Investigation of the Model of Microscopic Contact Parameters for Grinding M200 Using Elastic Abrasive Tool

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Abstract
In this study; utilizing the elastic matrix ball has higher processing efficiency and better superficial quality than traditionalgrinding. The diversity of elastic abrasive tool characteristics contact with bend surface results in irregular wear abrasion, and abrasive tool machining status gets complicated. There is no theoretical interpretation of parameters affecting the grinding accuracy. Because of corrosion resistance, wear resistance and other characteristics of M200 material, it is often used as a material in aerospace precision components. In the study, grinding and polishing experiments has been carried out by using material of M200 to theoretically show the relationship between stress magnitude and grinding efficiency, and to predict the optimal combination of grinding parameters for effective grinding. Just in order to achieve the high abrasion resistance features of M200, the micro-contact of elastic ball abrasive tool (Whetstone) was analyzed, mathematical methods were used todeduce the functional relationship between residual peak removal rate and the main parameters which impact the grinding accuracy on the plane case. Thus they lay the foundation for the study of elastic abrasive prediction and compensation.

Keywords
Flexible abrasive tool, Hertz theory, polishing parameters, Removal rate

1. Introduction

With the traditional processing methods, it is expanded to the field of spacecraft flight, high-frequency communications and other advanced technology and engineering. The M200 Steel has high hardness, resistance, excellent abrasion resistance and other characteristics. The hardness can reach 31-35HRC after heat treatment.It is easy to reach the needed high polished and mirror-polished bend surfaces. There is a wide range of applications in the field of aerospace, precision components. The requirement of ultra-high precision leads working course and technological parameters to have extremely strict requirements. Utilizing the elastic abrasive tool precise processing technology has been increasingly studied in recent years, due to grinding process low efficiency, high cost and complicated process of M200 material steel. Compared with the traditional abrasive tool, using the elastic abrasive tool to polish has a higher efficiency of process. Professor Kita Yoshihiro in Osaka Institute of Technology tried to use high elastic abrasive tool and utilized the previous processing to grind and polish surfaces directly. Northwestern Polytechnical University studied the correlation of each elastic abrasive tool parameters experimentally [1, 2]. However, since the elastic deformation of the ball head and the grinding wheel wear amount which directly affect the complexity of the contact pressure are abnormal, this result in inconsistency between actual and the theoretical amount of the grinding rate. The related parameters in grinding process are difficult to obtain random theory relations and therefore still lack a comprehensive accurate resolution. The main factors affecting the surface polishing effect are stated as follows:

1) The primary factor affecting the effects of surface polishing is the diversity of the abrasive tool contacting with bend surface.

The characteristic of the contact of the abrasive tool and bend surface is various; the contact has some wear at the same time. If we ignore the abrasive wear and the diversity of contact characteristics, actual polishing effects will be very different under the microscope and the stability of the surface polishing will be much less than the simple type surfaces the stability of the surface polishing is much less than the simple type surfaces [3].

2) Another factor is the complexity of elastic abrasive regenerative feedback and the effect of contact pressure which is influenced by wear [4].

The polishing experiments have proved that the different contact characteristic of elastic grinding tool and other curvature surface affects the contact pressure of the work piece. It is greater than the relative motion way and the speed [5]. The effect causes the elastic grinding tool to be worn somehow The grinding and polishing parameters affecting their precision were studied in the paper and the concept of removal rate was proposed, which is the removed residual peak height under grinding and polishing in unit of time, so it reflects the relationship between the level of efficiency and parameters affecting grinding and polishing precision, which can estimate the elastic contact deformation and micro-abrasive tool wear in advance [6, 7].

2. Geometric Features of Microscopic Residual Peak on Elastic Grinding and Polishing

The state of the contact residual height and elastic abrasive tool contact with surface When the elastic abrasive tool is grinding and polishing,. Also the actual amount of deformation is unpredictable. Contact state Making and elastic ball contact with the residual peak are shown in Figure 1[2,8].

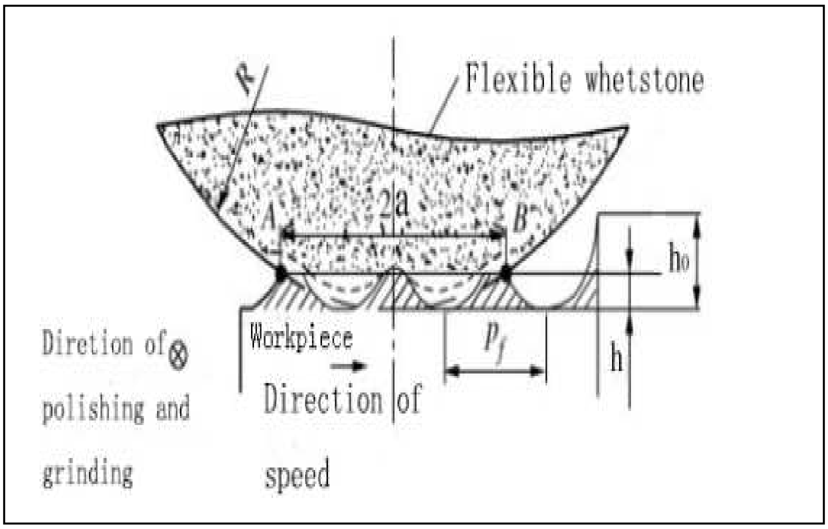

Figure1. Contact state of residual height in elastic abrasive tool ball head

Because in the course of feeding, each of the residual peaks are being constantly changed with over time by the linear velocity and pressure, the workpiece contact surface of the elastic ball head can be approximated as circle, which radius is “a” (the contact area is very small, the ball head contact with the workpiece contact surface can be consideredas a plane). Residual peaks under different coordinates are not the same to the different pressure and it is known that the radius is “a”, while residual peak spacing is p_f . According to the tribology theory [9], the amount of residual peak is random, so we can only use mathematical statistical methods to determine the appropriate parameters [10]. On an actual rough surface, the height of the asperity distribution is random, the degree of deformation of different asperity produced is also uneven, the maximum plastic deformation will be occurred on the highest asperity, and only elastic deformation may be occurred on a smaller asperity. As long as the asperity height distribution accords with the Gaussian or exponential function, it can still achieve the linear relationship between contact area and the load. The height of the distribution curve is symmetrical with the center linefor the abrasive tool surface, which is similar to the standard normal distribution or Gaussian distribution, so it can approximate the peak height of the residual surface as the triangular distribution of residual peaks, as shown in Figure 2 [11].

Assuming that the remaining height of grinding and polishing after the completion of polishing is "h", then the single residual peak of the inclination angle is "θ", in Analyzing residual peaks for any contact surface within the circle.

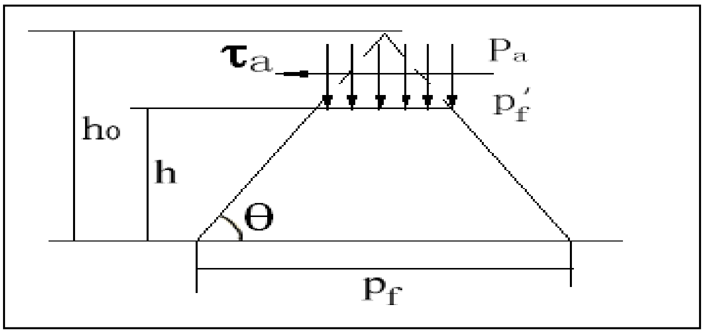

Figure2. The contact state of the residual peak in contact circle at any point

According to the directional theory, proposing parameters of surface model as "γ" to describe the directionality of three-dimension morphology of the surface profile, Due to the direction of grinding, it causes uneven distribution of the residual peaks or different shapes. This is resulting in isotropic distribution of the residual peaks by sandblasting the surface [9].In a function of the function height h, the relationship between actual removed surface area and the "h"is:

$$A(h)_{3D} = p_f' \tag{1}$$

Assuming that considering outline of onlookers roughness spacing "S_m" is as a tiny variable in contact circle and then $P_f \approx S_m$. S_m is the relevant parameter which is related to the surface profile horizontal spacing and is mainly used to control the density of surface machining marks.

According to the geometric relationship:

$$\begin{aligned} h_0 &= \left(\frac{s_m}{2}\right)\tan\theta \\ h &= \left(\frac{s_m - A_f}{2}\right)\tan\theta \end{aligned} \tag{2}$$

Based on similar triangles,

$$A_f = (1 - h / h_0) S_m \tag{3}$$

Where h_0 is initial residual peak height, h is height of residue peak after grinding and polishing and A_f is surface area of residual peak after grinding and polishing [12].

3. Utilizing the Hertz Contact Theory to Establish the Grinding and Polishing Model

In the Hertz contact theory, deformation near the contact area is strongly constrained by the surrounding medium, thus each point is in three-dimensional stress state, contact stress distribution is highly localized with distance increasing from the contact surface, and the stress attenuates rapidly. With contact of sphere in sphere by Hertz contact model shown in Figure 3 [13]:

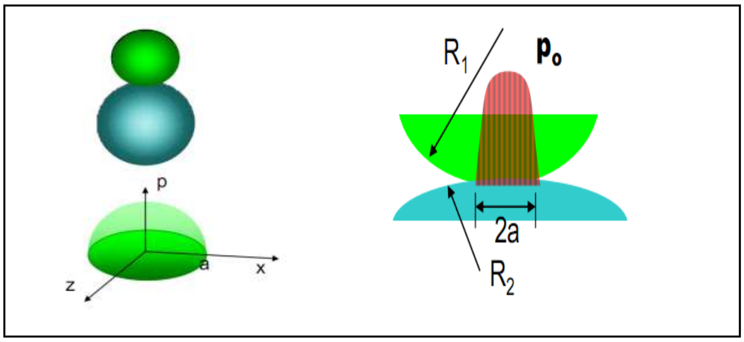

Figure3. the Hertz theoretical model of two contact spheres

While:

$$a = (3NR' / 4E')^{1/3} \tag{4}$$

$$p = (3N / 2\pi a^2)[1 - (x/a)^2 - (z/a)^2]^{1/3} \tag{5}$$

Where is two elastomers contact radius, N is normal load of pressing two goals and p is Hertz contact pressure of the contact surface.

$$\begin{aligned} 1/R' &= 1/R_1 + 1/R_2 \\ 1/E' &= (1-\upsilon_1)/E_1 + (1-\upsilon_2)/E_2 \end{aligned} \tag{6}$$

When the discussed test block surface is a simple surface, the radius of the elastic abrasive tool is R and when the processing specimen surface is flat, is $R' = R, \ \ R_2 = \infty$.

$$\begin{aligned} a &= 1.109\ (NR/E)^{1/3} \\ p_0 &= 0.385\ (NE^2 / R^2)^{1/3} \end{aligned} \tag{7}$$

Where E is Young's modulus of elasticity abrasive tool.

By the theory, assuming that ball head and the workpiece only have normal contact pressure and not horizontal speed of relative motion, then the pressure distribution is shown in Figure 4 [14].

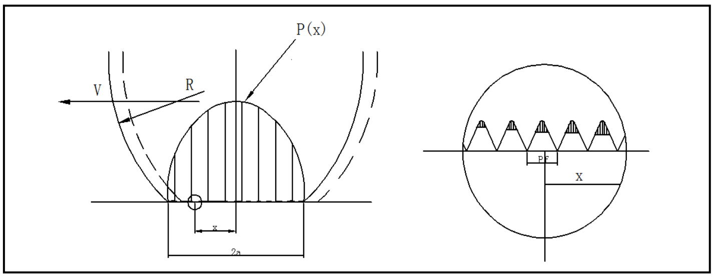

Figure4. Hertz pressure distribution curve

Definition: $P_\alpha = P(x)/ A_f$ where P(x) can be obtained through the Hertz pressure distributed formula. It is determined by “x”, which is the distance between a single residual peak with a residual contact and center circle distance; This shows a peak instantaneous residual stress determined by the residual peak Hertz pressure and the actual removal of the surface area decision, and after grinding, the surface area A_f is related to the contact time of workpiece “t” and the feed rate.

There are two ways for surface grinding and polishing process on elastic ball head:

- One is the normal contact with a sustained processing methods for processing;
- The other one is improving the fixture to cause the horizontal machining direction and processing surface is on certain angle.

According to the characteristics of elastic abrasive tool, using the second program can reduce the wear of the ball; in order to achieve higher accuracy, it is necessary to consider the impact of the line speed as it is shown in Figure 5 [15].

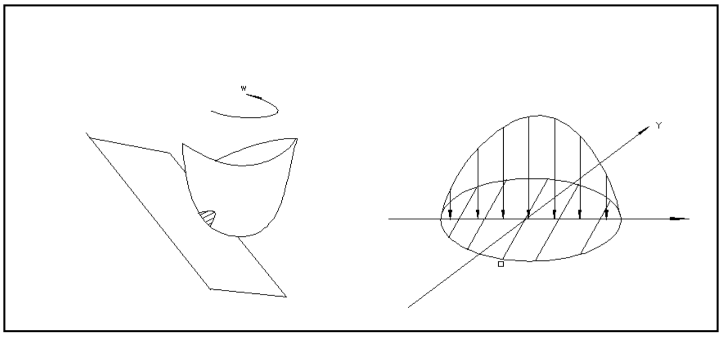

Figure5. Grinding and polishing from the side of ball

According to the concept of grinding and polishing parameters, grinding and polishing speed and feed rate influence the actual grinding depth significantly, tilt a certain angle, according to the bend surface, adjust to the grinding and polishing the rail line and cause the rate constant. This process can ignore the line speed which impactsthe grinding process; only consider the impact of feed rate.

According to the theory, assuming Young's modulus of the ball head is E_1, variable X of side grinding and polishing model at any position is distributed from the horizontal direction. Consider the outline of on looker's roughness spacing “S_m” as a tiny variable, which is ignored the influence sliding friction by the Hertz equation (8). The maximum pressure occurs at $a=1.109[NR/E]^{1/3}$ and the feed rate sets “v”, then:

$$\begin{aligned} h_0 &= \left(\frac{S_m}{2}\right)\tan\theta \\ h &= \left(\frac{S_m - A}{2}\right)\tan\theta \\ A_f &= (1 - h/h_0)s_m \end{aligned} \tag{8}$$

According to the concept of grinding and polishing parameters [2], the most important parameters affecting the actual amount of grinding and polishingare normal contact pressure, tangential force, feed rate, elastic modulus. If the stress is too high, the feed rate will increase but the elastic abrasive tool increasing the amount of abrasive tool attribution will also increase; if the stress is too low, due to the elastic rebound abrasive tool of elastic ball, it will not reach ideal precise grinding and grinding efficiency is low.

Therefore, to study the relationship among stress parameters on the grinding efficiency, it is assumed that:

$$Q = \frac{dh}{dt} = CP_{\alpha}^{m}\tau_{\alpha}^{n} \tag{9}$$

Where in Q is the removal rate which means removes the residual amount of the peak height per unit time; P_α is residual peak stress suffered by law; τ_α is shear stress of suffered residual peak; C, m, n are undetermined coefficients determined by experiment; dh is tiny difference between original residual peak height and after experiencing time of dh.
From the Hertz theory view, normal stress P_α and shear stress τ_α are related by many other visual factors (such as elastic modulus, the contact circle radius), and deduce the assumed relation to obtain the relationship between grinding area and the other parameters relationship, in order to determine the values of C, m, n, it also justify the formula reasonable.

According to equation (9):

$$\frac{dh}{dt} = C\left(\frac{P}{(1-h/h_0)\ s_m}\right)^m \tau_{\alpha}^{n} \tag{10}$$

And integral:

$$\int\left(1-\frac{h}{h_0}\right)^m dh = (C\tau_{\alpha}^{n}/s_m)\int P^m dt \tag{11}$$

While considering the change rate of the feed, the amount of site change of residual peak x at any point is the contact radius minus the distance which ball head passed by at a certain position:

$$x = a - vt \quad (0<x<a) \tag{12}$$

$$dx = -v\,dt = s_m \tag{13}$$

Where v is feed rate.

By using $dx = -vdt = s_m$ in the equation (11):

$$S_m\int_{h_0}^{h}\left(1-\frac{h}{h_0}\right)^m dh = K'\int_{a}^{-a} p^m(x)dx \tag{14}$$

Where $K' = -\frac{C\tau_{\alpha}^{n}}{v}$; $P(x)$ is the force changes under the case of $y=0$ for the Hertz curve.

Then:

$$s_m\int\left(1\text{-}\frac{h}{h_0}\right)^m dh = h_0 s_m\int\left(1-\frac{h}{h_0}\right)^m d\left(\frac{h}{h_0}\right) \tag{15}$$
$$=\frac{h_0 A_f^{m+1}}{(m+1)s_m^m}$$

$$K = s_m^m K' / h_0 = -\frac{s_m^m C\tau_\alpha^n}{vh_0}\ \phi(x) = \int_{-a}^{a} P(x)dx \tag{16}$$

To get $\frac{A_f^{m+1}}{m+1} = K\phi^m(x)$ (17)

From Hertz relation (6)

$$P(x) = \frac{3N}{2\pi a^2}\left[1-\left(\frac{x}{a}\right)^2\right]^{1/2} \tag{18}$$

$P(x)$ is Hertz contact pressure only when y=0.

Using $P(x)$ in $\phi(x)$:

$$\phi(x) = \int_{-a}^{a} \frac{3N}{2\pi a^2}\left[1-\left(\frac{x}{a}\right)^2\right]^{1/2} dx$$
$$= \frac{3N}{2\pi a}\int_{-a}^{a}\left[\left(1-\left(\frac{x}{a}\right)^2\right)^{1/2}\right] d\left(\frac{x}{a}\right) \tag{19}$$
$$= \frac{3N}{2\pi a}\int_{-1}^{1}\sqrt{1-\lambda^2}\,d\lambda$$

By Charles standings, $t=\sqrt{1-x^2}$:

$$\phi(x) = \frac{3N}{2\pi a}\left\{\frac{\lambda\sqrt{1-\lambda^2}}{2}+\frac{1}{2}\sin^{-1}\lambda\right\}_{-1}^{1} \tag{20}$$

Among them:

$$\frac{1}{2}\sin^{-1}(1) - \frac{1}{2}\sin^{1}(1) = \frac{\pi}{2} \tag{21}$$

Using (20) in the (22):

$$\phi(x) = \frac{3N}{2\pi a}.\frac{\pi}{2} = \frac{3N}{4a} \tag{22}$$

By using the Hertz equation (8):

$$a = 1.109[NR/E]^{1/3} \tag{23}$$

Using in the $\phi(x)$

$$\phi(x) = 0.676(NR/E)^{1/3} \tag{24}$$

Finally:

$$A_f^{m+1} = -\frac{0.676C(m+1)\tau_\alpha^n s_m^m}{vh_0}\left[\frac{NR}{E}\right]^{1/3} \tag{25}$$

1.3 Grinding and Polishing Process Experiments

Milling cutter is used to mill workpiece before the experiment. Utilizing M200 is as an experimental test block of grinding and polishing, adopting creep feed grinding,experiments in grinding and polishing center ,since creep feed can get grinding depth and arc length increases, while a mount of grain participating in grinding is increasing, it could be grind and polish the shape needed directly , it mainly used in grinding gouge and shaping surface.

The experimental conditions of Grinding and polishing are given in advance; in order to extend the range of variables change, giving several sets of different parameters to test.

The experiment parameters observed that increased with time and the change residual contact area or residual peak height, for the parameters given in advance, grinding surface in the processing center to derive topography residual peak, utilizing Infinite focus automatic zoom dimensional surface roughness profiling instrument, were photographed to obtain amplified graphical contour, by definition and measuring irregularities and residual initial height according to the above conditions in Table 1 and Figure 6:

Table 1. Experimental parameters

Material	Speed of Feed	Elasticity Modulus	Speed of Main shaft	Radius of Ball	Normal Load	Inclination of workpiece
M200	1000r/min	196GPa	75/150/225mm/ min	40min	5N/7N/10N	30°

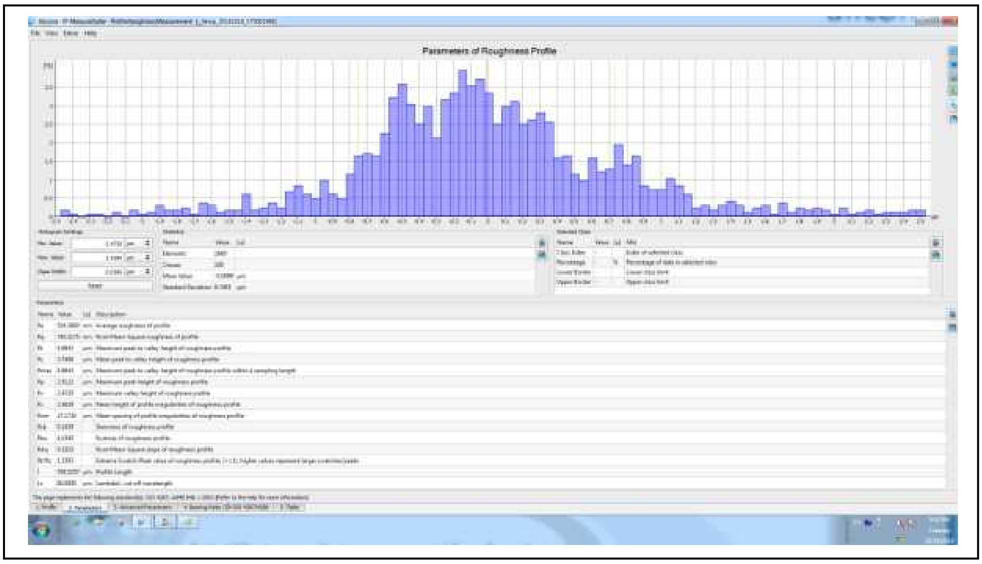

Figure6. Surface roughness parameters

Cutting force τ_α is related to the hardness of the material itself, seeking for units cutting force of common workpiece material. All parameters were obtained from measurement and calculation; we can confirm the values of C, m, n obtained by linear analysis [16].

$$X = \frac{\tau_\alpha^n s_m^m}{v h_0}\left[\frac{NR}{E}\right]^{1/3} \qquad (26)$$

$$A_f^{\ m+1} = -0.609C(\ m+1)X$$

According to different requirements of the given parameters, measured parameters are corresponding change, it is still continued to try to change the value of m and n, so that make the values of Y and X is linear.

Since the assumed original constant term is positive, if we want to make the left and right sides of equation equal then m< l. According to the proportion, it was attempted to bring values m, n and finding n that is always 1 smaller than m, thus we ensure the "X" is gradually decreasing and has positive correlation with the removal of the area.

According to substitute parameters in the formula, it was obtained X and value of Y measured after experiment. The measured data are shown in Figure 7.

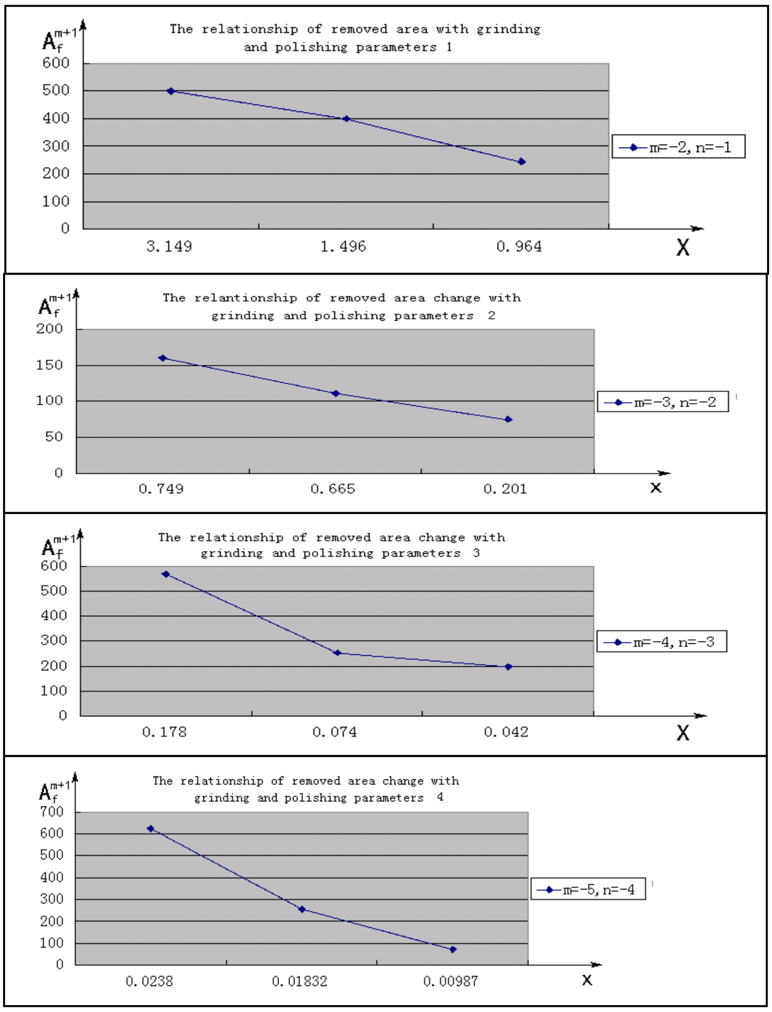

Figure7. The relationship of removed area changed with grinding and polishing parameters

According to the chart data, it can be seen that X is approximately proportional to the value of A_f^{m+1}, when m = -3 and n = -2. According to the least square method, when m = -3, n = -2 and then $C = 1.55 \times 10^5$. At the same time, according to the derivation of the formula, we can get important conclusion: removal rate is proportional to the normal pressure and the radius of the ball head; and isinversely proportional to the velocity, residual peak height and modulus of elasticity. In the confirmation experiment, Hitachi SU-1080 was utilized to scan electron microscope contrast test block before grinding and polishing process and according to the requirement to select different acceleration voltage, it was magnified 1000 times to observe the change of surface characteristics in different parameters combinations. Through continuous trajectory coordinates grind and polish. Surface accuracy is significantly improved before and after processing; while ball radius is increasing appropriately and reducing the elastic modulus of the surface, surface scratches and fine particles embedded in the workpiece surface are reduced correspondingly[16].

The surface morphology which is not grinding and polishing, is shown in Figure 8 and the surface morphology which is using parameters of E = 150 and 100 Gpa, v = 150 and 75 mm / min, R = 20 and 30 mm, are shown in Figure 9 and 10.

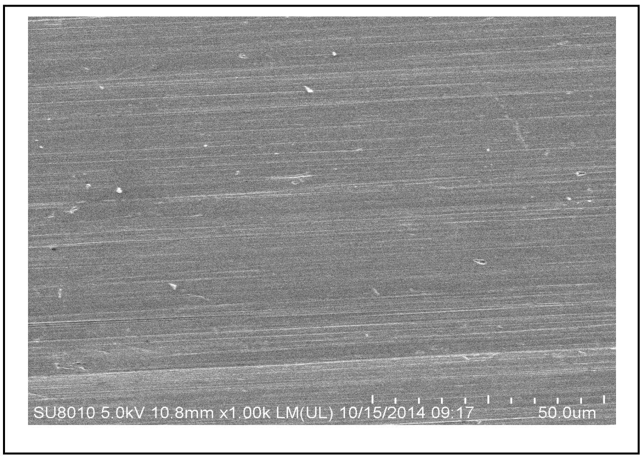

Figure8. The surface morphology that is not grinding and polishing

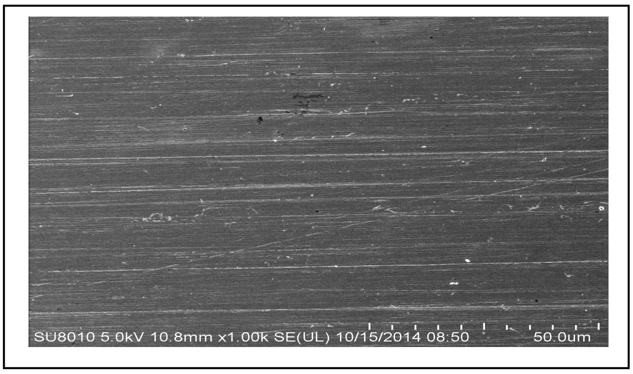

Figure9. The surface morphology which is using parameters of E = 150Gpa, v = 150mm / min, R = 20mm

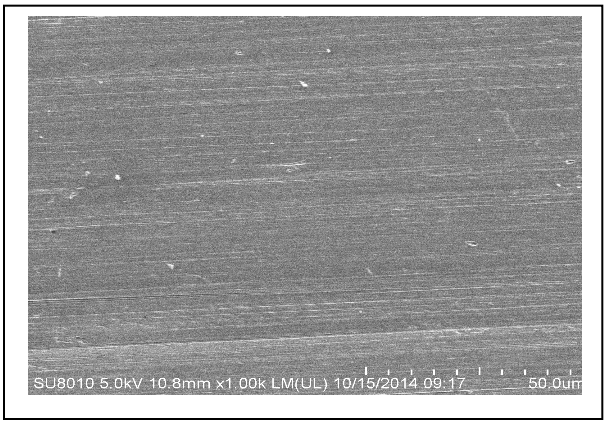

Figure10. The surface morphology which is using parameters of E = 100Gpa, v = 75mm / min, R = 30mm

4. Conclusion

According to theoretical deducing and experiment for M200 work surface, considering the feed rate and the amount of wear comprehensively, we can derive estimated parameter values of $Q = \frac{dh}{dt} = CP_{\alpha}^{m}\tau_{\alpha}^{n}$. Size range of removal rate can be estimated by calculating values of the contact pressure and shear stress. Meanwhile, the impact of normal stress is greater than tangential stressfor grinding and polishing efficiency. Consider the case of removed area of residual peaks: we reduce the elastic modulus appropriately, increase the abrasive tool wears pressure and the radius of the ball head, so that the feed amount is increased, the wear decreased and grinding efficiency increased. There exist errors between theoretical and the actual derivation, mainly because when we deduce the formula, considered outline of onlookers roughness spacing as dx to integral was not precise enough, residual peak was significantly affected by the changes of the feed rate, and each factors exits interaction, so choosing the appropriate microscopic variable quantity is the key of improvement in the future. Meanwhile, the number of residual peaks within the scope of the contact circle is as $n = 2a / p_f + 1$ [2], we should make "n" larger, so that more residual peaks distribute and the model would be more accurate.

5. References

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