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Analysis of Distribution of Contact Loads on Tool Surfaces

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Abstract: The article covers an analysis of magnitude and nature of distribution of contact loads on tool surfaces in order to evaluate the strength of the tool, as well as the modeling of the cutting tool.

Keywords: strength, tool, contact loads, loading, titanium alloy, cutting edge, cutting wedge, cutting plate, replaceable non-collapsible plate.

Introduction

In order to assess the strength of a tool, it is necessary to know the magnitude and nature of the distribution of contact loads on tool surfaces. The tangential *Rz* and radial *Ry* component forces act on the front surface, as well as on the rear surface [1, 2, 3].

Research of distribution of contact loads is a very laborious and expensive process, and there is a possibility of calculation errors because of changes in the chip formation process due to the sufficient instability of the cutting process itself [4, 5]. Therefore, we will consider how much the distribution error affects the deflected mode (DM) of the tool. Let us study the deflected mode of the cutting wedge under the action of three types of external loads with the same total value:

Main part

Concentrated load is the simplest type of loading and does not require a special study of the distribution of external stresss. On the front surface, a concentrated load is applied at the center of forces. Because the greatest share of forces is created by normal stress (Fig. 1), then this center is usually located from the cutting edge at a distance of 0.3 of contact length of the chips with the front surface C.

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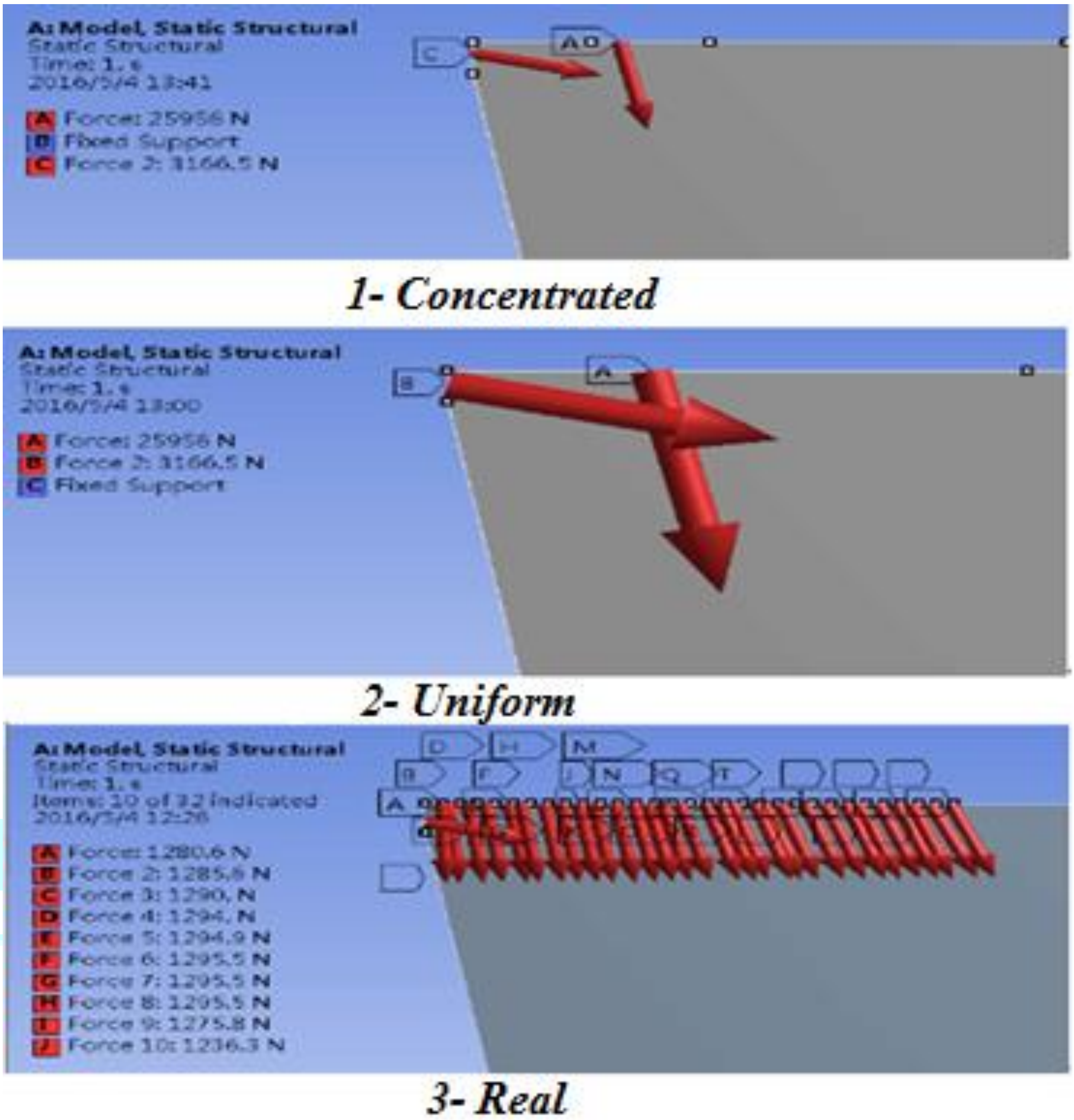

Fig. 1. Types of application of contact loads on rear surface when machining steel.

Uniformly distributed load. There is a uniform distribution of normal and tangential stresses over the entire length of contact of the chip with the front surface and on the chamfer of the rear surface that simulating wear. The total forces on the front and rear surfaces are the same as under the action of concentrated loads.

To apply real external stresses acting on the front surface, we divide the section of the chip contact length with the front surface into sections. In those places where there is an intense change in contact stresses, we divide the diagrams into smaller sections. For the application of external load at the nodes of the grid of the finite element method (FEM), we calculate the total normal and tangential forces acting in this area (Table 1). To create loading conditions closer to real, we divide the length of contact of the chips with the front surface of the cutter into a large number of sections (15 sections).

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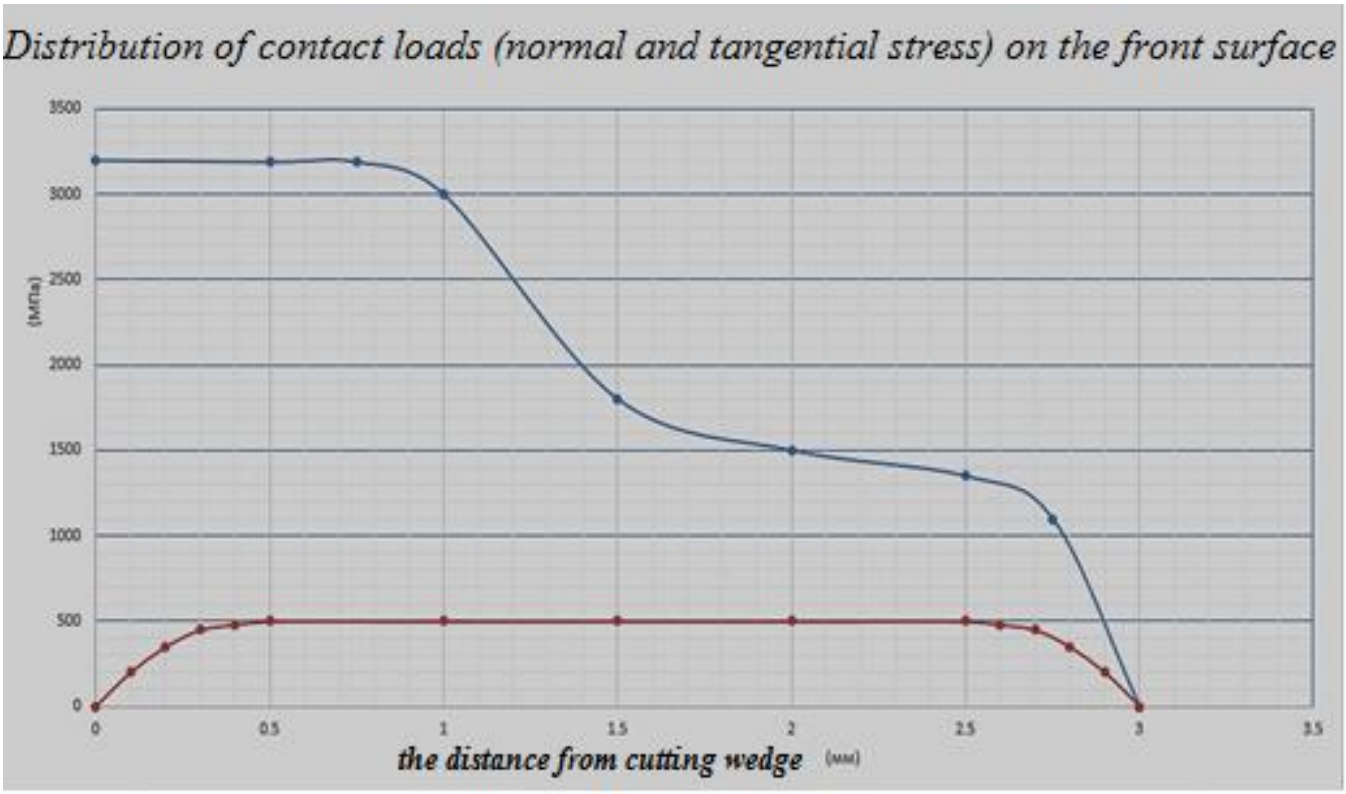

Fig. 2. Distribution of normal (upper graph) and tangential (lower graph) stresses on the front surface

When processing titanium alloy VT3-1 under cutting conditions, the length of contact of the chips with the front surface of the cutter is $C \leq 3$ mm, therefore, we take the length of the cutting plate equal to 9 mm. We assume that at a greater distance from the cutting edge, the elastic deformations of the cutting plates are negligible. This assumption will allow restricting the area in which the stress-strain state of the cutting wedge is studied. Reducing the DM study zone will reduce the calculation time, will allow using small sizes of finite elements, which will increase the resolution in the cutting edge region, which is characterized by large stress and strain gradients.

The thickness of the cutting plate will be taken equal to the standard thickness of brazed and replaceable non-collapsible plates. We assume that the contact of the cutting plate with the bottom plane is absolute rigid. The width of the cutting plate will be taken as 4.2 mm, i.e. 0.2 mm wider than the width of the disc to be machined. Such a slight increase in the width of the cutting plate will allow considering the stress-strain state of the cutting wedge as flat.

According to research of T. Zhang and V.N. Kozlov [6, 7], uniformly distributed contact loads are the most optimal for studying the stress-strain state of the cutting plate of the tool, i.e. they are quite simple to calculate and their application gives almost the same result as when applying stresses, the distribution of which was obtained using the laborious and difficult to implement the method of the split cutter.

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The magnitude of contact stresses on the front surface of the cutter

Table 1

No.	Distance from the cutting edge to the beginning of the section	Section length	The value of the average stress in this area, MPa
Distribution of the normal contact stress, σ			
1	0	0.5	3200
2	0.5	0.25	3190
3	0.75	0.25	3190
4	1	0.5	3000
5	1.5	0.5	1800
6	2	0.5	1500
7	2.5	0.25	1350
8	2.75	0.25	1100
9	3	0	0
Distribution of the tangential contact stress, τ			
1	0	0.1	0
2	0.1	0.1	200
3	0.2	0.1	350
4	0.3	0.1	450
5	0.4	0.1	480
6	0.5	0.1	500
7	1	0.5	500
8	1.5	0.5	500
9	2	0.5	500
10	2.5	0.1	500
11	2.6	0.1	480
12	2.7	0.1	450
13	2.8	0.1	350
14	2.9	0.1	200
15	3	0	0

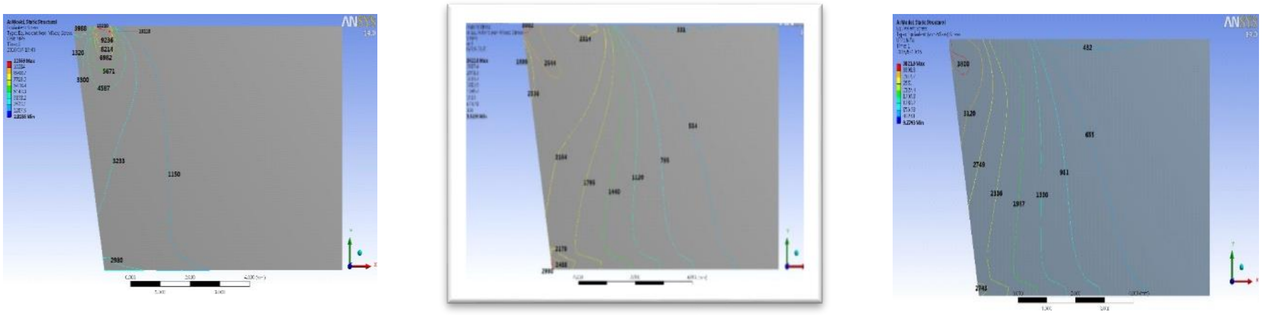
Influence of the type of loading on calculation of internal stresses in the cutting wedge

Calculation of internal stresses in the cutting wedge was carried out by the finite element method (FEM) using the ANSYS 13 software for the condition of free rectangular turning of disc made of titanium alloy VT3-1 with a radial feed. In the calculations, the thickness of the cutting plate was taken h = 6 mm, the length l = 9 mm, the width of the chip contact with the front surface was taken equal to the width of the disc $b = b_d$ = 4 mm, the width of the cutting insert was taken slightly larger than the width of the disc, i.e. b_p = 4.2 mm, with a symmetrical arrangement of the disc relative to the cutting plate. The material of the cutting plate in the calculations is VK8 hard alloy.

Components of the cutting force and the distribution of contact stresses were obtained experimentally with free rectangular turning of a disc made of titanium alloy VT3-1 using the method of a split cutter. The cutting part of the cutter was made of hard alloy VK8. Cutting mode: cutting speed: v = 1 m/s, radial feed s = 0.43 mm/rev.

Cutting geometry: front angle: $\gamma = 0^o$, main rear angle $\alpha = 10^o$, length of the chamfer on the flank surface that simulating wear, $h_f = 0.2$ mm, clearance angle on this chamfer $\alpha_h = 0$

In strength calculations, it is better to use equivalent internal stresses. After replacing concentrated forces with uniformly distributed over a small area, the zone with a high concentration of stresses at the point of application of loads disappears, but on the front surface at the place of application of loads at a distance from the cutting edge there is still a zone with unrealistically large equivalent stresses ($\sigma_{экв\ max\ сосред} = 10\ 230$ MPa) (Fig. 3.a).



a. b. c.

Fig. 3 a) when loading with concentrated forces, b) when loading with uniformly distributed specific loads c) when loading with contact stresses that have a real distribution

Under the action of a concentrated load at a distance of more than 3 mm from the cutting edge, the internal stresses become small, of the order of 1000 MPa.

On the rear surface near the cutting edge there is an area with large internal stresses ($\sigma_{экв\ сосред} = 3\ 988$ MPa), and in the entire area of the rear surface up to the supporting bottom surface there are rather large internal stresses of about 3200 MPa. On the lower support surface on the left edge, there are rather large internal stresses of the order of 2980 MPa, which corresponds to the principles of mechanics.

At the cutting edge and in the loading area there is a zone of compressive stresses (the figure is not given in the article). At a distance of more than 4 mm from the cutting edge, the area of tensile stresses begins ($\sigma_{x\ сосред} \approx \sigma_{y\ сосред} = 1\ 100\text{-}1300$ МПa), which should lead to breakage of the cutting plate.

When uniformly distributed specific contact loads are applied, the nature of the distribution of internal stresses changes significantly in comparison with the action of concentrated forces. Lines of equal equivalent stresses for the most part run approximately perpendicular to the front surface of the cutting plate. The greatest value of internal stresses ($\sigma_{экв\ max\ равном} = 3022$ MPa) is at the cutting edge.

On most of the front and on the entire rear surface, there are rather large internal stresses of the order of 2100 MPa. On the lower support surface on the left edge, there are large stresses ($\sigma_{экв\ равном} \approx 3000$ MPa), which are the same as under the action of concentrated forces.

When loaded with uniformly distributed contact loads, internal stresses quickly decrease to 785-554 MPa at a distance of more than 3 mm from the cutting edge. A zone of compressive stresses is located at the cutting edge and in the loading area (the figure is not given in the article). At a distance from the cutting edge of more than 4 mm, the area of tensile stresses begins ($\sigma_{x\ равном} \approx 480$ MPa, $\sigma_{y\ равном} \approx 90$ MPa). Summarize:

1. The nature of the distribution of equivalent stresses obtained under the action of uniformly distributed contact loads does not differ much from the nature of the distribution obtained under the action of external contact stresses that have real distributions.

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2. The highest equivalent stresses obtained under the action of a real distribution of external stresses are 25.7% higher than the highest equivalent stresses obtained under the action of a uniformly distributed contact load, ($\sigma_{\text{экв max реал}}$ = 3 800 MPa, $\sigma_{\text{экв max равном}}$ = 3 022 MPa)

3. The highest equivalent stress at the cutting edge obtained under the action of a concentrated load is several times greater than under the action of a real distribution, which does not correspond to reality ($\sigma_{\text{экв max сосред}}$ = 10 230 MPa, $\sigma_{\text{экв max реал}}$ = 3 800 MPa).

4. For the calculation of internal stresses for modeling external loads, it is possible to use a uniform distribution of contact loads with an increased by 25% the highest equivalent stress at the cutting edge. Compared to the application of the real distribution of DM of the cutting wedge, it changes insignificantly. This allows reducing the complexity of obtaining the initial data on the distribution of contact stresses, and at the same time ensure sufficient accuracy.

5. Errors made in the study of the distribution of contact stresses on the working surfaces of the tool by the split cutter method, insignificantly affect the distribution of internal stresses in the cutting wedge.

Conclusions

In order to simplify the research of deflective mode of the cutting wedge, we created a model of the cutter as a small part of the cutting tool (Fig. 3), for which the parameters (rear angle, clearance angle, thickness of the cutting plate, wear on the rear surface, the formation of rounding of the cutting edge with a radius of ρ, etc can be changed. The tool can be modeled in any CAD system according to the selected parameters.

Open the ANSYS 13.0 program (workbench). Right click **Geometry**. Import the file Cutter of the straight-line **x_t.** in ANSYS13.0 (workbench). We call the command Open. The program may require the execution of diagnostics of the import of the part: click **OK**.

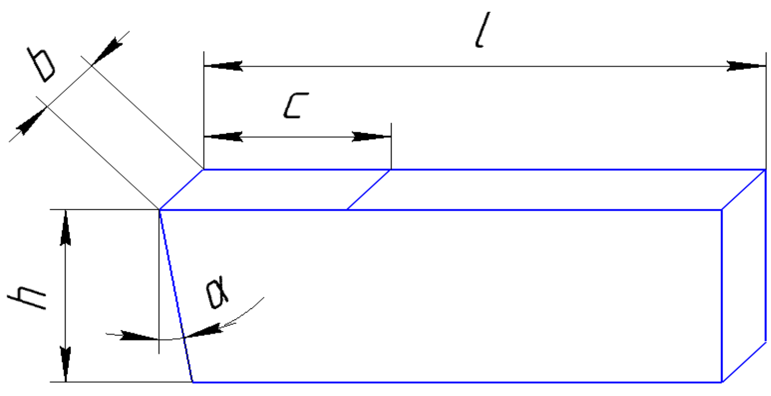

Fig. 4. Cutter model for research. *a is the width of the cutting plate (cutting wedge), the width of the cutting plate b; h is the thickness of the cutter model; ρ is the radius of rounding of the cutting edge, ρ = 0 mm; α is rear angle, α = 10 °; γ is front angle, γ = 0 °; C is the length of contact of the chips with the front surface, C = 3 mm; l is length of the cutter model, l = 9 mm*

Then assign the material of the cutter by clicking on **Engineering Data**, enter Young modulus and Poisson ratio.

After completing these operations by clicking the mouse button.

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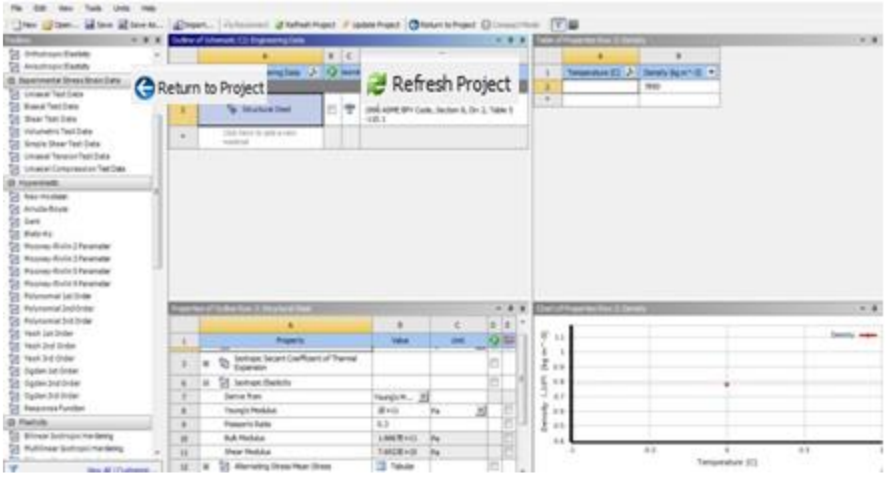

Fig.5. data input window.

After that, the window appears:

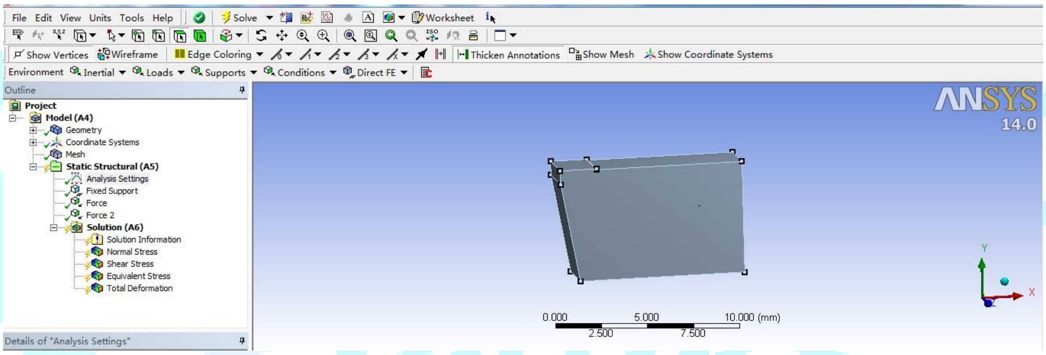

Fig. 6 Window of parameter placement.

In the upper part of the ANSYS 13.0 working window there is the main menu and command icons, to the left is the browser, and to the right of the browser is the working area in which the part is being built. In the main menu, call the geometry command and make the placement of the parameters that were specified above.

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