Research on the Force Density Function in the Rake Face of H-slot Tool

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Abstract

In machining high steel 2.25Cr-1Mo-0.25V, cutting force is large, and tool is prone to adhesion failure. In order to study the distribution of force density function and stress state on the rake face of H-slot blade. Experiments were carried out to study the contact phenomenon in tool rake face. Based on it, the force density function was established and it was showed through 3d view. The force distribution law was analyzed. The force density function was used as the boundary conditions. Tool stress field was simulated using FEM. The simulation results are in good agreement with the theoretical analysis results. The investigative results provide a theoretical foundation for solving the key technical problems of tool breakage in the automated production, and for studying optimization technology of groove.

Keywords: *turning inserts; force density function; stress field*

1. Introduction

High-strength steel 2.25Cr-1Mo-0.25V is difficult to machine materials, the large cutting force and high cutting temperature in the turning process, the tool is prone to bonding breakage [1-2]. Chen Yaonan *etc.*, of the Harbin University of Science and Technology studied the force density function of the milling tool surface [3-6]. Wang ling *etc.*, through measuring the cutting force component size of the working parts online, comparing and analyzing, she finds that the feed, cutting depth and the interaction between them have a great influence on the cutting force, then speculates that the tool damage is very serious when the interaction between the feed and cutting depth too [7-8]. Zhao Jianbo *etc.*, studied the intercalation milling force of the titanium alloy materials, gained that there was a direct relationship between tool breakage and the stress distribution by analyzing [9-11]. Liang Yingchun, Bai Qingshun study the micro milling cutter relationship between milling force and the wear and study the influences of cutting parameter on the milling force [12-15].

The situation of blade force is complex in the turning process, the size and direction of the force will change with the cutting conditions, the failure of the tool include impact damage and adhesion failure when cut tube section material 2.25Cr-1Mo-0.25V. Therefore, using the finite element simulation software to simulate the stress field of the tool and to analyze the stress distribution of the tool to seek tool groove and geometric parameters which can reduce tool breakage, simulation can reduce the cost by the test consumed, it has great significance for the study of mechanism of tool breakage.

In this paper, we use H-shaped groove carbide cutting tools to do the experiments of turning high strength steel 2.25Cr-1Mo-0.25V, study the force density function and force distribution on the H-type turning inserts’ surface, and use the created force density function to simulate stress field and to further reveal the heat distribution on the rake face of tool.

2. Experimental Process

2.1. Experimental Materials

In the cutting experiment process, select hard materials of high strength steel 2.25Cr-1Mo-0.25V for the workpiece material, the specific chemical composition [16] are shown in the table1.

Table 1. Chemical Constituents of 2.25Cr-1Mo-0.25V Steel

element	C	Si	Mn	P	S	Cr
rated value	0.10~0.17	≤0.10	0.27~0.63	≤0.01	≤0.01	1.95~2.60
product analysis	0.10~0.16	0.03~0.10	0.51~0.56	0.003~0.005	0.001~0.004	2.29~2.50
element	Ni	Mo	V	Nb	Cu	Ti
rated value	≤0.25	0.85~1.15	0.25~0.35	≤0.07	≤0.20	≤0.30
product analysis	0.11~0.18	0.93~1.10	0.26~0.31	0.045~0.056	0.05~0.08	0.01~0.03

Experiments are using the indexable turning tool, choose carbide insert: YT15; tool rake angle γ=20°, relief angle α=0°, tool cutting edge angle k_r=45°. Cutter groove shape and size as shown in Figure 1:

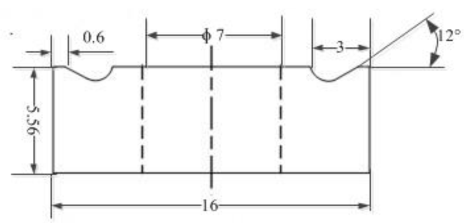

Figure 1. Dimensioning Diagram of Cutting Tool

Use the orthogonal experiment of three factors and three levels, cutting parameters are shown in the Table 2:

Table 2. Cutting Parameter of Experiment in Cutting 2.25Cr-1Mo-0.25V

factors / level	cutting speed v(m/min)	Cutting depth a_p(mm)	feed f(mm/r)
1	160	1.0	0.10
2	160	2.0	0.15
3	160	2.5	0.20

Experiment machine is CK6163A CNC lathe, Using Kistler9257B dynamometer, charge amplifier, combined with the measured cutting force data acquisition card, record F_x, F_y, F_z, three directions of the cutting force component signal, Experimental apparatus as shown in Figure 2.

Figure 2. Processing Equipment and Measuring Device

With the dynamometer collected cutting force value of the waveform as shown in Figure 3:

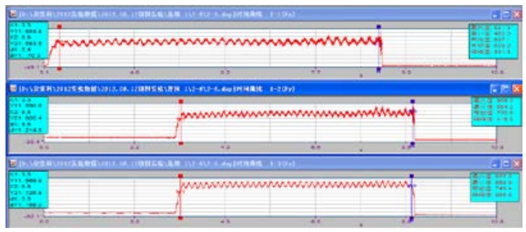

Figure 3. Variation of Cutting Force in Cutting Region

2.2. Establish Empirical Formula of the Tool-chip Contact

Before researching the force density function of the turning blade rake face, you must determine the tool-chip contact length and tool-chip contact width of the tool rake face. Before the experiment, paint the tools. The Figure 4 is the tools of before coating, coated and after cutting.

Measuring the contact length and width of tool-chip on the tool rake face after cutting, as shown in Figure 5:

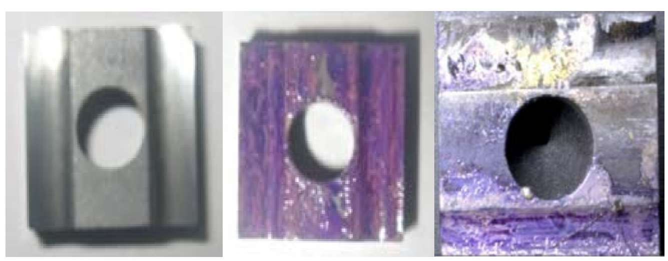

Figure 4. Tools of Before Coating, Coated and After Cutting

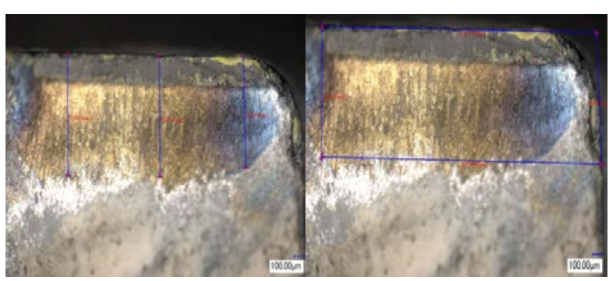

Figure 5. Tool-chip Contact Length and Tool-chip Contact Width

According to the data from the experiments obtained, analyzed and fitted the data of the feed, cutting depth and the tool-chip contact length, tool-chip contact width.

Table 3. Value of Tool-chip Contact Length and Width

No.	Tool-chip contact length l_f	Feed f	Tool-chip contact width l_{ap}	Cutting depth a_p
1	0.73 mm	0.10 mm/r	1.42 mm	1.0 mm/r
2	1.35 mm	0.15 mm/r	2.93 mm	2.0 mm/r
3	1.97 mm	0.20 mm/r	3.74 mm	2.5 mm/r

The fitting results are:

$$\begin{cases} f = 0.08 l_f + 0.04 \\ a_p = 0.65 l_{ap} + 0.08 \end{cases} \quad (1)$$

3. Establishing Force Function on the H-slot Blade Rake Face

3.1. Establish Empirical Model of Cutting Force

Different cutting parameters will result in different values of cutting force by using mathematical calculation methods of statistical regression for cutting force's data processing. Then, confirm the relationship between cutting force and the cutting conditions. Since the most direct and the most significant factor of cutting force are the feed and cutting depth, so, in the empirical formula, only apparently number the two conditions of cutting depth and feed, and the regression coefficient is numbered in the cutting force empirical formula instead of the other cutting conditions, use the following form:

$$\begin{cases} F_x = C_x a_p^{a_x} f^{b_x} \\ F_y = C_y a_p^{a_y} f^{b_y} \\ F_z = C_z a_p^{a_z} f^{b_z} \end{cases} \quad (2)$$

The common equation of cutting force and cutting parameters is:

$$F_i = C_i a_p^{a_i} f^{b_i} \quad (3)$$

According to orthogonal experimental data, establish the multiple linear regression equation:

$$\begin{cases} y_{i1} = x_i + D_1 a_i + E_1 b_i \\ y_{i2} = x_i + D_2 a_i + E_2 b_i \\ \cdots\cdots\cdots\cdots \\ y_{i9} = x_i + D_9 a_i + E_9 b_i \end{cases} \quad (4)$$

Using the method of linear fitting to establish the cutting force empirical formula, take advantage of Matlab software to program procedures for solving regression coefficients, so work out the various coefficient, the index and coefficients of the cutting force empirical formula are shown in the Table 4.

Table 4. Index and Coefficient's Value of Cutting Force's Empirical Function

factors	C_i	a_i	b_i
F_x	547.01	0.92	0.40
F_y	1284.98	0.95	0.65
F_z	1011.58	0.93	0.45

The obtained cutting force empirical formula is as follows:

$$\begin{cases} F_x = 547.01 a_p^{0.92} f^{0.40} \\ F_y = 1284.98 a_p^{0.95} f^{0.65} \\ F_z = 1011.58 a_p^{0.93} f^{0.45} \end{cases} \tag{5}$$

3.2. Establishing Density Function of Cutting Force

Simultaneous the relationship between the tool-chip contact area and cutting parameters and the empirical formula of dynamic cutting force in cutting process, we can get the suffered distribution of the cutting force:

Bring (1) into equation (5), obtained the following formula:

$$\begin{cases} F_x = 547.01(0.65 l_{ap} + 0.08)^{0.92} (0.08 l_f + 0.04)^{0.40} \\ F_y = 1284.98(0.65 l_{ap} + 0.08)^{0.95} (0.08 l_f + 0.04)^{0.65} \\ F_z = 1011.58(0.65 l_{ap} + 0.08)^{0.93} (0.08 l_f + 0.04)^{0.45} \end{cases} \tag{6}$$

To seek the partial derivative for the parameters of the tool-chip contact area in the upper type, that is seeking the partial derivative of tool-chip contact width l_{ap} and tool-chip contact length l_f.

$$\begin{cases} f_x = \dfrac{\partial F}{\partial l_f \partial l_{ap}} = 10.49(0.65 l_{ap} + 0.08)^{-0.08} (0.08 l_f + 0.04)^{-0.60} \\ f_y = \dfrac{\partial F}{\partial l_f \partial l_{ap}} = 41.21(0.65 l_{ap} + 0.08)^{-0.05} (0.08 l_f + 0.04)^{-0.35} \\ f_z = \dfrac{\partial F}{\partial l_f \partial l_{ap}} = 24.10(0.65 l_{ap} + 0.08)^{-0.07} (0.08 l_f + 0.04)^{-0.55} \end{cases} \tag{7}$$

The upper type is the force density function on the tool surface of the YT15.

According to the former analysis, we can know that the force condition of the cutting rake face is only connected with tool material itself, under the effect of tool-chip, the tool will change with the cutting parameters' changing, but no qualitative changed, so the force density function of the tool can be used to analyze the stress distribution of tool on the rake face in the continuous process, if there are the same cutting tool materials and workpiece materials, but other cutting parameters are different.

3.3. Mapping and Visualization of Force Density Function and Analysis of Stress State

After getting the stress density function of the tool surface, to further discuss its distribution, first of all, we need to use charts to represent the force density function, and use Matlab to make the mathematical analysis, and make the visual simulation of the surface force density function, so that we can get the distribution model of the stress density function on the surface of H carbide tool, as shown in Figure 6.

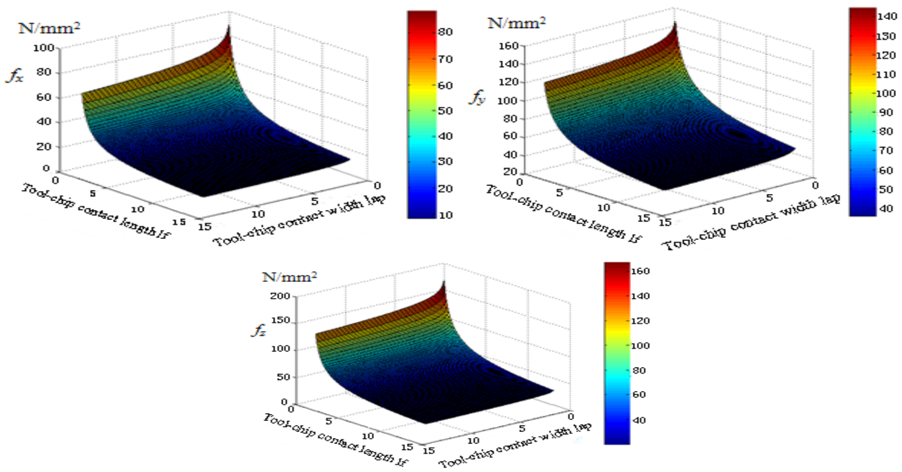

Figure 6. Visual Map of Cutting Force Density Function

From the visual express of the stress density function, we can find that: density function is concentrated in the vicinity of the tool nose region, namely, the cutting force is relatively concentrated in the area near the tool nose, and the closer from the tool nose position, the greater value of the density function, the steeper trend. We can also find that, the density function values of three cutting component in the direction of the tool-chip contact width are larger than in the direction of the tool-chip contact length, that is to say the values in the direction of the main cutting edge are larger than in the direction of the minor cutting edge.

Figure 7 also shows that the value of main cutting force F_z density function at the tool nose and closely the main cutting edge area are greater than the value of F_x and F_y, it indicates that the H-slot carbide tool's main cutting force mainly influence on the tool tip and the main cutting edge in the cutting processing. Taken together, the cutting force of the H-type carbide cutting tools distribute on the rake face in the cutting process, mainly concentrated in the tool nose area and the direction of main cutting edge.

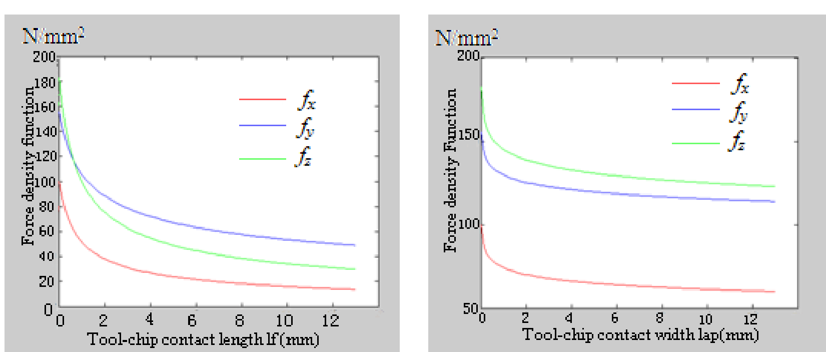

Figure 7. Function Chart for f_x、f_y、f_z Density Function

4. The Simulation Analysis of Tool Stress Field

Simulating the stress field of the tool by using the finite element simulation software ANSYS Workbench 12.0. The step of simulating stress field is: solid modeling→define material properties→ meshing of solid modeling→ given the constraints imposed→ load→ solving.

Based on the analysis steps above, simulate the tool stress field, the steps are as follow: use the UG modeling software to solid model the tool, the model shown as Figure 8, import the model into the ANSYS Workbench 12.0, mesh the tool entity, the result of the network is shown in Figure 8.

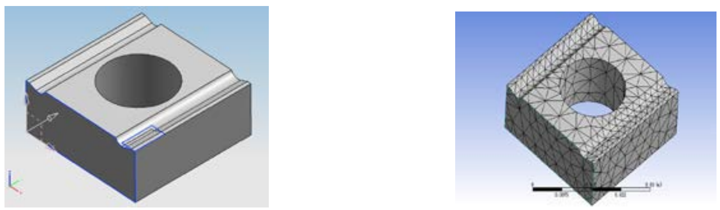

Figure 8. Chart, Meshing of Cutting Tool Model

Three sides of the turning blade are contact with the shank tool-slot, namely the three surface A, B, C are equivalent to fixed, the constraints are Fixed Support as shown in Figure 9.

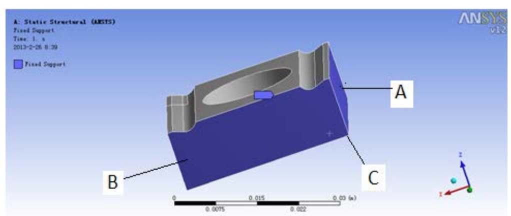

Figure 9. Apply Fixed Constraint

According to the obtained force density function of the tool rake face previously, select Pressure load, as shown in Figures 10 and 11:

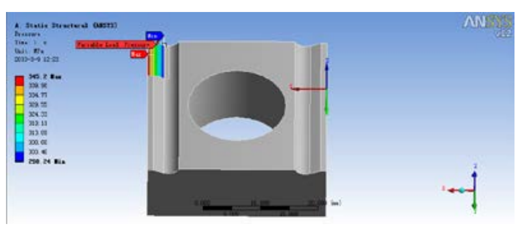

Figure 10. Apply Load on Contact Length of Tool-chip

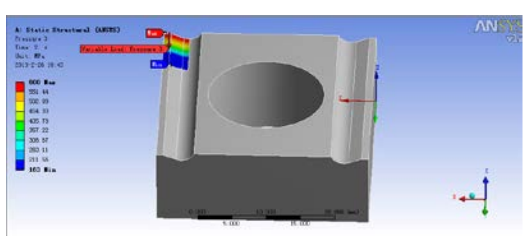

Figure 11. Apply Load on Contact Width of Tool-chip

Stress Analysis of simulation is as shown in Figure 12, and then solve, select Solve, you can get the equivalent stress field of the tool:

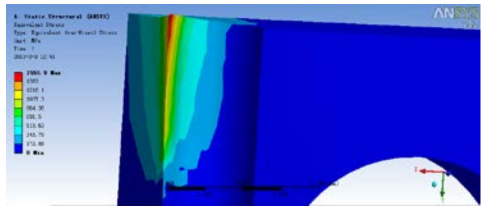

Figure 12. Simulation Result of Stress Field

From the finite element simulation equivalent stress field results, it is evident that H-type turning insert cut the high strength steel 2.25Cr-1Mo-0.25V material, the stress of the tool rake face is concentrated on the tool nose and the main cutting edge, it is in accordance with the formmer force density function analysis results. Verify the accuracy of the results theoretical analysis.

5. Conclusions

1) Based on cutting force experimental data of the high-strength steel of the 2.25Cr-1Mo-0.25V to establish the cutting force empirical formula, based on the experimental results of tool-chip contact area to establish empirical formula of the tool-chip contact area, based on the empirical formula of cutting force and tool–chip the contact area to build tool rake face force density function.

2) Analyze force density function on the cutting surface, use Matlab software to visualize the force density function graphics to reveal the distribution of cutting force on the rake face of carbide cutting tools: the cutting force distribute on the rake face, the stress is mainly concentrated in the direction of the cutting edge region along the main cutting edge.

3) Make force density function of the tool rake face as the boundary conditions of stress field simulation, simulate the equivalent stress field of the cutting, simulation results are in accordance with the theory analysis of the force density function, that is to say when cutting high-strength steel 2.25Cr-1Mo-0.25V, the stress on the H-slot carbide cutting tools mainly concentrated with the tool nose and the main cutting edge, verify the accuracy of theoretical analysis results.

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