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Carbide Twist Drill Spiral Groove Abrasive Flow Polishing and Abrasive Flow Analysis

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In this paper, the abrasive flow polishing experiment for the spiral groove of twist drill as well as the flow simulation was carried out. CFD analysis was carried out for the abrasive flow in the spiral groove during the polishing of a twist drill by abrasive grain flow using FLUENT software. In order to obtain the state parameters of dynamic pressure and abrasive velocity in the flow channel, and to analyze their effects on the flow of abrasive and polishing result in the spiral groove, the CFD simulation calculations were carried out with different inlet velocities and abrasive grain concentrations respectively. The analysis results show that the dynamic pressure in the spiral groove of the twist drill increases with an increase in inlet speed, the pressure decreases as the abrasive flows along the spiral surface. Under the condition of different abrasive concentration, the velocity of abrasive decreases gradually with the increase of abrasive concentration. Under the same abrasive concentration condition, the abrasive velocity decreases gradually from inlet to outlet. For actual polishing, 50-60% abrasive concentration was suggested. In this research, the parameters of polishing process were set based on the simulation analysis results, experiment was designed adopting orthogonal test method the test data were analyzed using polar analysis method. Results showed that the priority order of the influencing factors of spiral groove polishing was: abrasive type > inlet flow velocity > polishing time. In addition, the inlet velocity of SiC abrasive was set to 0.5 m.s^{-1}, and polishing for 30 min. After polishing under these parameters, the surface roughness of cemented carbide twists drill spiral groove is the smallest, only Ra 0.189 μm, which is far less than the design requirements.

Keywords: Twist Drill, Spiral Groove, CFD Analysis, Abrasive Flow Polishing

1 Introduction

The twist drill is used for hole machining and is the most widely used tool in machining, as well as the most consumed [1]. The twist drill spiral groove play a role chip removal and heat dissipation during drilling. By reducing the surface roughness of the spiral groove, the drill chips can be better discharged and heat dissipated, improving the cutting performance of the twist drill bit [2]. At present, twist drills mostly use grinding machines, dedicated CNC abrasive belt polishing machines and multi-axis CNC machine tools to grind the spiral groove, which has problems such as long machining time, low efficiency and expensive equipment [3].

For the polishing of spiral grooves or spiral curved surfaces, domestic and foreign scholars have related research [4], for example, Yu et al. [5] conducted polishing research on the spiral grooves of superplastic aluminium alloy groove barrels, and proposed an active profiling mechanical polishing method combined with the polishing process characteristics of spiral groove barrels. Wan et al. [6] examines a simple, zero-order semi-mechanistic approach towards the analysis of the two way flow abrasive flow machining process. A wall slip model, as a function of wall shear-rate, to calculate the relative motion between the media and the confining wall. Uhlmann et al. [7] examines a CFD approach to the flow simulation by integrating the non-Newtonian, shear-thinning characteristics of a Maxwell fluid into the inelastic Navier-Stokesl equations. The simulation data is compared to experimental machining results. With the use of calculated flow characteristics and machined workpieces, material removal mechanisms are investigated. Wei et al. [8] took spiral gears as the research object and used the solid-liquid two-phase abrasive flow method to polish their surfaces, providing technical support for the development of polishing technology for spiral curved surfaces. Jain et al. [9] developed a finite element model of forces acting on a single grain has been developed. Results obtained from finite element analysis for material removal have been compared with the experimental data obtained during AFM and found to have the same trend but quantitatively there are deviations between the two.

It is difficult to implement uniformity and controllability for material removal in AFM, which makes material removal and its distribution along media flow direction significantly important. Flow field simulation of abrasive media in a constrained passage in abrasive flow machining (AFM) plays a decisive role in optimising process parameters [10-11]. This paper takes a carbide twist drill with a diameter of ø8mm as the research object, and a unidirectional polishing jig is designed. The solid-liquid two-phase flow model was used to simulate and analyse the spiral groove surface of the abrasive flow polishing carbide twist drill, and then the optimum combination of process parameters for abrasive flow polishing the spiral groove surface of the carbide twist drill is obtained through experiments.

2 Abrasive flow polishing fixture

The principle of the twist drill spiral groove abrasive flow polishing fixture is shown in Figure 1. The twist drill bit to be polished is mounted in a special fixture with "horn" shaped drainage openings at both ends of the holder, facilitated the inflow of the abrasive stream, which flows through the holder and over the surface of the spiral groove to be machined and polishes the surface of the spiral groove through the micro-cutting action of the abrasives.

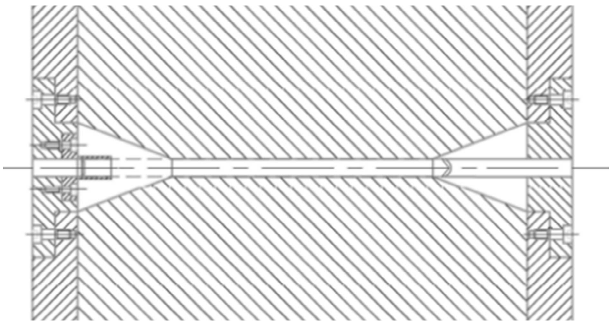


Fig. 1 *Schematic diagram of the twist drill spiral groove abrasive flow polishing fixture*

3 Analysis of abrasive flow in twist drill spiral grooves

ANSYS Fluent was used to analyze the abrasive flow in the spiral groove of a carbide spiral drill polished by abrasive flow to investigate the effect of machining parameters on the spiral groove of a spiral drill polished by abrasive flow [12-13]. To study the motion law of the flow field in the spiral groove of twist drill and to provide theoretical support for the abrasive flow polishing test.

Abrasive flow simulation analysis is carried out using a coupled pressure-velocity solution method, the classical SIMPLEC algorithm [14-15]. Momentum, volume fraction, turbulent kinetic energy and turbulent dissipation rate are chosen in one order upwind. The fluid model is a multiphase flow model and the flow is treated as a pseudoplastic fluid [16].

When polishing carbide twist drill spiral grooves, the abrasive used for the machining is formulated in a certain ratio of oil and abrasive etc., such as SiC, SDC etc. In the simulation the abrasive are set in the solid phase and the liquid phase is aviation hydraulic oil [17].

After setting the initial conditions according to the structural characteristics of the twist drill spiral groove workpiece and the actual machining process, the simulation analysis was started and obtain the distribution of the dynamic pressure and velocity etc. concerning the abrasive flow. For ease of description, the entire spiral groove flow path from inlet to outlet is divided into 3 homogeneous region as shown in Figure 2.

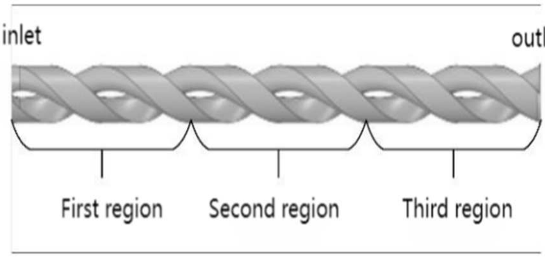


Fig. 2 *Map of twist drill spiral groove runner area division*

3.1 Dynamic pressure at different inlet speeds

The greater the dynamic pressure, the more intense the disturbance of the abrasive, the stronger their grinding and scraping effect on the wall surface, and the better the polishing effect may be [18]. The analysis shows that the dynamic pressure in the spiral groove of the twist drill increases with the entrance speed and becomes progressively smaller as the abrasive flows along the spiral surface. Therefore, increasing the inlet speed improves the polishing effect and the polishing effect in the inlet region is better than in the outlet region.

3.2 Numerical simulation of abrasive concentration on the polishing machining of twist drill spiral grooves

Tang et al. [19] studied the wall effects of abrasive flow machining, used Preston's equation to describe material removal in abrasive flow machining, and analyzed the processes of the formation of velocity and shear in the flow field at the inlet.

In this paper, the distribution of pressure and velocity is analyzed to reflect the amount of material removal in the abrasive flow.

Preston's equation is used to describe the amount of material removed from the surface of the workpiece:

$$\Delta z = \int_0^t k_p v p dt, \quad (1)$$

Where:
Δz…The volume removed,
k…The Preston coefficient,
v…The velocity of the fluid,
p…The pressure of the fluid.

The relationship between shear force and shear rate in abrasive flow processing is described using a non-Newtonian fluid:

$$\tau = \eta \gamma^n, \quad (2)$$

Where:
τ…The shear force,
η…The viscosity,
n…The flow index ($0<n<1$), and is the shear rate.

The shear rate is defined as:

$$\gamma = dv/dr, \quad (3)$$

Where:
dv/dr…For the velocity gradient,
r…For the velocity gradient of any section of the cylinder radius.

The coupling equation (2), (3) gives the relationship between velocity and shear:

$$v = \frac{r}{\eta^{\frac{1}{n}}} \tau^{\frac{1}{n}} + C_1, \quad (4)$$

The equation for the amount of material removed versus the shear force can be obtained by collating associative equations (1) and (4):

$$\Delta z = k_p \int_0^t \left(\frac{r}{\eta^{\frac{1}{n}}} \tau^{\frac{1}{n}} + C_1 \right) p dt, \quad (5)$$

Where:
C_1…Constant.

From equations (4), (5), it can be seen that the shear force is directly related to the velocity, and the amount of material removed is directly related to the pressure and shear force of the flow field, and the inlet velocity is set at a constant value to correspond to the size of the cutting volume with the distribution of pressure and velocity.

The abrasive concentration of the abrasive in the abrasive stream has a greater impact on polishing. The abrasive concentration is too small, the grinding effect of the abrasive on the wall surface is not obvious when polishing, and the polishing effect is not obvious [20]. The concentration of abrasives increases, the cutting effect of abrasives on the wall can be made more even, thus improving the uniformity of polishing, but if the concentration of abrasives is too large, the flow of abrasive will become poor, which will easily lead to the accumulation of abrasives in the flow channel, not only the polishing effect is not good, but also may lead to the damage of the workpiece surface.

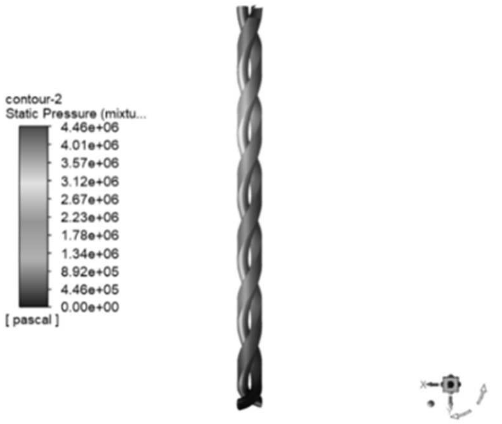
The grain size of the abrasive was set to 200 grit (0.074mm), the inlet velocity was set to 0.3m/s and the abrasive concentration was 20%, 30%, 40%, 50%, 60% and 70%.

Setting different abrasive particle concentration parameters, numerical simulation analysis, obtained different abrasive particle concentration twist drill spiral groove static pressure numerical cloud diagram shown in Figure 3.

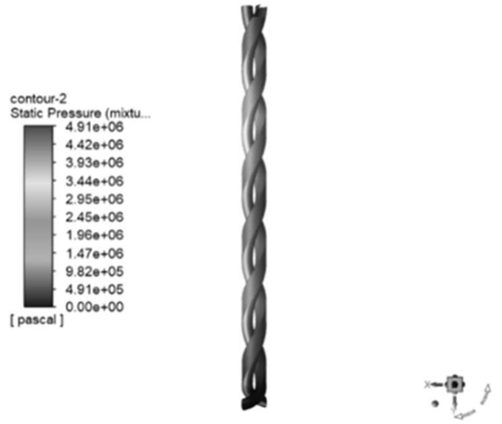
As shown in Figure 3, it can be seen that under the condition of the same abrasive grain concentration, the static pressure at the entrance of the twist drill spiral groove runner is the largest, and as the abrasive grains continue to flow with the runner to the exit, the static pressure continuously decreases. Under the condition of different abrasive grain concentration, as the abrasive grain concentration increases, the static pressure value will gradually increase in each stage and each region, which is due to the increase of abrasive grain concentration, the abrasive grain itself will increase with the energy, the number of abrasive grains will also increase, which also makes the abrasive grains on the wall of the cutting action will also be strengthened, so appropriate increase in the concentration of abrasive particles will help to improve the quality of polishing [21]. However, the concentration of abrasive grain is not the greater the better, too large will affect the polishing effect. In order to better analyze the different regions of the abrasive flow polishing effect, more intuitive to see the static pressure of the numerical changes in the first region, the second region, the third region of the numerical analysis, the different regions of the fluid static pressure value distribution as shown in Table 1.

Tab. 1 *Static pressure distribution on the surface area of twist drill spiral groove under different abrasive concentration conditions*

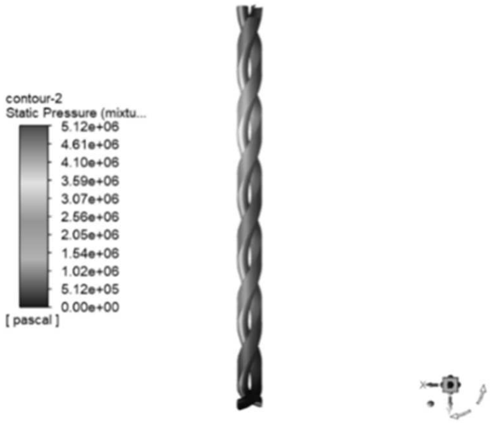
Abrasive concentration (%)	**Static pressure(10^6Pa)**		
	Region I	**Region II**	**Region III**
20	3.60	2.24	0.89
30	3.94	2.46	0.98
40	4.15	2.59	1.03
50	4.25	2.66	1.05
60	4.41	2.71	1.09
70	4.57	2.82	1.13



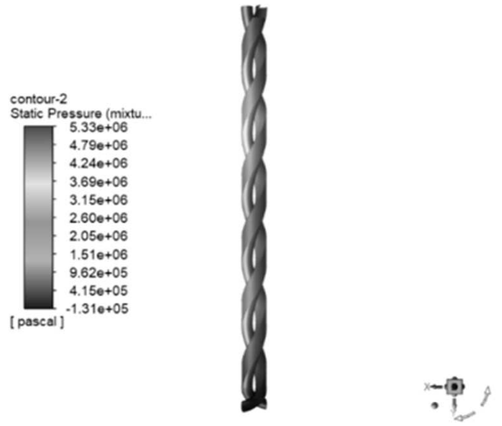
a) Static pressure cloud at 20% abrasive grain concentration



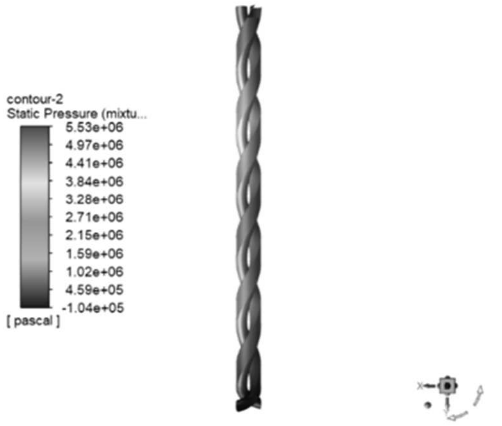
b) Static pressure cloud at 30% abrasive grain concentration



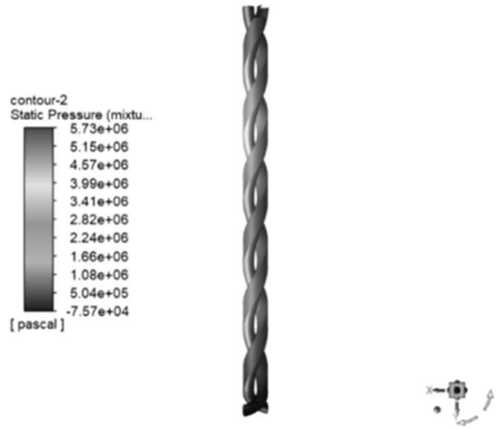
c) Static pressure cloud at 40% abrasive grain concentration



d) Static pressure cloud at 50% abrasive grain concentration



e) Static pressure cloud at 60% abrasive grain concentration

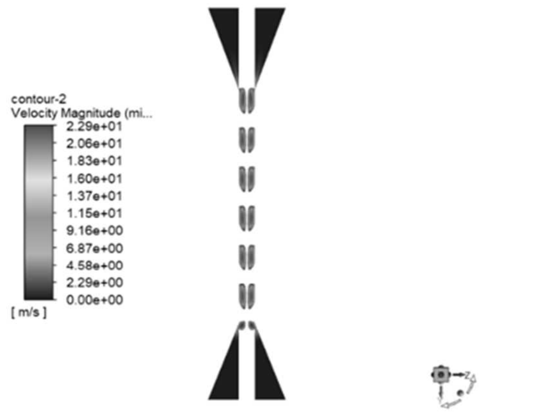


f) Static pressure cloud at 70% abrasive grain concentration

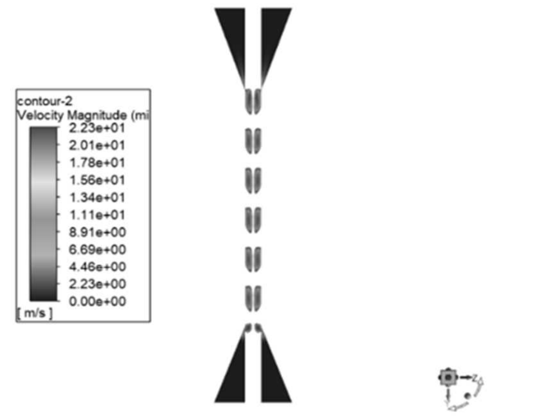
***Fig. 3** Numerical clouds of the static pressure of the twist drill spiral groove at different abrasive concentrations*

As shown in Table 1, under the condition of the same abrasive grain concentration, the static pressure value shows a decreasing trend in the three regions in turn. The more intensive the abrasive grain movement, the better the scraping effect on the wall surface and the better the polishing effect, so the polishing effect in the first region is better than that in the other two regions, and as the region progresses, the polishing effect becomes worse. Under the condition of different abrasive grain concentration, as the abrasive grain concentration increases, the pressure value in the three regions also increases, so the polishing effect also becomes better.

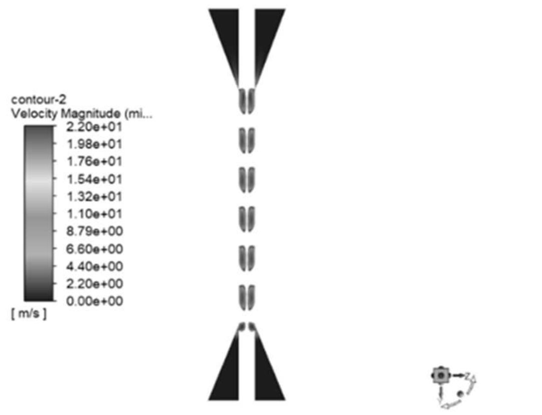
And the velocity clouds at different abrasive concentrations were analyzed as shown in Figure 4.



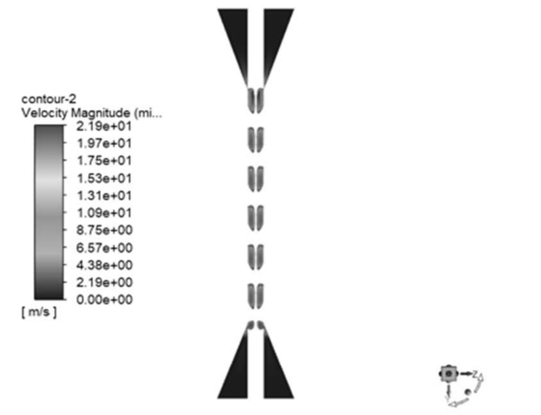
a) Velocity cloud at 20% abrasive concentration



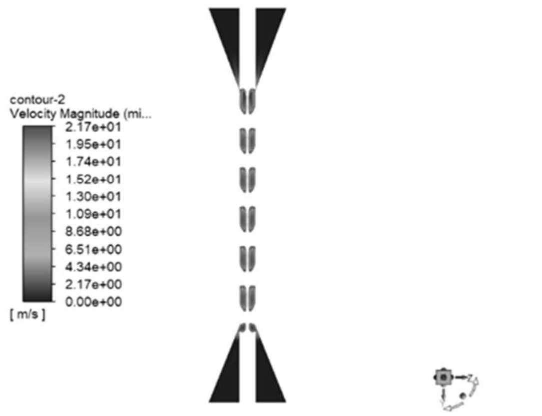
b) Velocity cloud at 30% abrasive concentration



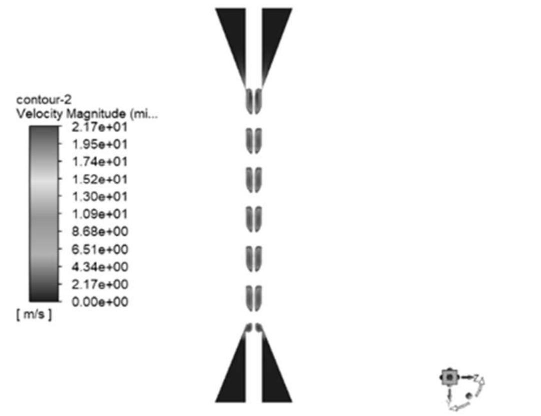
c) Velocity cloud at 40% abrasive concentration



d) Velocity cloud at 50% abrasive concentration



e) Velocity cloud at 60% abrasive concentration



f) Velocity cloud at 70% abrasive concentration

Fig. 4 *Numerical cloud of twist drill chip discharge groove speed at different abrasive particle concentrations*

As can be seen from Figure 4, under the condition of different abrasive grain concentration, the flow rate of the abrasive gradually decreases with the increase of the concentration of the abrasive. The increase in the concentration of abrasive grains leads to a weakening of the fluidity of the abrasive material and a decrease in the activity of the abrasive grains, and therefore leads to a weakening of the cutting effect of the abrasive grains on the wall surface, which in turn will lead to a deterioration of the polishing effect on the wall surface.

Under the same conditions of abrasive concentration, the change in velocity is not obvious when the abrasive is at the entrance of the runner, and the velocity suddenly becomes larger when it just enters the twist drill spiral groove spiral-shaped runner. This is because the shape of the runner suddenly changes, resulting in a sudden increase in the velocity of the abrasive as well. The speed in the spiral groove runner is much greater in the area near the centre than in the area near the wall. This is because when abrasive enters the spiral groove flow channel of twist drill, the abrasive and the wall surface are cut and rubbed, which makes the abrasive speed near the wall area of the centre area of low speed, because the shape of the flow channel is spiral shape, as the abrasive penetrates deeper, the speed of the wall surface area of twist drill will not change much,but the speed of the centre area will gradually reduce. Therefore, as the abrasive penetrates deeper, the polishing effect diminishes in the three areas, with the best polishing effect in the first area, followed by the second area and the worst in the third area.

Take the middle of each region and do the radial analysis and make the highest value, lowest value and velocity difference analysis for each section as shown in Table 2.

***Tab. 2** Velocity maximum and velocity difference for each region*

Abrasive concentration (%)	Velocity (m/s)								
	Region I		Region II		Region III		Region I	Region II	Region III
	Max	Min	Max	Min	Max	Min	Speed differential		
20	22.91	0.62	20.95	0.89	20.84	0.95	22.29	20.06	19.89
30	22.31	0.63	20.70	0.92	20.62	0.98	21.68	19.75	19.64
40	22.05	0.65	20.41	0.96	20.31	1.02	21.40	19.45	19.29
50	21.93	0.68	20.04	1.00	20.02	1.05	21.25	19.04	18.97
60	21.76	0.72	19.75	1.05	19.60	1.09	21.04	18.70	18.51
70	21.75	0.72	19.74	1.06	19.59	1.10	21.03	18.68	18.49

From the speed extremes and speed difference values shown in Table 2, it can be seen that under the same concentration condition, the abrasive speed from the first region to the third region highest speed difference gradually decreases, the lowest speed difference gradually increases, the speed difference value gradually decreases along the three regions, so the cutting effect of abrasives on the wall surface gradually becomes weaker and the polishing effect gradually weakens; under different concentration conditions, with the increase of abrasive concentration, the speed of abrasive in each region decreases with the increase of abrasive concentration, the lowest speed difference increases with the increase of concentration, the speed difference value in the three regions decreases with the increase of abrasive concentration.

According to Figure 4 and Table 2, the amount of variation in polishing speed in each region when the concentration reaches 70% is very small compared to a concentration of 60%, therefore, in practice the selection range of abrasive concentration can be chosen between 50% and 60%.

4 Experimental study on the polishing of carbide twist drill spiral grooves by abrasive flow

Set up the process parameters of the abrasive flow machine based on the simulation analysis results. Different process parameters are used to polish the spiral groove of the carbide twist drill. The influence of the type of abrasive, the inlet speed and the polishing time on the polishing quality of the abrasive flow is analyzed, finally the surface roughness of the spiral groove is used as the evaluation standard and the obtained data were analyzed in terms of extreme deviation to find the optimal parameters of the abrasive flow polishing machining.

Commonly used abrasive grain sizes from coarse to fine are 48 grit, 60 grit, 80 grit, 115 grit, 150 grit, 200 grit and until to 2500 (W5) grit, with 60 to 1250 grit being more commonly used. The two abrasives used in the tests were 200 grit SiC and SDC abrasives. The workpiece was a Ø8mm carbide twist drill, the drill and machine tool fixture are shown in Figure 5.

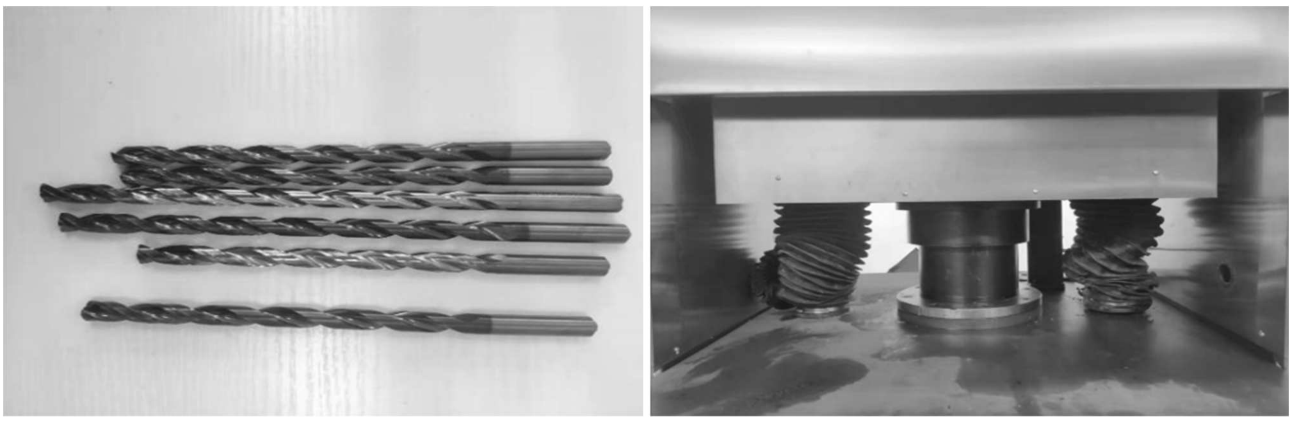


***Fig. 5** Carbide twist drills and machine tool fixtures*

4.1 Orthogonal test parameter setting

Overall consideration three machining factors of abrasive type, polishing time and entrance speed were taken into account and three levels of each machining factor were selected for testing. The results are shown in Table 3.

Tab. 3 *Table of orthogonal experimental factors*

Level	Factors		
	Types of abrasives (Factor 1)	Polishing time (min) (Factor 2)	Inlet velocity (m/s) (Factor 3)
1	SiC abrasives	10	0.1
2	SDC Diamond Abrasives	20	0.3
3		30	0.5

The orthogonal test method was used for the experimental design. A 3-factor, 3-level test was used in this trial, as one factor had only two levels, so the pseudo-level method was used for that factor. The experiment was conducted using two orthogonal tests with two levels proposed [22], and the orthogonal test table was chosen to be used $L_9(3^3)$.

4.2 Analysis of test results

The use of polar difference analysis enables an intuitive analysis of the test results [23]. The extreme difference R indicates the fluctuation between the levels of each factor. If the number of extreme values of a factor is larger, it means that the change in the level of that factor has a greater impact on the test results, therefore, according to the size of the value of the extreme difference R, the priority of the test factors on the test results can be judged.

4.3 Analysis of test results of SiC abrasive taken at the pseudo-level

The roughness measurement of the surface of the spiral groove of the carbide twist drill after the test, the test results are shown in Table 4, the pseudo-level to take the SiC abrasive test data polar analysis table. The factor corresponding to the maximum value of the polar deviation is the factor that has the greatest influence on the roughness, i.e. the main factor of this test.

Tab. 4 *Analysis of twist drill spiral groove grinding grain flow polishing results table*

Test number		Factor level			Surface roughness Ra (μm)
		j=1 (abrasive grain types)	j=2 (Inlet speed m/s)	j=3 (Polishing time)	
1		SiC	0.1	10	0.556
2		SiC	0.3	30	0.371
3		SiC	0.5	20	0.262
4		SDC	0.1	30	0.533
5		SDC	0.3	20	0.458
6		SDC	0.5	10	0.336
7		SiC	0.1	20	0.499
8		SiC	0.3	10	0.446
9		SiC	0.5	30	0.189
K_{jn}	Kj1	2.323	1.588	1.338	
	Kj2	1.327	1.275	1.219	
	Kj3	0	0.787	1.093	
k_{jn}	kj1	0.387	0.529	0.446	
	kj2	0.442	0.425	0.406	
	kj3	0	0.262	0.364	
Extremely poor R		0.442	0.267	0.082	
Order of priority of factors		abrasive grain type > Inlet speed > Polishing time			
Optimal parameters		abrasive grain type SiC, inlet speed 0.5m/s, polishing time 30min			

In tests with SiC as the pseudo-level of abrasive flow polishing carbide twist drills, the degree of influence of each factor on the polishing effect was in the following order: abrasive type > inlet speed > polishing time. This shows that the type of abrasive is the most influential factor on the surface quality of the polished spiral groove for polishing carbide twist drills with abrasive flow. In this test, when analyzing the values of the surface roughness of the spiral groove after grinding with two abrasives, the choice of SiC abrasive gave a better result; when considering the factor of inlet speed, it can be found that its influence on the polishing effect is also very obvious; the polishing time has the least influence on the polishing effect in this test, which means that after the polishing reaches a certain time, then increasing the polishing time has little significance on the improvement of the polishing effect.

In order to achieve a better polishing effect, the best combination of process parameters was chosen: abrasive type SiC, inlet speed 0.5 m/s, polishing time 30 min, with the above combination of parameters for machining tests to obtain a surface roughness value of Ra = 0.189 μm.

4.4 Analysis of the results of the pseudo-level take SDC abrasive test

The pseudo-level to take the SDC, and the roughness of the surface of the spiral groove of the carbide twist drill after the test is measured, and the test results are shown in Table 5. Similar to the test results of the pseudo-level to take the SiC, the degree of influence of each factor on the surface roughness Ra was: abrasive type > entrance speed > machining and polishing time. Abrasive grain type had the greatest effect on the surface roughness of the tool, followed by the entrance speed, and the least effect was the polishing time [24]. The type of abrasive grains gives the lowest value of roughness Ra at the first level, the entrance speed gives the lowest value of roughness Ra at the third level and the polishing time gives the lowest value of roughness Ra at the third level.

The surface roughness decreases rapidly with the increase of inlet speed and reaches a minimum value of 0.309 μm at the third level; As the polishing time increases with the factor level, the surface roughness value decreases from the first level to the third level, and reaches a minimum value of 0.411 μm at the third level; the abrasive grain type increases with the factor level, the surface roughness value increases from the first level to the second level, and reaches a minimum value of 0.396 μm at the first level; therefore, the optimal combination of the process parameters is chosen as follows: abrasive grain type, SiC, inlet speed 0.5 m/s, polishing time 30 min. SiC, inlet speed 0.5m/s, polishing time 30min. the surface roughness value obtained by processing test with the optimal combination of parameters is Ra=0.262μm, which is smaller than the results obtained by other combinations of process parameters.

Tab. 5 *Analysis of twist drill spiral groove grinding grain flow polishing results table*

Test number		Factor level j=1 (abrasive grain types)	j=2 (Inlet speed m/s)	j=3 (Polishing time)	Surface roughness Ra (μm)
1		SiC	0.1	10	0.556
2		SiC	0.3	30	0.371
3		SiC	0.5	20	0.262
4		SDC	0.1	30	0.533
5		SDC	0.3	20	0.458
6		SDC	0.5	10	0.336
7		SDC	0.1	20	0.549
8		SDC	0.3	10	0.478
9		SDC	0.5	30	0.330
K_{jn}	Kj1	1.189	1.638	1.370	
	Kj2	2.667	1.307	1.269	
	Kj3	0	0.928	1.234	
k_{jn}	kj1	0.396	0.546	0.457	
	kj2	0.445	0.436	0.423	
	kj3	0	0.309	0.411	
Extremely poor R		0.445	0.237	0.046	
Order of priority of factors		abrasive grain type > Inlet speed > Polishing time			
Optimal parameters		abrasive grain type SiC, inlet speed 0.5m/s, polishing time 30min			

In summary, by analyzing the test results in Tables 4 and 5, it can be seen that the priority order of the three test factors on the abrasive flow polishing of the twist drill spiral groove is: abrasive type > inlet speed > polishing time, the best combination of parameters is SiC abrasive, inlet speed 0.5m/s, polishing time 30min, the surface roughness of the carbide twist drill spiral groove obtained by abrasive flow polishing under this combination of parameters value of 0.189μm, which is much less than the Ra0.8μm required by the drill design.

The experimental data also shows that, within a certain range, the polishing effect of the abrasive stream improves as the abrasive stream polishing inlet speed increases, which is largely consistent with the numerical simulations.

5 Conclusions

In this paper, the research is carried out on the polishing of abrasive flow in the spiral groove of Ø8mm cemented carbide twist drill. The following conclusions are obtained through numerical simulation and polishing test:

- (1) From the dynamic pressure analysis, it can be seen that the polishing effect at the entrance is better than at the exit; the increase of the entrance speed can effectively improve the polishing effect.
- (2) Analysis of the abrasive speed under different abrasive concentration conditions, the following law is obtained: with the increase of abrasive concentration, the flow speed of the abrasive shows a gradual decrease, and with the increase of abrasive concentration, the uniformity of the overall polishing in the flow channel will be improved, so the appropriate increase of abrasive concentration is conducive to improving the polishing effect of the abrasive flow. In the actual machining, the abrasive concentration can be selected between 50%-60%.
- (3) The orthogonal test method is used to design the carbide twist drill spiral groove polishing test, and the polished surface roughness value is analyzed by the extreme difference analysis method to determine the influence of the test factors on the test results in the following order: abrasive type > inlet speed > polishing time, and the best combination of abrasive flow polishing process parameters is: SiC abrasive, inlet speed 0.5m/s, polishing time 30min, the parameters The surface roughness of the polished carbide twist drill spiral groove is the smallest with Ra0.189, which is much smaller than the design requirement, and the polishing effect is better with SiC abrasives than SDC abrasives.

The results of the above research can be used for the selection of abrasive type and concentration, as well as the setting of process parameters in the polishing of spiral fluted grit stream of twist drills.

At the same time in the abrasive grain flow polishing carbide twist drill spiral groove of the test there are some shortcomings and disadvantages:

- (1) The temperature has not been considered in the research process, and different methods should be used for numerical simulation. Meanwhile, the abrasive should be treated as a discrete phase to analyze the effect of individual abrasive grains on the wall of the twist drill spiral groove.
- (2) In the test of abrasive flow polishing carbide twist drill spiral groove, more types of abrasive grain and more tests should be considered; meanwhile, more professional testing equipment should be employed in analysis and process of the test results.

These will need to be further studied and improved.

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