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Research on surface characteristics of non-traditional finishing

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Abstract: This paper reports results of investigations of some surface characteristics, and resulting performance of parts processed using non-traditional finishing methods. The friction factor, precision keeping and anti-conglutination performance of the finished surfaces are considered, and surface characteristics such as microtopography and machining texture were investigated. The overall performance of surfaces finished using non-traditional finishing methods was found to be significantly better than that of traditional finishing methods.

Key words: Non-traditional finishing, Surface characteristics, Machining texture, Microtopography
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INTRODUCTION

Finishing is a kind of machining technology for greatly increasing the surface quality of a machined object while maintaining stable precision and improving the machining precision grade. Finishing is the last procedure for most parts and is an important manufacturing technology.

Finishing can be divided into two kinds of technologies. One is traditional finishing which utilizes mechanical processes such as grinding, abrading, polishing, etc.; the other is non-traditional finishing, which utilizes chemical or electrochemical processes such as chemical finishing (CF), electrochemical finishing (ECF), electrochemical mechanical finishing (ECMF) or utilizes heat energy.

Some recent years experiments confirmed the good results of non-traditional finishing methods such as CF, ECF and ECMF. In addition, the surfaces finished by these techniques had excellent all-around performance (Klocke and Sparrer, 1998; Rajurkar *et al*., 1999). For instance, examination of large batches of tiny aluminum computer parts finished by ECF revealed that the machined parts had no burrs, good appearance, and anti-erosion and anti-conglutination properties. In another application where a bearing bush was finished by ECMF, the running noise of the bearing was decreased from 60 dB to 47 dB, and its effective life was increased by over ten times. Similarly, the running noise of a gear finished by ECMF was decreased by 7.5 dB on average, and the life was prolonged over eight times.

These results indicated that there is a direct relationship between the all-around performance of a part and the finishing techniques used.

MECHANISM OF TRADITIONAL AND NON-TRADITIONAL FINISHING

First, we should consider the differences between traditional finishing and non-traditional finishing. Traditional finishing methods mainly include cutting-type finishing methods such as finishing grinding, fine abrading, honing, abrasive belt polishing, elastic wheel polishing, steam spraying, and pill spraying. Non-cutting finishing includes methods such as roll pressing, diamond chasing as well as hole squeezing. Each traditional finishing method generally utilizes mechanical energy to achieve the machining objective. Take fine abrading as an example. The machining mechanism is as follows, a machining effect such as cutting, slip rubbing and extrusion is applied to the part surface by an abrasive tool through regular cutting motion, the uniform and complex cutting tracks on the surface of the workpiece are formed by the abrasive to reduce the surface roughness. The machining mechanism of fine abrading and moving track are shown in Fig.1 (Yang, 2000).

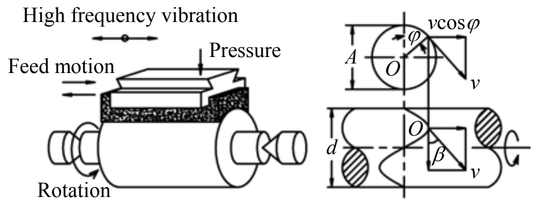


Fig.1 Mechanism of fine abrading and moving track

The machining process in non-traditional finishing is generally accomplished by utilizing heat, chemical or electrochemical energy. The emphasis in this paper is placed on the finishing machining methods that mainly involve CF, ECF and ECMF. An oxidization reaction on the surface of a workpiece is utilized in both CF and ECF, where metal atoms lose electrons and erode away from the surface of the workpiece. ECMF is a new finishing machining method developed by combining a surface-dissolving oxidization reaction like CF and ECF with a mechanical polishing action. The basic composition of an ECMF system is shown in Fig.2 (Li and Zhou, 2004). A workpiece and a tool electrode are placed into an electrolysis trough; the workpiece is connected to the positive electrode of a DC power supply; the tool electrode is connected to the negative electrode, electrolyte is used to fill the gap between the workpiece and the tool electrode with a cycle pump. During the machining process, the tool electrode is moved back and forth. As electrical current passes from the positive electrode to the negative electrode, an electrochemical passive dissolution of the surface of the workpiece takes place, and a non-reacting passive layer is formed. As the passive layer builds up, the electrochemical dissolution is slowed and ultimately prevented from continuing. As the electrode moves back and forth the hone strips on the tool electrode continuously clear the passive layer on the workpiece. In this process, fresh metal surface is revealed and then dissolved to form a new passive layer. As the passive layer is continuously formed and cleared, the microtopographical peaks on the surface are continuously dissolved and cleared, while the rest of the surface (the valleys) remains protected by uncleared sections of the passive layer (that cannot be reached by the hone strips), until finally the surface reaches the desired smoothness.

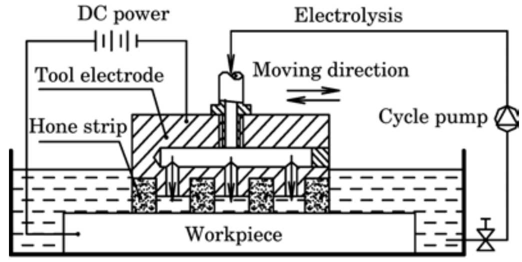
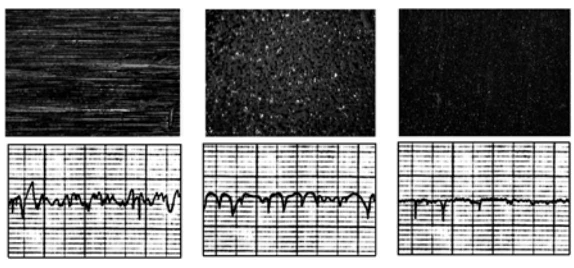


Fig.2 Principle of ECMF

EVALUATION OF SURFACE GEOMETRIC CHARATERISTICS

There is a significant difference between the geometric shape of a surface finished by traditional finishing and that finished by non-traditional finishing methods. Fig.3 illustrates the texture and microtopography of surfaces finished by grinding, ECF and ECMF (Krishnaiah *et al.*, 1981; Konig, 1978).

Fig.3a shows the microscopic surface finish obtained by fine grinding, where the microtopography of the surface is the "mountain type" with alternation of sharp peak and valley; Fig.3b shows a surface finished by ECF, where the microtopography of the surface is characterized as a mild "wave type"; Fig.3c shows a surface finished by ECMF, where the microtopography of this surface is characterized as a flat



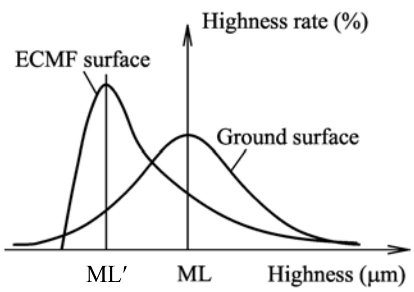
(a) (b) (c)

Fig.3 Texture and microtopography of different surfaces
(a) Ground surface; (b) ECF surface; (c) ECMF surface

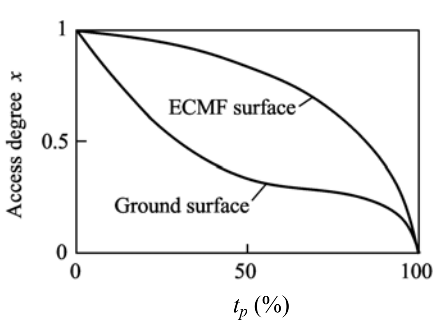
"plateau type".

In many cases, even if the surface roughness parameters of highness and transverse distance (such as R_a, R_y, R_z and S, S_m, etc.) were entirely the same, two surfaces with different microtopography would have different precision keeping ability, wear resistance, contact rigidity and other application performance characteristics. Thus to be comprehensive, surface roughness parameters should include the shape characteristic parameters, such as profile supporting length (η_p), profile supporting length rate (t_p), etc. Compared with the surfaces finished by grinding and ECMF, the microscopic highness probability distribution curves and the profile supporting length rate curves of the two kinds of surface are shown in Fig.4 (Zhang and Yi, 1999).

Fig.4a shows that the highness probability distribution of the ground surface is Gaussian, while the probability distribution of the ECMF surface is more typical of logarithmic normal distribution. For a ground surface, the highness ratio above and below the middle line is 1:1, while that of ECMF surface is about 1:1.86. As a result, the relative supporting length of the surface microtopography with a logarithmic normal distribution is longer than that with Gaussian distribution. As shown in Fig.4b, when the access degree is x=0.3, the relative supporting length rate of grinding machined surface is t_{p1}=22%, while that of ECMF surface is t_{p2}=70%, the ratio of the two rates t_{p1}:t_{p2}=1:3.18.



(a)



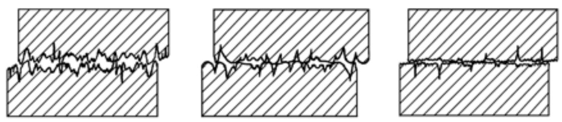
(b)

Fig.4 The microscopic shape characteristics of grinded and ECMF surfaces
(a) Highness probability distribution; (b) Supporting length rate curve

It can be seen from the supporting length rate curve of the surface profile, that there is a difference in the supporting area between the different types of surfaces with the same surface roughness. The bigger the supporting area is, the stronger is the contacting rigidity.

EFFECT OF SURFACE GEOMETRIC CHARATERISTICS ON FRICTIONFACTOR

For the same surface roughness, the microscopic profiles with "wave type" and "plateau type" shape have better wear resistance than a "mountain type" microscopic profile, and the frictionfactor is lower. From Fig.5, the different contact states of two surfaces, finished by grinding, ECF or ECMF were directly observed. These figures tend to indicate that in a friction system, the frictionfactor is largely determined by the machining texture and shape microtopography of the surface.



(a) (b) (c)

Fig.5 Contacting states of different types of surfaces
(a) Ground surface; (b) ECF surface; (c) ECMF surface

Some experiments proved this conclusion. Comparison of the static frictionfactors of the surfaces finished by grinding and ECF with the same surface roughness is given in Table 1. The data in the table indicates that the static frictionfactor of the ECF surface is generally lower than that of the ground surface, and that the average reduction is about 50% (Wang, 2002).

Comparison of the dynamic frictionfactors of the ground surface and the ECMF surface is shown in the Fig.6. At a constant relative speed of v=2.5 m/s, the dynamic frictionfactors of the two kinds of surfaces

Table 1 Comparison of static frictionfactor of surfaces

p (N/cm^2)	f_{j1} (Ground surface)	f_{j2} (ECF surface)	f_{j1} / f_{j2}
7.8	0.12	0.08	1.50
11.8	0.18	0.10	1.80
15.7	0.24	0.15	1.60
19.6	0.29	0.20	1.45

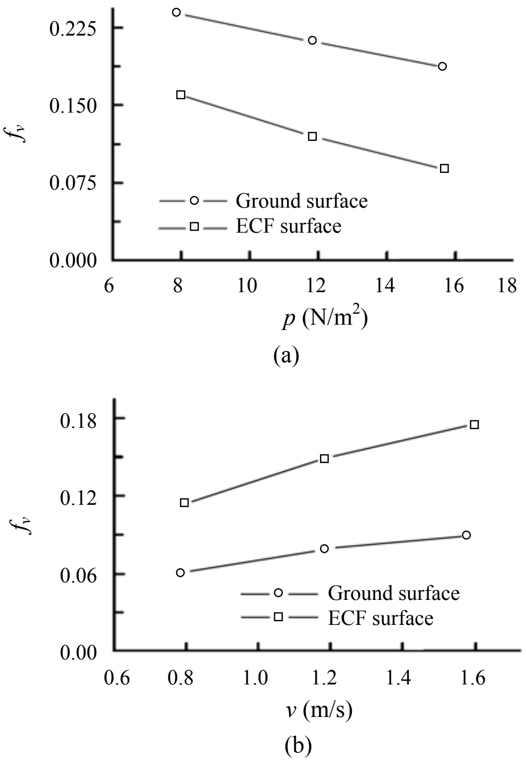


Fig.6 Comparison of the dynamic frictionfactors of different surfaces (R_a0.04 μm). (a) f_v-p curve (v=2.5 m/s); (b) f_v-v curve (p=15.7 N/m^2)

all have a declining trend with the increase of normal pressure, as shown in Fig.6a. The dynamic frictionfactor of the electrochemical finishing machined surface f_{v2} is lower than that of grinding machined surface f_{v1}, and f_{v1}:f_{v2}=1.5~2.1. Additionally, in Fig.6b, when p=15.7 N/cm^2, the dynamic frictionfactors of the two kinds of surfaces both have a rising trend with increasing relative velocity, and that the dynamic frictionfactor of the ground surface is 1.4~2 times that of the surface finished by ECF.

This experimental data suggests that the static frictionfactors and the dynamic frictionfactors of the ECF surface are generally lower than those of the ground surface.

EFFECT OF SURFACE GEOMETRIC CHARATERISTICS ON PRECISION KEEPING

Precision keeping of a surface is its ability to resist the loss of its initial manufacturing precision when put to use. It is very important for critical machine components to keep their precision under normal operating conditions. If precision keeping is poor, the parts can quickly lose their initial manufacturing precision and fall outside of the design tolerances and possibly fail.

Precision keeping of a surface can be expressed by its initial wear capacity. From Fig.7, the different initial wear capacities of different types of surfaces can be observed directly, showing that the initial wear capacity of ECMF surfaces is the smallest among the initial wear capacities of ground surfaces, ECF surfaces and ECMF surfaces.

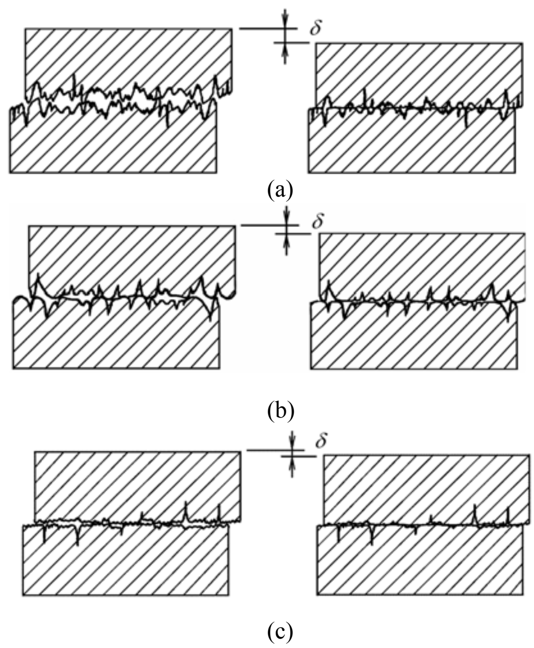


Fig.7 Initial wearing status of different types of surfaces
(a) Ground surfaces; (b) ECF surfaces; (c) ECMF surfaces

The difference in the initial wear capacities between ground surfaces and ECMF surfaces were obtained experimentally (data given in Fig.8). In the experiment, the pressure was 15.7 N/cm^2; the principal axis rotation speed was 1800 r/min, lubricating with machine oil No. 40, and the workpiece material was 45C steel quenched. The results showed that there was prominent loss of the highness and profile section of the microtopography on the ground surface, that the highness wear was ΔR_{max1}=1.25 μm, that the profile section loss was ΔW_1=3.61 mm^2/mm; and that during the friction wear process, the moment friction and the dynamic friction factor of the surfaces change rapidly. For the ECMF surfaces, ΔR_{max2}=0.35 μm, ΔW_2=2.1 mm^2/mm, and during the friction wear process, the change of the moment friction and the dynamic frictionfactor was very slow. As for the ratio of area wear and highness wear, $\Delta W_1/\Delta R_{max1}$= 2.5~2.9, $\Delta W_2/R_{max2}$=5.2~6, where a high ratio indicates that the wear-resistance of a surface is higher. The experimental results revealed that the ratio of area wear and highness wear of the ground surface was about half of that of the ECMF surface, which means the wearability of a ECMF surface is two times the wearability of the ground surface in the initial wear period.

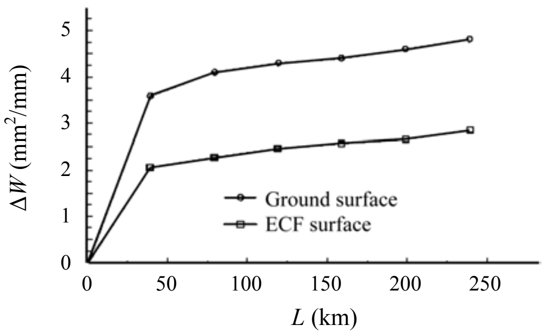


Fig.8 Initial wears of ground surfaces and ECMF surfaces

The conclusion can be drawn that a surface finished by ECM and ECMF type non-traditional finishing has better wear resistance than that of a surface finished using traditional finishing methods. This conclusion similarly means that the surface machined by non-traditional finishing has better precision keeping ability than the surface machined by traditional finishing.

As discussed above, the frictionfactor of the ECMF surface is lower than that of the ground surface, and the precision keeping ability is higher. As a result, the part made by non-traditional finishing would tend to run with lower noise and have longer life than the part made by traditional finishing. This result was also observed in two other experiments.

In the first experiment, as shown in Table 2, five pairs of identical gears typed 1700C-053, provided by the Second Automobile Factory of China, were finished by ECMF, and the running noise was found to have decreased by about 7~10 dB on average.

Table 2 Change of running noise of the gears finished

No.	Test distance (cm)	Running noise (right/left) (dB)		Change (right/left)
		Aboriginality	Being finished	
1	200	90/92	82/84	−7/8
2	200	93/94	83/85	−10/9
3	200	93/93	81/83	−12/10
4	200	92/93	85/85	−7/8
5	200	92/93	83/85	−9/8

In the second experiment, as shown in Fig.9, three identical sets of gears in the gear-box named FS8026, provided by the First Automobile Factory of China, was finished by ECMF. One set of gears, not finished by ECMF, was named number 0; the others, finished by ECMF, were named number 1 and number 2. Compared with the gears in number 0 team, the lives of the gears in sets 1 and 2 were prolonged by 4~6 times on average, as determined using a friction wear tester.

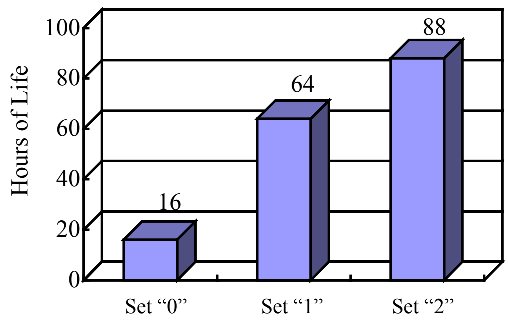


Fig.9 Comparison of the lifes of FS8026 gears finished

EFFECT OF SURFACE GEOMETRIC CHARATERISTICS ON ANTI-CONGULTION

Under the same exterior conditions, different microtopograpies and the statistical characteristics of different surfaces with the same surface roughness have significant effect on the conglutination performance of the surface. The microtopography of a ground surface typically has a sharp peak, and the conglutination of the surface to the contacted substance is very strong, while the microtopography of an ECF or ECMF surface is of a wave or plateau type, and the conglutination of the surface is weak (Konig, 1978). This conclusion is very important for a machine used in chemical industry, light industry and food industry. Conglutination performance influences various aspects of a machine, such as efficiency, cost, life and other application performance characteristics. For example, several key parts of a machine used to can food were finished using ECM here. The resulting conglutination of the medium to the contact surface of the parts was decreased significantly; as a result, the continuous period of tomato sauce production was increased from 10 d to 45 d before there was need for the production machinery to be stopped and cleaned. The efficiency was increased, and the cost for the whole process was decreased.

CONCLUSION

In this paper, the surface characteristics of parts finished using non-traditional finishing methods were compared to those of parts finished using traditional methods. The microtopography and machining texture of the non-traditionally finished surfaces showed many advantages over traditionally finished surfaces with regard to frictionfactor reduction, precision keeping and anti-conglutination. These good surface characteristics were shown to translate into improved performance of machine parts. Non-traditional finishing methods helped to decrease the running noise and prolonged the useful life of ball bearings and gear boxes, while reducing operating costs in a food processing machine.

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