are shown in their plastic deforming, including while turning.

Many researches of characteristics of materials at temperatures close to the temperature of the turning are provided. These data are contained in both the standard documentation relating to most steels and alloys (State standards, technical terms), and numerous references.

But it is extremely difficult to define the real local temperature in contact zone in the process of turning. The allocation of heat is the result of deformation in the area of turning, as well as friction of cutter on the back surface and chips that goes on the rake surface.

Direct methods for measuring of the temperature in the area of the landslide there, estimates its values depending on the temperature of workpiece, chip and tool too quite inaccurate, because in this case there is a fairly high temperature gradient. There are methods of modeling to determine the temperature in a zone of deformation, based on the theory of similarities, proposed by S.S. Silin [12].

Figure 6 demonstrates graphic images showing the dependence of the temperature in the area of displacement and temperature on the rake surface of the cutter dependently of speed of turning to different tool materials by complex criterion *F*, taking into account the effect of the geometry of the tool and the ratio of thermal conductivity of tool material and material processing, which shows that the temperature on the rake surface of the cutter varies from 800 to 1200 °C depending on the tool of and the temperature in the area of the shift at optimal on tool-life cutting speeds – from 500 to 700 °C, and for PcBN Kiborite-type a more narrow range from 500 to 550 °C [14].

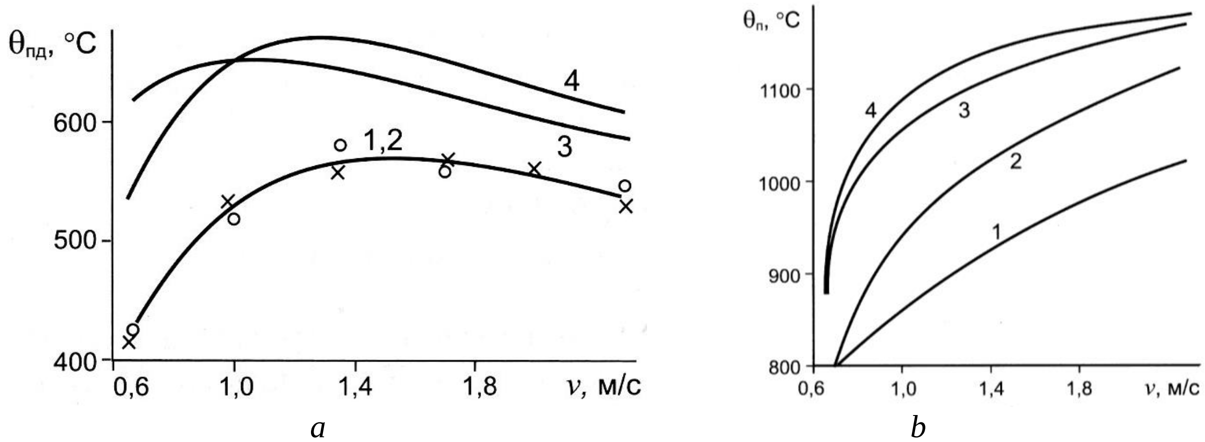


Fig. 6. The dependence of temperature in the conventional shear plane (s) and temperature on the rake surface of the cutter (b) from the speed of turning [10]

Taking into account the relation between the longitudinal and transverse deformations (7), based on the terms of the continuity of the scheme in Figure 5, and analyzing dependence between longitudinal and transverse deformation when testing on the strength of materials machined, it could be assumed that the longitudinal deformation Δl when cutting will be proportional to the relative narrowing δ, and deformation in thickness cut Δa respectively is proportional to the relative lengthening of the ψ in static or dynamic testing, moreover, in temperature range determined these characteristics are almost identical [14].

In this case, equation (7) can be represented in the following form

$$\frac{a}{l} = \frac{\Delta a}{\Delta l} = \frac{\delta}{\psi} = tg\Phi \tag{8}$$

Based on the scheme of the ratio of the thickness of cut and the thickness of chips depending on the magnitude of the shear angle (fig. 7), we get:

$$\frac{a}{\sin\Phi} \cdot \cos(\Phi + \gamma) = a_c \tag{9}$$

where: a – the thickness of the cut, a_c – the thickness of the chip.

The ratio of the thickness of the cut to the thickness of the chip will be chip shrinkage:

$$\frac{a_c}{a} = \frac{\cos(\Phi + \gamma)}{\sin\Phi} = \xi \tag{10}$$

Taking into account the Merchant dependence of the shear angle, the angle of friction and the cutter rake angle

$$\Phi = \frac{\pi}{4} - 0{,}5(\eta - \gamma) \tag{11}$$

or equation Oxley:

$$\Phi = 50^0 - 0{,}8(\eta - \gamma) \tag{12}$$

the angle of friction for the known values of the shear angle and set the rake angle of the cutter can be obtained.

The following table provides reference values of the relative values of deformations in appropriate temperatures in a shift zone for some types of alloyed tool steels and the metal processing in hardened condition and ones calculated for the above formulas to determine the shrinkage of chip and angle of friction.

Obtained values of angle use at zgahodžennì angle of friction formulas (10) or (12). Shrinkage of chips is calculated by equation (10).

The following table shows the data obtained as a result of calculations by the method proposed. What is offered on quantify characteristics of the angles, friction. coefficients of friction and shrinkage of chip in the turning of typical representatives of hardened to the high hardness of low, medium doped, tool and alloyed steels.

Data on relative elongation and narrowing these are with reference data properties of steels [13].

Shear angles, angles of friction, friction coefficient and shrinkage of chip in the turning of steels

№	Mark Steel		Temperature test °C	Relative Elongation δ %	Relative Constriction ψ ,%	Shear angle, Φ degrees	Angle of friction, η, degrees (γ=-10^0)	Coefficient of friction μ	Shrinkage of chip, ζ
1	2	3	4	5	6	7	8	9	10
1	Medium alloyed Steels	20X	500	26	75	19^{0}07'	41^{0}46'	0,9105	2,67
2			600	35	77	24^{0}34'	30^{0}52'	0,5977	1,99
3			800	51	90	29^{0}02'	21^{0}54'	0,4090	1,60
4		30X	600	32	90	19^{0}35'	40^{0}50'	0,8642	2,60
5			650	35	90,5	21^{0}11'	39^{0}48'	0,8282	2,15
6			800	48	79	31^{0}27'	17^{0}06'	0,3060	1,44
7		40X	500	25	78	17^{0}46'	44^{0}32'	0,9838	2,90
8			600	26	81	17^{0}48'	44^{0}24'	0,9850	2,90
9			800	48	94	27^{0}48'	24^{0}44'	0,4606	1,70
10		40ХГН	500	25	78	17^{0}46'	44^{0}32'	0,9838	2,90
11			600	27	85	17^{0}37'	44^{0}46'	0.9925	2,91
12			800	57	96	30^{0}52'	18^{0}16'	0,3496	1,51
13		12ХН3А	500	26	75	19^{0}08'	41^{0}42'	0,8909	2,66
14			600	35	65	28^{0}08'	23^{0}42'	0,4390	1,67
15			700	43	67	32^{0}42'	14^{0}36'	0,2606	1,36
16	Tool Steels	ШХ-15	614	13	37	19^{0}22'	41^{0}04'	0,8714	2,33
17			650	14,5	48	17^{0}48'	44^{0}24'	0,9737	2,19
18			695	21	50	22^{0}47'	34^{0}26'	0,6856	2,17

End of the table

1	2	3	4	5	6	7	8	9	10
19	Tool Steels	У8А	500	40	77	$27^{0}28'$	$25^{0}04'$	0,4677	1,72
20			600	48	85	$29^{0}24'$	$21^{0}06'$	0,3859	1,57
21			800	58	100	$30^{0}07'$	$19^{0}46'$	0,3594	1,52
22		У10А	500	38	77	$26^{0}17'$	$27^{0}26'$	0,5191	1,89
23			600	46	85	$28^{0}24'$	$23^{0}12'$	0,4286	1,62
24			800	52	100	$31^{0}20'$	$17^{0}20'$	0,3121	1,44
25		У12А	500	32	68	$27^{0}28'$	$25^{0}04'$	0,4677	1,72
26			600	44	82	$28^{0}23'$	$23^{0}14'$	0,4259	1,65
27			800	52	96	$32^{0}48'$	$14^{0}24'$	0,2567	1,33
28	High alloed Steels	12Х13	600	41	80	$28^{0}17'$	$23^{0}26'$	0,4338	1,66
29			800	62	98	$32^{0}19'$	$15^{0}22'$	0,2748	1,38
30		12Х18 Н9Т	650	17	43	$21^{0}24'$	$37^{0}12'$	0,7590	2,26
31			800	24	51,5	$24^{0}59'$	$32^{0}02'$	0,6253	1,94

If you compare the N.N. Zorev angle of the texture, shown in Figure 3 when turning of steel 20Х (20H) with data for this brand of steel that are given in the table (p.p. 1, 2, 3 of table above), the average value of the shear angle, calculated under the temperature range from 600^{0}C to 800^{0}C in shear plane, it practically coincides with the labeled in Figure 3.

There are graphics of shrinkage of chips from the hardness of steel processing, and the speed of the cutting in Fig. 7.

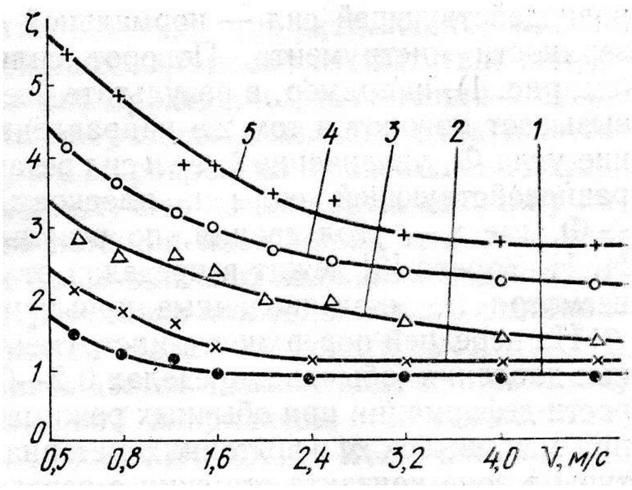


Fig. 7. The dependence of the shrinkage of chips from the hardness of steel turning and cutting speed when turning [15] ХВГ (HVG) steel with PcBN Ismit cutter (γ= - 50, φ= 450, t= 0,2 mm, S=0,084 mm/rev). 1 – 61 HRC; 2 – 55 HRC; 3 – 45 HRC; 4 – 37 HRC; 5 –- 23 HRC

As can be seen from the graphs in Figure 6, the temperature in the conventional shear plane is in the range of 500^{0}C to 750…800^{0}C, as shown in Figure 9 according to shrinkage of chips from the cutting speed when turning of steels of high (1.2 curves) and elevated (curve 3) hardness are very close approaching to the calculated by the formula (9) and are within the range of values between 2.5 to asymptotically approximate to 1.

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РОЗРАХУНОК КУТІВ ЗСУВУ ПРИ ПРЯМОКУТНОМУ ВІЛЬНОМУ РІЗАННІ З ВІД'ЄМНИМ ПЕРЕДНІМ КУТОМ

Визначення кута зсуву та кута дії при вільному прямокутному різанні низькопластичних залізо-вуглецевих сплавів здійснено за допомогою аналітичного метода, що базується на механічному опорі матеріалу, що оброблюється. Здійснено аналіз деформаційних характеристик численних марок сталей при температурах різання, а також результатів експериментів з точіння. Метод, що пропонується, уможливлює розрахунки кутів зсуву, кутів та коефіцієнтів тертя, а також усадки стружки залежно від марки сталі, питомого подовження та питомого вкорочення сталі при її деформуванні з відповідною температурою різання при точінні.

***Ключові слова**: кут зсуву, кут дії, коефіцієнт тертя, усадка стружки, марка сталі, деформаційні характеристики.*

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РАСЧЕТ УГЛОВ СДВИГА ПРИ ПРЯМОУГОЛЬНОМ СВОБОДНОМ РЕЗАНИИ С ОТРИЦАТЕЛЬНЫМ ПЕРЕДНИМ УГЛОМ

Определение угла сдвига и угла действия при свободном прямоугольном резании малопластичных железоуглеродистых сплавов осуществлено аналитическим методом, основанном на механическом сопротивлении обрабатываемого материала. Проведен анализ деформационных характеристик многих марок сталей при температурах резания, а также экспериментальных результатов по точению. Предлагаемый метод позволяет осуществлять расчеты углов сдвига, углов и коэффициентов трения, а также усадки стружки в зависимости от марки стали, относительного удлинения и удельного укорочения стали при ее деформировании с температурой резания при точении.

***Ключевые слова:** угол сдвига, угол действия, коэффициент трения, марка стали, деформационные характеристики.*

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