GRINDING RESIDUAL STRESS OF CEMENTED CARBIDE [1]

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ABSTRACT

Grinding residual stress in the surface layer of WC–6 wt.-%Co hard alloy was measured by means of X–ray diffraction. The effects of various grinding parameters and treatment processes on the stress were studied. By means of electrolytic etching, the stress distribution along the depths beneath the surface was measured. The relationship between the stress and the service life of the alloy is discussed.

Key words. residual stress hard alloy X–ray diffraction

1 INTRODUCTION

Generally, some precision work is necessary for parts of hard alloys. For example a diamond abrasive wheel is used to grind the surface of the cemented carbide parts. It was reported that the residual stress produced by grinding would obviously influence the strength and service life of the hard alloy[1]. Therefore, measuring the residual stress and exploring ways to control or eliminate the stress are of greatly practical importance. In this project, a method of measuring the residual stress was introduced. The effects of various grinding parameters, natural ageing, and annealing temperature and times on the stress were studied in detail. By means of electrolytic etching, the stress distribution along the depths beneath the surface was measured. The effect of this stress on the service life of a hard alloy anvil workpiece used to synthesize diamond was also measured.

2 METHOD OF MEASUREMENT FOR THE RESIDUAL STRESS

Because of the large absorption coefficient for most metal elements, only the residual stress existing in a very thin surface layer can be detected by means of XRD. According to the principle of measuring stress by XRD, if the variation of the interplanar spacing of certain crystallographic planes of various grains in the surface layer can be measured, the residual stress can be calculated as follows[2]:

$$\sigma_{\varphi} = -\frac{E}{2(1+\gamma)} \cdot \mathrm{ctg}\theta \cdot \frac{\partial(2\theta_{\psi})}{\partial(\sin^2\psi)} \qquad (1)$$

where ψ is the deflection angle of the normal line of the sample surface; $2\theta_{\psi}$ is the diffraction angle for a given angle ψ, E is the elastic modulus for the diffraction plane of the measured phase; and γ is Poisson's ratio.

The measurement was carried out with a common powder diffractometer with divergent

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incident beam and graphite monochromator (Fig. 1). CuKα radiation, a divergent slit of 1° and a receiving slit of 0.3 mm were selected. It is a quasi-focusing method. The diffraction line of a (212) crystal plane in the WC phase was recorded under the following experimental conditions: the 2θ angle of the goniometer was scanned stepwise from 149° to 158° in a step of 0.2°; the counting time per step was 10 s, the angle ψ was chosen to be 0°, 15°, 30° and 45° respectively. The obtained data were processed with a computer according to the following procedures: smoothing the curve; corecting the Lor- entz polarization factor; correcting the absorp- tion coefficient; calculating the slope M by means of least square approximation $M = (2\theta_\psi) / (\sin^2\psi)$; and lastly, calculating the stress value σ from Eq. (1), and let $E = 524$ GPa and $\gamma = 0.22$[3].

3 THE EXPERIMENT METHOD AND RESULT

3.1 *Effect of Various Grinding Feeds*

The samples of YG6 hard alloy were ground by a diamond abrasive wheel with various grinding feeds and quantities. Then the residual stresses of these samples were measured. The multi-measurement values were averaged. The grinding parameters and measured results are shown in Table 1.

Table 1 shows that the residual stress in the surface layer is a compressive stress which increases with the grinding feed, but the increase is small. The dependency between the stress and the total grinding quantity seems indistinct because of the following facts: the total grinding quantity can not be realized by only one grinding because of the great hardness of the WC–Co alloy; especially, when the feed is large, multiple grindings are necessary for a feed. Then, just the grinding quantity of the last grinding determines the stress value. However it is difficult to assign the quantity precisely during continuous grinding. Moreover, because the WC–Co hard alloy is a typical brittle material, as the measured strength data are discrete, so are the measured data of the residual stress. Therefore, the averaged values of several measurements of a number of samples should be used.

Table 1 Stress values of samples worked at various grinding feeds and quantities*

№of sample	Grinding feed, mm	Gringing quantity mm	Residual stress MPa	Average stress Mpa
0	as-sintered	–	−3	−3
1		1.50	−1 267.3	
2	0.01	1.00	−1 041.0	−1 103.0
3		0.40	−1 0001.2	
4	0.02	2.00	−1 232.8	−1 142.3
5		1.00	−1 051.7	
6		0.60	−1 356.3	
7	0.04	2.30	−1 051.6	−1 199.5
8		0.70	−1 190.5	
9		1.50	−1 137.7	
10	0.05	0.80	−1 254.5	−1 229.6
11		0.50	−1 296.6	

* All of the stress data in this paper were the values measured at the grinding direction on the grouned surface.

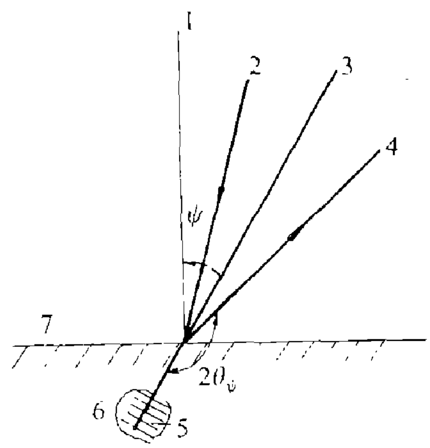

Fig. 1 Difractional geometry of stress measurement
1—normal line of sample surface; 2—incident beam; 3—normal line of crystal sarface; 4—diffraction line; 5—crystal surface for diffraction; 6—crystal grain; 7—sample surface

3.2 *Effect of Natural Aging on the Grinding Stress*

A small sample of YG6 hard alloy was ground with a large feed and the residual stress in the ground surface was measured. Then, the sample was shelved at room temperature, and remeasured at certain later times. The incident X-ray beam radiate on the same region of the sample surface for all the measurements. This ensured that the measured data could be compared with each other. A large anvil workpiece was made in the same way as the small sample. All the experimental results are listed in Table 2. The residual stress could not be obviously relaxed by natural ageing.

Table 2 Relation between the grinding residual stress and the ageing at room temperature

Shelved time	Residual stress MPa	
d	Small cutting sample	Large anvil workpiece
0	−1 129.1	1 137.9
10	−1 127.2	
165	−1 072.1	
200	−1 110.4	
220	−1 157.9	−
250	−1 067.5	
300	−	−1 133.5
410	−1 246.4	−1 155.5

3.3 *Reducing the Residual Stress by Means of Annealing at Lower Temperature*

A ground sample was annealed in a tube furnace in H_2 to reduce the stress. The annealing temperatures were 200, 300, 350, 400 and 450 ℃ respectively. At each temperature, the following holding times were chosen: 0 (grinding state), 1, 2, 4, 8 and 16 h. At 200 ℃, the holding time was prolonged up to 48 h. At each state of temperature and time, the sample was taken out of the furnace for measuring stress. Two sets of measurement data were averaged. After the measurement, the sample was returned to the furnace to go on annealing. The experiment was carried out on one sample. As above, the incident X-ray beam radiated on the same region of the sample surface for each measurement. After finishing the treatments and measurements for a certain temperature, the same sample was ground again and similar experiments at another temperature were carried out. All the results are shown in Table 3. In order to compare the data of various temperatures with each other, the stress values of the ground state at each temperature are normalized in Fig. 2.

Table 3 Measuring results of the residual stress (σ%*) at various annealing temperatures and time

Time	Temperature ℃				
h	200	300	350	400	450
0	−1 341.8	1 028.0	−1 198.4	−1 155.0	−1 116.5
1	−	−867.5	−794.0	−614.4	488.0
2	−1 241	722.1	−818.0	−562.7	−437.7
4	−1 168.4	−726.0	674.2	−411.4	−298.4
8	1 220.9	−559.6	−705.6	399.4	−303.7
16	1 127.3	663.0	−676.6	−426.2	247.6
32	−972.8				
40	−997.9				
48	−953.0				

* Normalized data expressed as percentage for comparison of results of various temperatures

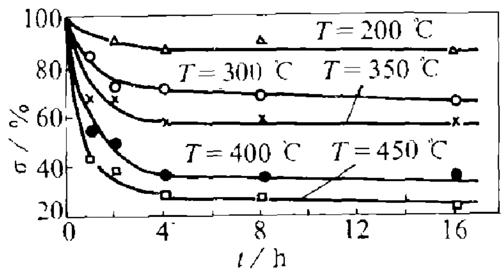

Fig. 2 Relationship between the residual stress (σ) and annealing times (t) and temperature (T)

From Fig. 2 it is known that annealing at low temperatures can efficiently reduce the residual stress existing in the ground surface of a hard alloy. The higher the temperature is, the faster the reducing rate is. With prolonged annealing time, the rate of the stress reduction decreases. At last, the stress remains at a certain value.

3.4 *Stress Distribution Along the Depths Beneath the Surface*

According to the experimental conditions shown in Table 4, the sample was electrolyzed to etch its surface layer step by step. The thickness of the etched layer was calculated by weight loss which was measured by a balance with a sensitivity of 0.1 mg. After each etching the X-ray stress measurement was made. The results are shown in Table 5.

Table 4 Experimental conditions for electrolytic etching of cemented carbide

Electrolyte	Etched phase	Voltage / V	Electric current / A	time / min
Aqueous solution of 10 % NaOH	WC	1.9	0.1	10
Aqueous solution of 10 % HCl	Co	0.7	0.1	2

Table 5 Residual stress distribution beneath the ground surface of YG6 hard alloy

№ of measurement	weight loss mg	Etched depth μm	Stress MPa
1	0	0	−1236.0
2	0.0173	4.82	−576.6
3	0.0466	12.98	−448.5
4	0.0938	26.12	−204.2
5	0.1270	35.37	−177.6
6	0.1740	48.46	−179.0
7	0.2211	61.58	−112.0
8	0.2611	72.72	−154.7

4 DISCUSSION

According to calculation[4], the efficient penetration depth of an X-ray is about 6 μm for WC−6wt.−% Co alloy. That is, the residual stress measured by means of XRD is an average value of the stress distribution through this depth. Table 5 reveals that the stress value decreases rapidly to half as much as surface value at about 4.82 μm depth. So, it is conceivable that the real stress in very thin layer of the surface is far stronger than the measured data.

In the monograph[1], the grinding stress produced by various diamond abrasive wheel on the strength and service life of sintered carbide was studied in detail. It was pointed out that the compressive stress existing in the sample surface is beneath the surface and the strength and the service life would be evidently decreased. It is obvious that the compressive str- ess existing in a workpiece surface is a good quality when it is used as a cutting tool which suffers tensile or cutting stress.

All external surfaces of the anvil workpiece were ground. When the workpiece is mounted in an apparatus used to synthesize diamond, it is situated in a complex stress state. Its top surface suffers very high pressure, but its side surface bears tensile stress. In practice, it was observed that the burst always took place on the side surface for most anvil workpieces before being damaged. It is conceivable that the surface compressive stress produced by grinding work can partly counterbalance the external force, prolonging the service life of the workpiece. On the other hand, because the thermal expansion coefficient of the Co phase is about three times as high as that of the WC phase, in the sintered state alloy there is very strong thermal stress formed during cooling. The characteristics of the thermal stress in the two phases of the alloy are opposite. The WC phase posses-ses compressive stress, while the Co phase suffers tensile stress. The lower the content of the Co phase is, the stronger the tensile thermal stress is[1]. It is well known that the main cause of destruction of the workpiece is the damage to the binder phase Co. So, the strong tensile thermal stress existing in the Co phase is a very disadvantageous factor. Therefore, it is necessary to find certain means of eliminating the tensile thermal stress existing in the Co phase and to keep the compressive stress existing in ground surface as much as possible. This pases

(*To be continued on page* № 57)

(2) The P enrichment just below the surface oxide layer is supposed to facilitate the Cr surface segregation. Concurrently, the surface segregation of C is disturbed by the active formation of the Cr oxide layer;

(3) The surface layer is rather inhomogeneous. Remarkable enrichment of O, Cr as well as a slight enrichment of C occurs in the surface layer, whereas Ni and P are correspondingly depleted. Cr is a strong oxidation element, but Ni undergoes no oxidation.

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is a couple of contradictions. Now, the following two experimental methods have be generally utilized in industry: a) shelving the assintered and ground workpiece in a storehouse for more than three months before using it; b) annealing the workpiece at a lower temperature (about 250 ℃) for more than 48 h. According to the experimental data obtained in this paper, the former (natural ageing) cannot reduce the grinding residual stress. But, shelving the workpiece for a long time might be beneficial to relaxing the opposite thermal stresses which are sealed in the parts. The latter (annealing at lower temperature) can not only eliminate the thermal stress, but also reduce a portion of the grinding stress. Therefore, both theory and experimental data have confirmed the effectiveness of the above two experimental methods.

5 CONCLUSION

(1) The residual stress existing in ground surface of cemented carbide is a compressive stress, its value is about 100 to 1. 300 MPa;

(2) The stress increases with grinding feed;

(3) Natural ageing at room temperature can not obviously relax the grinding stress, but annealing at an appropriate temperature is effective for eliminating the residual stress;

(4) For the anvil workpiece used at high pressure, natural ageing for a long time and annealing at a lower temperature for a longer time may be used to eliminate the sintering thermal stress and to retain the grinding stress as much as possible for prolonging its service life.

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