Finger Milling of Details to be Machined

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**Abstract.** The development of mechanical engineering and agricultural technology places great demands on the quality and reliability of the manufactured product. The researchers' research shows that the most important operating characteristics of machine parts - dimensional accuracy, residual strength, bending resistance, uniformity in contact, stability of bearings and a number of indicators - are determined by the quality of certain surface layers of parts. They, in turn, are characterized by the roughness, strength and microstructure of the treated surface, as well as the amount of residual stresses. Titanium alloys are increasingly being used in many engineering industries, which are preferred for the production of parts that are considered responsible during operation under the influence of high temperatures and stresses, active environments. The relative size and uniformity of the parts reduces the weight of the structure. In such conditions, the quality of machined surfaces, which affects the performance of machine parts, is of particular importance. Physical and mechanical properties of titanium alloys and specific characteristics of their structure in many cases make it difficult to use processing standards intended for other structural materials. Information on the effect of technological factors on the quality of the surface layer of titanium alloys in cylindrical milling is small, and differs from and often contradicts information obtained in other types of processing.

**Keywords:** titanium, physical-mechanical, milling, difficult, processing, detail, durable.

**INTRODUCTION**

Despite the extensive nomenclature of workpieces made from difficult-to-machine workpieces, the stress state of curved workpiece surfaces machined with end mills on milling CNC machines has not been studied. Milling in mechanical engineering and tool making, in order to lighten the weight of details in the operation of CNC machines, it is desirable to process all its surfaces, as milling is often considered the final operation. Therefore, depending on the design and function of the part, it may impose one or another requirements on the quality of milled surfaces during its production and operation. Also, the reduction of surface roughness as a result of milling can reduce or completely eliminate the task of adjusting the dimensions by the next fitter; compressive residual stresses can be obtained, allowing for an increase in residual strength and an extension of the life of the part. The reduction of residual stress in the surface layers during milling of weak parts reduces the warpage of the machined parts and reduces the amount of heat treatment, straightening and leveling operations. Therefore, it is considered an urgent task to determine the ways of controlling the quality of surface layers of details [1-6].

Therefore, the main goal of the work is to research the main technological factors and structural elements of details processed in milling CNC machines, which have a significant effect on the formation of surface layers of titanium alloys, and to develop measures to achieve the required quality of the surface layer [7-9].

To evaluate the quality of the outer layers, the following main indicators were adopted, which determine the description of the operation of the machine details:

a) roughness height of the treated surface;

b) level and depth of impact (reinforcement) in the surface layers;

c) type 1 residual stress;

g) microstructure of the surface layer.

The variable factors of the cutting process are conditionally divided into technological (milling scheme, cutting parameters, geometric parameters of the cutting tool and lubrication-cooling oils) specified by the technologist and constructive (part material, the shape of the processed surface, the curvature radius and height of the contour) given by the designer.

**METHODS**

Of stainless and high-strength steels [1] and heat-resistant parts, the increase in thrust value leads to an increase in tensile residual stresses. On the contrary, it is stated in the source [2] that when milling 1xNMF steel, with an increase in the thrust value, the increase of residual compressive stresses and their depth intensifies. In the cylindrical milling of VT3-1, VT-5, TS5 alloys, it is said that compressive stresses increase in residual values when the thrust value increases [2] in the source, the thrust value prevails over other technological factors.

The nature of the effect of the value of pushing the difference of the given data on the level of the residual value of the stresses is determined to a high degree by the speed of cutting and the physical-mechanical properties of the material.

According to most researchers, the depth of cut has a certain influence on the quality of the surface layer.

An increase in the depth of cut when milling the VT4 alloy increases the burr. However, in cylindrical milling of steel, the height of micro-uniformities does not depend on the depth of cut.

An increase in the depth of cut has a small effect on the degree of compaction, depth, and the amount of residual stress when processing stainless high-strength steels and heat-resistant alloys with cylindrical milling cutters.

an increase 3,0 ммin the depth of cut in cylindrical milling of XN70VMTYu alloy 0,4 ммincreases the depth of surface layer densification from 125 to 140 μm and the level of densification from 26 to 31%. In the sources, it is said that the same result will occur in cylindrical milling of VT3-1, VT-5, VT6, VT8 and steels.

Milling widthtitaniummicrohardness of metal, depth and level of surface densification does not affect the milling of alloys.

Thus, in milling, the types of influence of the cutting parameters on the quality of the surface layer are not many and they are mostly opposite. The collected results were obtained in the process of milling different materials under different conditions.

Research and practice of machining titanium alloys shows that the influence of the lubricating coolant in machining titanium alloys is different from that in machining carbon and alloy steels.

The reasons for the low efficiency of the cooling-lubricating medium in the processing of titanium alloys:

* High chemical stability due to the formation of oxide and nitride films that interfere with metal and cooling-lubricating contact;
* Small contact between the slag and the front surface of the tool;
* A large number of specific loads on the tool surfaces;
* Weak lubrication of the liquid medium.

Unlike cutting, water and water cooling-lubrication does not reduce the average coefficient of friction, but rather increases it when machining carbon and alloyed steels.

In counter milling of steel 40, the boundary between cooling and lubrication increases the deformation;

The depth of deformation is greater than when dry processing.

Information on cooling-lubrication effects in cutting titanium alloys is scarce and differs from information on machining other materials. For example, as determined in, a+b of titanium alloys significantly affects the deformation of the alloy being cut. At the same time, according to, cooling-lubrication during milling of VT3-1 alloy reduces the indentation depth compared to dry processing;

In cylindrical milling of the EI437B alloy in all speed ranges, cooling-lubricant injection leads to increased tensile stresses during cooling, but their penetration depth into the metal is small.

In addition, it is known from the source that the transition of tensile stresses to shear stresses is observed when using cooling-lubrication in comparison with dry machining of EI437B alloy.

Cooling-lubrication increases the amount and depth of maximum shear stresses in turning and milling of VT14 titanium alloy compared to dry machining.

According to the sources, there is a dependence of the nature of the cooling-lubrication effect on the thrust value and cutting speed.

VT3-1, VT5, VT6 alloys have small thrust values and signs of small shear stresses decrease without change.

When the cutting speed is increased with cooling-lubrication, the shear stresses increase.

In both cases, the effect of oil cooling-lubrication is not significant compared to water cooling-lubrication.

On the contrary, water cooling-lubrication increases the residual stresses in turning and milling of VT6s and VT14 alloys compared to oil cooling-lubrication, which can be explained by the metal penetration and cooling ability of water cooling-lubricants.

As the thrust value increases, the effect of cooling-lubrication on residual stresses decreases.

In turn, the effect of cutting speed on residual stresses depends on cooling-lubrication. Effect of cutting speed on residual stresses during milling of VT3-1 titanium alloy was observed with cooling-lubrication application.

The effect of cooling-lubrication is known when the wear on the back surface of the cutting tool is significantly reduced.

The application of cooling-lubrication during milling of OT4 and VT14 titanium alloys increases the hydrogen content in the surface layer by 20-30% and reduces fatigue resistance compared to dry machining.

According to their data, the fatigue resistance of VT3-1 samples treated with archon was higher than when treated with air.

Thus, cooling-lubrication has a very complex effect on the formation of the processed surface layers, which depends on the properties of cooling-lubrication, chemical composition, activity and characteristics of the cutting process (cutting mode, tool geometry, etc.).

As the cutting speed increases, the influence of cooling-lubrication on surface quality, cutting force, and tool stability becomes less and less [3].

Therefore, the influence of cooling-lubrication on the parameters of the surface quality is effective when processing titanium alloys in a cutting mode that is not high.

However, information on the influence of cooling-lubrication on surface quality in cylindrical milling of titanium alloys is incomplete and contradictory in the technical literature.

The state of the surface layer of details determines their operational characteristics, the greatest force imposed on the surface layer, the concentration of stresses in the layer and the influence of the external environment on them.

Titanium alloys and difficult-to-work materials are used to make responsible parts that operate under high static, dynamic and cyclic loads, high temperatures and active environments [4].

In the preparation and operation of details with low precision (thin-walled) and complex configuration, their dimensions may be inaccurate due to loss of precision and twisting [5].

In aircraft engineering and equipment manufacturing, not only the necessary and basic surfaces, but also other surfaces are machined to reduce their mass, and milling is the finishing operation [6].

Therefore, fatigue resistance, corrosion resistance and deformation tolerance are the most important operational characteristics for the nomenclature of machined parts on CNC machines.

Endurance (fatigue) limit in titanium alloys is the same as in steels (0.4÷0.6) sv , the sensitivity to stress concentration is not too great.

Unlike steels and non-ferrous alloys, titanium alloys do not degrade their fatigue strength in a corrosive environment.

Reduction of macro- and microstructures (particle size) of titanium alloys leads to an increase in fatigue strength by 20-30%.

Research shows that for titanium alloys and plastics, residual compressive stresses increase the fatigue strength of parts, while residual tensile stresses decrease, especially when stresses are concentrated.

But for these cases, it is appropriate for working temperatures that are not high.

At a temperature of 450-600°C, technological relaxation of residual stresses occurs in titanium alloys, and at a temperature of 650-700°C, they completely disappear [6].

The main axes of technological residual stresses affect the working load of the part. For example: the operational algebraic superposition of tensile and compressive stresses in the corresponding direction relieves the surface layer of the detail from forces and increases its static and fatigue strength.

Strengthening (densification) of surfaces increases the fatigue strength of titanium alloys after processing by vibragoltovka, hydrodrobestruyka method.

Surface hardening is more effective for titanium than for iodide.

Deformation hardening after cutting at working temperatures of 400-500 °C reduces the fatigue strength of heat-resistant materials, because the deformation exceeds the optimal level and reaches the limit value, and the defect layer and thermal stresses appear on the surface of the part.

Therefore, in the source, when preparing details from heat-resistant materials, cutting modes that ensure the minimum level and depth of surface layer density are recommended.

Decreasing the densification of heat-resistant alloys reduces the overall corrosion rate, reducing the resistance of titanium alloys to detail cracking [7-8].

The amount and direction of deformation in the operation of details depends on the amount, sign and depth of stress distribution, because the residual deformations of the detail depend on their residual stresses and relaxation.

Intermediate heat treatment operations do not eliminate residual stresses in parts with complex configuration, low roughness (thin-walled), where most of the metal is cut during processing, processed on CNC machines.

Therefore, the performance indicators of details made of titanium alloys are primarily determined by residual stresses, as well as surface hardening and roughness.

**RESULTS AND DISCUSSION**

Torets cutters are widely used tools in CNC machines. Among the links of the DNIAD (STIHD) system, milling cutters are the weakest [1].

In turn, the accuracy of milling cutters can differ depending on the nature of the operation and the ratio between the diameter of the milling cutter and the length of the working surface.

In this study, three sizes of high-speed steel cutters are used:

D=32 mm, Z=6; ω =30°, mm according to this, the milling thickness *j = 17.4, 4/7 and 2.2 mn/m (≈1740.47 / 220 kgs/mm)* in relation to the milling length .

The static uniformity of milling cutters is presented in according to the method

the formula.

Here: R- applied force, N;

- static deformation of the milling cutter in the direction of the load effect M.

R power milling V = 15 mm (see Fig. 1) is set to a width equal to

Loading is carried out with a screw jack through a sample dynamometer 2 of the DOSM 3-1 type increased.

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**FIGURE 1.** The scheme of measuring the deformation of Torets cutters



**FIGURE 2.** Longitudinal roughness of Torets milling cutters - effect on this and the level of milling accuracy: with a cylindrical milling cutter a) and with a Toretz milling cutter b):mn/m, mn/m, mn/m.

The amount of deformation was measured with a multi-turn IIGM type, 1 µm scale indicator 20.

Milling cutters are loaded at different angular values.

OT 4 titanium alloy samples are milled in a linear pattern without cooling under the following conditions:

*V = 0.27 m/s (16.1 m/min), Sz = 0.08 mm/tooth, t = 3 mm.*

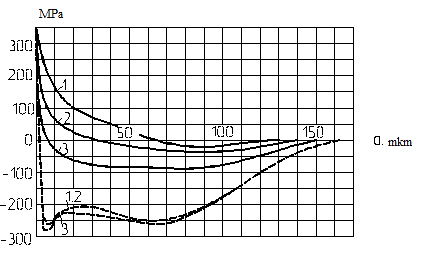
The reduction of the static roughness of Torets cutters leads to an increase in the roughness of the surface treated with the cylindrical part (periphery) of the cutter (see Fig. 2).

If the roughness does not increase much when going from a mn/m milling cutter to a mn/m milling cutter, with a mm/m milling cutter, the roughness increases sharply and reaches R a = 4.8 μm.

On the contrary, when processing with the toret part of the milling cutter, the reduction of static roughness changes the roughness and makes R a =7.4 μm.

When milling with a cylindrical part, the value of compressive stresses and the depth of settlement are higher when milling with a cylindrical part. However, when milling with a cylindrical part, the value of residual stresses and the depth of settlement depend to a large extent on the static stiffness of the cutters.

A decrease in stiffness leads to a decrease in tensile stress, an increase in compressive stress, and an increase in their propagation depth.



**FIGURE 3.** Effects of residual stresses of static buckling when milling with the cylindrical part of the toret milling cutter (continuous) and with the toret part (dashed lines) mn/m, mn/m, mn/m.

The reduction of the static roughness of the milling cutters also increases the microhardness of the surface milled with the cylindrical part (see Fig. 3).

The static stiffness of Torets milling cutters determines their vibration intensity (amplitude) when processing particularly difficult materials [1].

In our work, the vibration intensity increases with a decrease in the static sharpness of the milling cutters, which is caused by the non-fulfillment of the condition of uniformity in milling.

(1)

An increase in the intensity of vibration of milling cutters leads to roughness and a strengthening of the machined surface, which is reflected in an increase in the compressive stress and the depth of their penetration.

The intensity of vibration when milling with the upper part of the toret is lower than that of cylindrical milling. Therefore, when milling with a torets part, the change in the static uniformity of the torets cutters during the research period does not significantly affect the quality of the surface layer.

According to our data, the change of the front angle of the torets part from +6° to +13° (the recommended interval for the milling stability) does not change the quality parameters of the surface layer.

On the other hand, the teeth of the toret milling cutters perform the auxiliary operation of the toret part and do not determine the stability of the milling cutter. Therefore, during the study, the processing of the cylindrical (peripheral) part of the milling cutters was studied.

The review and analysis of the data in the literature presented in the first chapter shows that it is advisable to use cylindrical tape (chamfer with zero angle) burrs on the back surface of the tooth.

In this regard, it is appropriate to study the influence of cylindrical tape cutters on the quality of the surface layer.

The following milling cutters made of high-speed steel R8M3K6 are used for the study. D=30 mm, Z=4; ω =40°.

The width of the cylindrical strip on the back surface of the milling tooth: *f 3 = 0.05; 0.10, 0.15, 0,30 мм.*

The roughness of the tape surface is not more than *R a =0.32 μm .*

OTI - titanium alloy samples are processed in the following mode.

*V = 0.43 m/s (25.5 m/min), Sz = 0.08 mm/tooth, t = 3 mm. cooling-lubrication: MR-4*

In the samples treated with cylindrical tape cutters, the roughness in the transverse direction was reduced by 2.3 to 2.5 times compared to the ones treated with sharp pointed cutters (see Fig. 3).

In this case, the measured longitudinal undulations remain unchanged.

Thus, if when milling with a sharp end mill, the transverse burr is more than the longitudinal, then when milling with an artificial cylindrical tape mill, the longitudinal burr is more than the transverse.

The specified data can be explained by different reasons for the formation of microuniformities in the longitudinal and transverse direction.

In cylindrical milling, kinematic and geometrical factors have a significant influence on the formation of the measured longitudinal runout of the table. Therefore, the longitudinal burr at a constant (constant) feed does not depend on the shape of the back surface of the cutting tool.

Conversely, the transverse burr depends on the geometry of the milling tooth and the deformation of the surface layer.

The artificial cylindrical tape smooths out the irregularities of the plastic and reduces the repetition of the burr of the cutting tool.

This conclusion is confirmed by the comparative analysis of profilograms (see Fig. 3) and microrelief photographs of surfaces treated with different milling cutters.

Effect of cylindrical tapes on surface roughness *f 3 =0,03 mm.* As you can see, the character of impact in opposite and parallel milling is the same.

But the width of the tape is *f 3 =0,01 мм* and in the case of opposite milling, there are undulations with a height of *R a =20...30 μm on the processed surface.*

Deformation strengthening also confirms that the surfaces treated with band mills have an increased level of plastic deformation. (see Fig.4). The graphs also show a higher level of detail and depth with band cutters compared to those with a burr cutter.

As we have seen, the effect of artificial tapes is analogous to the effect of tapes on the back surface of the corroding tool and can be explained by the following reasons:

The degree of plastic deformation of the treated surface increases with the temperature increase in the contact zone.

From figure 3.9, it can be understood that with an increase in the value of *f 3* , the vertical component of the shearing force *Pv,* the horizontal component *Ph,* and the axial component R 0 remain unchanged.

The vertical component of the cutting force, *Pv,* indicates an increase in the loads on the surface of the milling cutter, which increases the point of the machined surface.

The resulting direction of the cutting force depends on the cylindrical tape on the surface of the milling tooth.

With the same front angle and the same sharpening condition, the cutting edge of the fourth non-angled ribbon tool tooth creates conditions for an increase in the sharpening angle and radius of rounding compared to sharpened milling cutters.



**FIGURE 4.** Effect of f 3 value on the degree of refinement (M) and depth (h) in path-path milling

This situation also confirms the nature of the effect of f 3 values on the distribution depth of compressive residual stresses in the surface layer.

As we can see, when using milling cutters with a value of *f 3* =0.3 mm, the compressive residual stresses for horizontal and opposite milling increase by an average of 1.5 times compared to those of sharp milling cutters.

*f 3* on the sign and value of the residual stresses is special.

Experiments show that, despite the increase in cutting force factors, compressive residual stresses are reduced when processing with cylindrical tape cutters compared to those with sharpened cutters [1].

During continuous milling, residual stresses with a depth of 25-35 μm are observed in the surface layer.

The reduction of compressive stresses and the increase of tensile stresses when working with cylindrical tape cutters can be explained by the increase of the starting work on the back surface of the cutter tooth as a result of the increase of the thermal field gradient in the surface layers. Cylindrical tape on the back surface of the milling tooth also greatly affects the distribution of residual stresses in the surface layer.

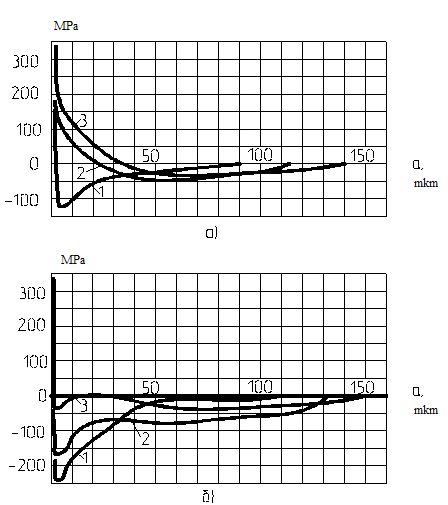
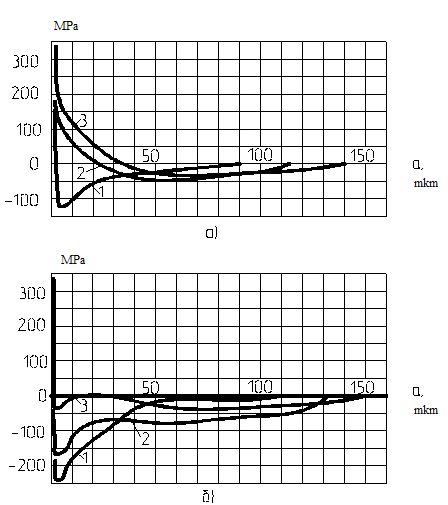
The compressive residual stresses increase again after the minimum in the gap in the stress profile of the samples processed in the opposite scheme with a f 3 tape cutter, that is, the compressive residual stresses have 2 maxima.

A. I. According to Isaev, the analogy of the effect of wear on the appearance of the residual stress pattern is explained by the change in the conditions of metal friction on the cutting elements of the tool, as well as the penetration of the stretched and deformed layer of the tool in the cutting zone.

Cylindrical tapes on the back surface of the milling tooth cause changes in the microstructure of the surface layers (see Fig. 5).

With sharpened milling cutters, grinding of a set of particles and a change in their movement is observed in relation to the surfaces and the metal core.

Thus, the artificial cylindrical tape made on the back surface of the milling tooth is a tool that effectively affects the quality parameters of the surface layer.



**FIGURE 5.** The effect of f 3 value on residual stresses in parallel (a) and opposite (b) milling : 1- *f 3 = 0 мм; 2* - *f 3 = 0.15, 3* - *f 3 = 0.3, mm*

In accordance with the recommendation in the research, the angle of deviation of the helical line: = 30°, 35°, 40° and 45° is used.

Samples from OTN titanium alloy are processed under the following conditions:

V = 0.39 m/s (23.5 m/min), S z = 0.008 mm/tooth, t- 3 mm; milling cooling-lubrication MR-4 in a linear scheme.

The cutting speed of the samples fixed to the device is adjusted relative to the milling axis, in the direction of the push movement and in the direction perpendicular to the movement.

The angle of deviation of the helical line of the milling tooth does not affect the depth of refinement of the roughness of the machined surface and the change of its structure under the specified conditions.

an increase in the angle from 30° to 45° causes a decrease in the degree of finish of the machined surface from 30% to 27% (in samples mounted in the direction of the cutting speed).

The effect of the angle of deviation of the helical line is seen in the amount of residual stresses and their settling depth.

an increase in the angle leads to a decrease in the amount and depth of distribution of compressive residual stresses moving in the direction of the X axis. The movement of compressive stresses (on the u-axis) is inversely affected by an increase in the angle.

The amount of tensile stresses is not significantly affected by the angle in a thin surface layer.

In order to explain the effect of the cutting edge deviation angle on the residual stresses and degree of refinement, we analyze the change in the components of the cutting forces due to the increase in the cutting edge deviation angle.

Let's graphically construct the projection of the direction of the cutting edges and the shear force R acting equally normal to it.

It can be seen that with an increase in the angle, the normal and relative displacement and the longitudinal contraction of the slag lead to a decrease in the component *Rh,* which leads to a decrease in the deformation of the metal particles*.* At the same time, the value of *R 3* force projection, which aligns the cutting along the blade, increases.

This reduces the deformation of the surface layer (on the X-axis) and leads to a decrease in the level of surface refinement and a decrease in the depth of their distribution. On the contrary, residual stresses and an increase in their depth were observed in the direction of the U-axis to = 45°.

However, residual stresses obtained from pre-prepared and machined samples allow to estimate the milling tooth deviation angle for one type of samples.

This is provided that the treatments in the mutually perpendicular direction to the samples are different from each other.

In particular, the milling width is different (15 and 71 mm).

In cylindrical milling, an experiment was carried out to obtain comparative data on the value of residual stresses in different directions and the direction of the stress field. The OT4-1 alloy plate with width V = 100 mm 50 ммwas treated with a toret milling cutter with a single tooth (table 1). Cutting mode parameters: V = 0.42 m/s (25.1 m/min), S z = 0.09 mm/tooth, t- 1 мм; milling along the way. Plates are processed with a = length cylindrical part of the milling cutter, that is, it was an open bevel bursa cutting process.

Cooling-lubrication is used to avoid uneven cooling-lubrication across the milling width.

Cutting forces are recorded during processing.

In this way, three plates are processed. Samples of size 70x10x4 mm are cut from the plates freed from the device by the electrocut method. Figure 3.14 shows sample directions.

The direction of the sample 1 corresponds to the cutting speed and suction vector (X axis), 2 – the sample is in the perpendicular direction, 3 – the sample is at an angle of 45° to X and U, and 4 – the sample is assumed to be in the exit direction.

The direction of slag smoking does not coincide with the normal of the cutting edge in the plane of the leading edge.

Samples 5 and 6 are oriented parallel and perpendicular to the cutting edge, respectively.

7 – the sample direction coincided with the equal effector R of the components Rh and R0 lying in the XOU plane of the shearing force.

are obtained from the oscillogram of the shear force on the graph of the equally acting direction *Rh* and *R0 .*

7 - the purpose of selecting the sample direction *R* is to check the agreement with the information given in about the direction of the residual stresses being aligned with the direction of the equal shearing effector.



**FIGURE 6.** Direction of samples in cutting (A.A. line corresponds to the direction of the discharge).

In samples 1, 2, 3, 4, 5, 6, 7, the normal residual stresses in the uniaxial tension state corresponding to the direction of the samples are determined.

It is possible to determine the flat (biaxial) state of the machined surface along certain axes. The actual value of the normal residual stresses in the direction of the forming movements (X axis) and in the direction perpendicular to it (U axis) can be determined from the following formula.

(2)

(3)

Here: and - residual stresses determined from the 1st and 2nd samples.

- Poisson's ratio.

The actual value of the residual stresses along the X and U axes is determined as follows.

- at a depth of 5 mm (respectively – )

MPa, MPa,

- at a depth of 70 mm (respectively – )

MPa, MPa,

Calculations - books show that when milling a titanium alloy, the compressive stresses lying at a depth of up to 40 μm correspond to the residual stresses directed along the U axis.

In cylindrical milling of 2x13 grade steel, the difference between the values of the residual stress in mutually perpendicular directions of the cutting speed is noticeable. When milling carbon steels, the direction of the cutting speed is characterized by a low level of tensile stresses compared to the direction perpendicular to it.

Thus, the surface residual stress after cylindrical milling has a directional character. In this regard, it is possible to determine the value and direction of the main residual stresses, that is, the position of the main axes.

In general, in addition to the principal residual stress direction, X and U axes, the normal stress in the new direction at an angle of 45° to X and U should be determined.

In that case

(4)

(5)

(6)

Here: and - the first and second main voltages.

, and - respectively, normal residual forces along the X axis (sample 1), along the U axis (sample 2) and at an angle of 45° to X and U (sample 3).

- Pkasson coefficient

- Angle between the X-axis and the 1st principal stress principal axis.

and - values of principal residual stresses at different depths calculated by formulas (5) and (6) are presented in table 1.

the principal residual stresses and , constructed from these data, correspond to the graphs of residual stresses determined in samples 6 and 5 As defined above, samples 5 and 6 were cut in the transverse direction.

For a range of values of the apparent surface layer depth, the first principal stress principal axis is determined from formula (6). For example: MPa for a depth of 5 μm .

yuu milling tooth helical line deviation angle is close to.

**TABLE 1.** Calculated values of principal and yield residual stresses

|  |  |  |  |
| --- | --- | --- | --- |
| **The depth of the removed cavity , μm** | Basic residual stress, MPa | | Test residual stress MPa |
|  |  |
| **2**  **5**  **10**  **15**  **20**  **25**  **30**  **40**  **50**  **60**  **70**  **80**  **90**  **100**  **110**  **120**  **130**  **140**  **150**  **160** | +345.2  +253.0  +168.2  +115.2  +67.6  +40.8  +4.3  -34.4  -11.4  +6.6  +16.9  +15.1  +19.0  +19.8  +11.9  +10.7  +6.6  +4.4  +2.5  0 | -131.0  -375.5  -266.8  -189.5  -130.4  -102.3  -70.4  -34.4  -60.0  -83.8  -96.9  -87.9  -86.2  -72.6  -54.7  -42.1  -28.0  -14.8  -5.3  0 | +231.0  +304.9  +211.0  +147.8  +96.0  +69.6  +36.3  0  +23.7  +44.1  +55.3  +50.3  +51.4  +45.2  +32.6  +25.9  +17.0  +9.1  +3.8  0 |

of the surface layer increases, the value of the angle also increases, and it is possible to change the position of the head at its depth.

OT4-1 titanium alloy torets milled residual stresses torsion in the change of the depth of the surface layer of the main axis is defined in the source [8].

Thus, in cylindrical milling of titanium alloys, the direction of the first principal residual stress coincides with the normal of the cutting edge.

This conclusion is also confirmed by the fact that the residual stresses in this direction (sample 6) are superior to the residual stresses in the X and U directions in the depth of settlement algebraically.

The residual stresses in the slag outlet direction and the residual stresses in the equally acting R direction have an intermediate value between the first principal residual stresses (Specimen 6) and the stresses in the X-axis direction (Specimen 1).

The maximum values of compressive residual stresses are characteristic for the second main residual stresses forming in the direction parallel to the angle of deviation of the cutting edge.

Therefore, the algebraic inequality is maintained throughout the depth of residual stresses.

axis of the residual stresses is also confirmed by the following point in the theory of the sum of stresses elasticity.

(7)

Here: and (2), (3) are calculated by formulas.

example: for a depth of 5 µm corresponding to

As a result of the inequality of the main residual stresses and the deviations from the direction of the movement of the cutting tool, the resulting residual stresses in this direction (X axis):

(8)

5 µm deep

In the perpendicular direction (U-axis) according to the law of the resultant stress couple

This, the surface layers milled with a helical cylindrical milling cutter are characterized by a clear orientation of the field of residual stresses:

The axis of the first principal residual stresses coincides with the normal to the cutting edge of the milling axis.

States that the first principal residual stress in right-angle cutting coincides with the shear rate gradient and the normal to the cutting edge.

Therefore, the angle of deviation of the helical line of the milling tooth not only has a great influence on the value of the residual stresses, but also determines its vector, that is, the direction of the main axis of the residual stresses on the surface layer.

In the first chapter, it is shown that their structure, mechanical properties, and chemical composition greatly influence the cutting process of titanium alloys. Moreover, these characteristics are different in different groups of titanium alloys. Processing conditions: Sharpened Torets milling cutter D = 30mm, Z = 4 (table 2.3), V = 0.4 m/s (23.5 m/min), S z = 0.08 mm/tooth, t- 2 мм, cooling- lubrication - MR-4, the scheme is milling along the way.

The roughness of the treated surfaces under the indicated conditions was not different for different alloys.

However, compared to the high plasticity and low strength OT4-1 alloy, TS5, VT22, VT20, VT3-1 alloys have a lower intensity of chip adhesion to the tool and the treated surface during counter milling. For this reason, if OT4-1 is µm in milling, it is reduced to µm in TS5, VT22, VT20, VT3-1 alloys with high strength and low plasticity .

Fig. 3.22 a shows the residual stresses in samples of various titanium alloys.

It should be noted that the OT4-1 alloy, which is more plastic, has less strength, and the residual stresses are less (tensile and compressive) than the milled VT20 and TS5 alloys with less plate, high strength.

High-strength VT22 and heat-resistant VT3-1 ( ) alloys - have a small depth due to a low level of compressive stresses compared to alloys. Also, according to the source, a large amount of residual stress is formed in low-alloyed alloys prone to plastic deformation and crushing.

Thus, the quality of surface layers of titanium alloys is largely determined by their physicomechanical properties and which structural group they belong to.

**CONCLUSION**

1. It is shown that the static roughness of milling cutters (in the ratio D/l = 0.3 - 0.2) is less than 4-3 mn/m due to the sharp increase in roughness of the processed surface. In this case, the degree of refinement, the amount of compressive residual stresses and the depth of their distribution increases.

2. It was found that the artificial cylindrical tape on the back surface of the milling tooth is a tool that effectively affects the quality of the surface layers of titanium alloys. In comparison with sharpened milling cutters, 0,10 ммthe presence of an artificial tape with a width of 0.05 reduces the transverse roughness by 2-2.5 times, ensures an increase in the depth and level of grinding; the depth of settling of residual stresses increases, but the amount of compressive stresses decreases.

3. The influence of the angle of deviation of the helical line of the milling tooth on the residual stresses is studied. An increase in the angle causes compressive stresses in the direction of cutting speed to decrease their propagation depth and to increase them in the direction perpendicular to it.

4. As a result of the study of the treated flat surface, it was found that residual stresses in cylindrical milling correspond to the angle of deviation of the cutting edge in the direction of the head axis and its normality.

In addition to the normal residual stresses in the surface layer, it was found that there are residual compressive stresses equal to 350 MPa.

5. In contrast milling, cooling-lubrication reduces the intensity of adhesion of cuttings to the processed surface in comparison to dry processing.

It has been shown that there is no chip adhesion during milling, and the roughness of the machined surface does not depend on cooling-lubrication and their composition.

6. The use of cooling-lubrication in milling of titanium alloys leads to a decrease and an increase in compressive residual stresses compared to milling in air. The effect of certain coolants on residual stresses in face and counter milling is related to their cooling ability and effect on the components of cutting forces.

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