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Experimental research on the polished surface quality of hard anodized film of aluminum alloy

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Abstract. An experimental study was conducted for the surface polishing of the oxide film after hard anodizing of 2D70 aluminum alloy. The surface roughness and surface morphology of aluminum alloy before, after anodizing and after polishing were analyzed, and the effects of polishing force, polishing speed, feeding amount and sandpaper grit on the polished surface roughness were investigated experimentally. The results showed that the surface roughness of 2D70 aluminum alloy decreased by 1 grade on average after hard anodizing. The hard anodized film surface has more linear protrusions, large pits and a large number of small pores. After polishing, the linear protrusions and small pores disappear, and a small number of new linear grooves appear, while the condition of large pits does not change much. The depth of small pores on the oxide film surface is within 11 μ m in most cases. As the polishing force, feeding amount and sandpaper grit increase, the decreasing trend of roughness value also gradually increases, and the decreasing trend of the thickness of hard anodic oxide film gradually increases. As the polishing speed increases, there is no clear trend in the decreasing trend of roughness value and no clear trend in the decreasing trend of the thickness of hard anodic oxide film.

Keywords: hard anodizing; polishing; surface morphology; roughness; thickness of oxide film

1. Introduction

As a light metal, aluminum alloy has the characteristics of low density, high specific strength and excellent corrosion resistance, and is widely used in aerospace and other fields[1]. In order to avoid the unfavorable characteristics of low hardness and easy wear of aluminum alloys, hard anodizing is often used on the working surface to improve surface hardness and wear resistance. This method can form a hard anodized oxide film with Vickers hardness close to 800HV on the surface of aluminum alloy, which is a common method for hardening of aluminum alloy surface. Hard anodizing can obtain a hard anodized oxide film with a maximum thickness of 250 μ m[7-8], and the bonding force between the oxide film and the aluminum alloy substrate is much greater than that of electroplating, painting, etc, so that it has excellent corrosion resistance.

After hard anodizing, the wear resistance of aluminum alloy is significantly improved, and it is widely used in aviation equipment fuel sliding and sealing structures, but it puts forward very high requirements on the surface roughness. The roughness of the hard anodic oxide film on the surface of the aluminum alloy piston rod of a certain type of aircraft (the Ra value is below 0.1) is required to be relatively high, which has approximated a mirror effect[9]. The surface roughness of the aluminum alloy piston rod can reach Ra0.1 through special machining methods, but after hard anodizing, the roughness will be reduced to about Ra0.4. Faced with the situation that the surface roughness of the parts decreases after hard anodizing, Rong-Bang Chu et al.[10] adopted the method of reducing the surface roughness during parts processing. Chun-Yan Shi et al.[11]compared the effects of two forming methods of 2A12 aluminum alloy rolling and extrusion on the comprehensive properties of the hard anodic oxide film through experiments, and came to the conclusion that rolling forming is more excellent. Wen-Bo Pan et al.[12] experimented the magnetorheological plane polishing of aluminum alloy anodized oxide film clusters under different conditions, and obtained the influence of workpiece's own rotation speed, the rotation speed of the polishing disc, the amplitude of the deflection, processing time, etc. on its surface roughness and material removal rate.

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There are few studies on the polishing of 2D70 aluminum alloy hard anodized film. In order to study the influence of polishing parameters on the hard anodized layer and obtain a good surface roughness of the hard anodized layer, an experimental study was carried out on the polishing of the oxide film after hard anodization of 2D70 aluminum alloy, and analyzed the effects of surface roughness, surface topography, polishing force, polishing speed, feed rate, and particle size of sandpaper on polishing roughness of aluminum alloys before, after anodizing, and after polishing.

2. Experiment

The polishing test of the aluminum alloy hard oxide film was carried out on the CM6140A precision ordinary lathe with a spindle capable of 24-level speed control from 10 to 1400r/min, spindle motor power of 7.5kW, and maximum machining diameter × length: Φ 210 × 900mm.The polishing experimental system is shown in Figure 1(a), one end of the aluminum alloy hard oxide film polishing test piece is clamped on the chuck of the ordinary lathe through the mandrel, and the other end is clamped with the aid of ordinary lathe tailstock top, and the polishing tool is installed on the tool holder of the lathe. During the experiment, the spindles of the lathe rotated to drive the workpiece to rotate, and the relative position of the tool rest driven polishing tool and the experimental piece was adjusted. During the experiment, the spindles of the lathe rotate to drive the workpiece to rotate, and the tool holder is adjusted to drive the relative position of the polishing tool and the experimental part.

The polishing force measurement system is shown in Figure 1(b) and includes a handheld digital liquid crystal meter MCK-HY instrument sensor and a JLBM tie rod diaphragm type pull pressure sensor to achieve the polishing force measurement.

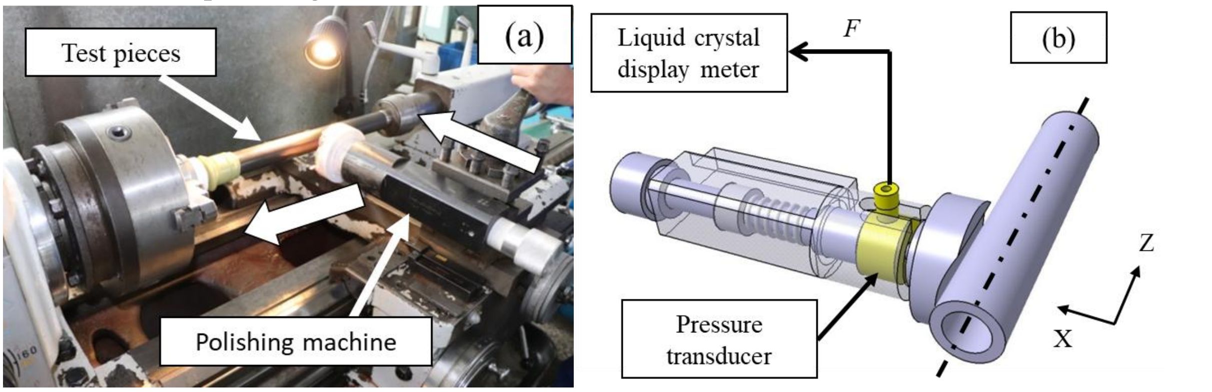

Fig. 1 Schematic diagram of the polishing experimental system and polishing force measurement system: (a) Polishing experimental system (b) Polishing force measurement system

Polishing tooling structure as shown in Figure.2, the polishing head is made of PTFE material with softer, stronger toughness and high temperature resistance, with adhesive backed sandpaper paste in the polishing head concave arc, and the polishing head is a concave arc surface, slightly larger than the arc surface radian of the piston rod. The polishing force is generated by compressing the spring after the contact between the polishing head and the workpiece. The size of the polishing force is adjusted by rotating the torsion plug to adjust the pressure on the spring, and the polishing force is measured by the polishing force measuring system.

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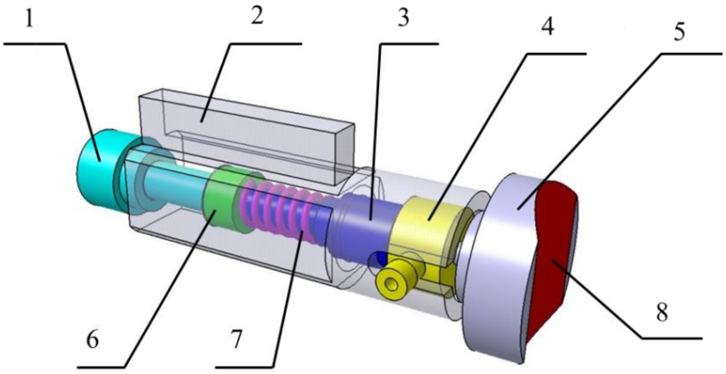

Fig. 2 Joint diagram of polishing device :1-Plug, 2-Base, 3-Arbor, 4-Pressure sensor, 5-Polishing head, 6-Positioning sleeve, 7-Spring, 8-Abrasive paper

The size of the aluminum alloy hard oxide film polishing test piece used in the experiment is: Φ 40mm × 350mm, the substrate is 2D70 aluminum alloy, the surface layer is hard anodic oxide film, the thickness is (60-70) μm, and its physical and mechanical properties are shown in Table 1[13].

Table 1. Material properties[13]

	ρ, density (kg/m3)	E, Young's modulus (GPa)	ν, Poisson's ratio	Coefficient of thermal expansion (10E-6)	k, thermal conductivity (W/m•K)
2D70 aluminum substrate	2700	70	0.3	23.5	162
Hard anodized film	3890	375	0.22	8.4	20

The experiment was a single-factor experiment, and the experimental variables were polishing force F, polishing speed v, feed rate f, and particle size of sandpaper n. The parameters of single-factor are shown in Table 2.

Table 2.Polishing experiment parameters

Parameters	Valus
F，Polishing force(N)	15、30、45、60、75、90
v，polishing speed(m/min)	31、40、50、56、62、70
f，Feed rate(mm/r)	0.1、0.15、0.2、0.3、0.36、0.41
n，Particle size of sandpaper(μm)	3、6、9、15

The outer surface of the aluminum alloy was hard anodized, and the thickness of the oxide film was about 60 μm. The surface micro-morphology of the polished aluminum alloy hard oxide film was observed and analyzed by a Japanese electronic scanning electron microscope JSM-IT800, with a maximum magnification of 2 million and a resolution of nanometer level. The surface roughness of the polished aluminum alloy hard oxide film was measured by SJ5730 large-range roughness profiler produced by Shenzhen Zhongtu Instrument Co., Ltd. with the measurement accuracy of Ra value up to 0.001 μm, and the average value was taken as the measurement result after removing the maximum and minimum values for 8 random measurements in the polished area. The initial thickness measurement equipment of hard anodized film was measured by TIME2606 cladding

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thickness gauge, and the subsequent thickness of hard anodic oxide film was measured indirectly by micrometer.

3. Results and Discussion

3.1 Comparison of roughness of hard anodized layers on aluminum alloy surfaces

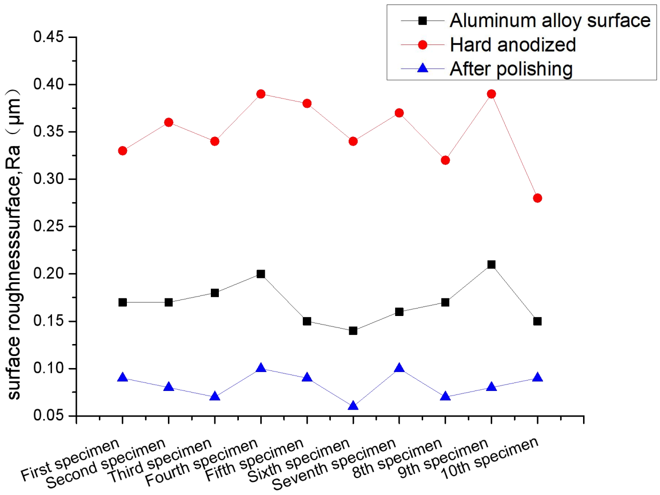
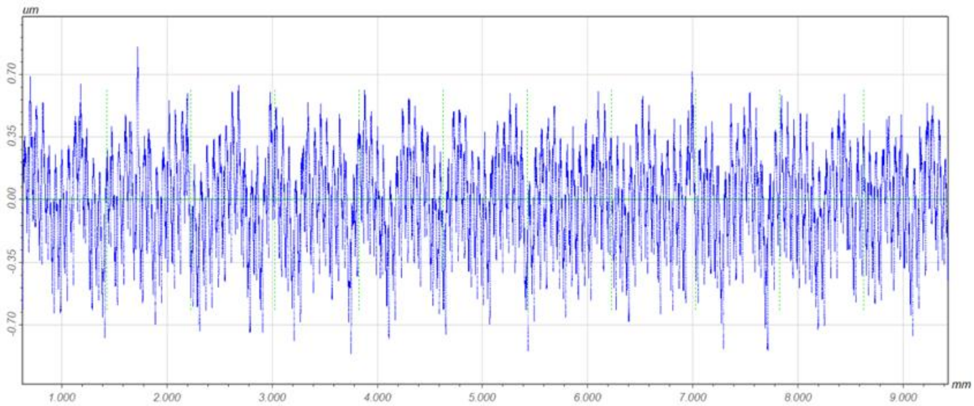


Fig. 2 Comparison of roughness of hard anodized film before and after polishing

After hard anodizing, the roughness of the aluminum alloy surface is all changed. For rougher surfaces, the appearance can be smoother than the original after treatment. But for parts with smaller original roughness, the surface roughness grade will decrease by 1-2 grades[14].It can be found from Figure 3 and Figure 4 that after hard anodizing the roughness Ra value of the aluminum alloy surface dropped from 0.14 (about level 8) to 0.366 (about level 7). After the hard anodized film was polished for many times, surface roughness Ra value went up from about 0.366 (about grade 7) to a roughness Ra value of 0.082 (about grade 10), and macroscopically, the surface quality improved significantly.



(a)

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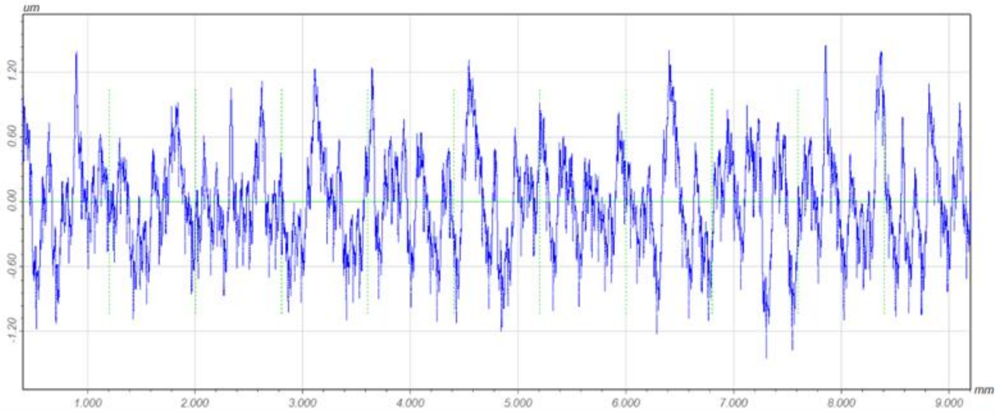
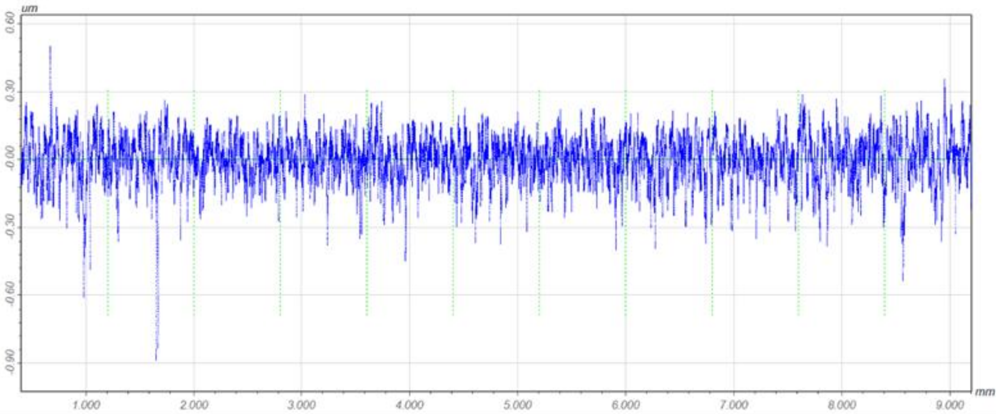


(b)



(c)

Fig. 4 Roughness measurement curve: (a) Aluminum alloy surface (roughness Ra0.140) (b) Hard anodized (roughness Ra0.366) (c) After polishing (roughness Ra0.082)

3.2 Comparison of microscopic morphology before and after polishing

The hard anodized film belongs to porous anodized film, which is composed of barrier layer and porous layer. From Figure 5(a), it can be found that there are many linear protrusions, large pits and a large number of small pores on the surface of the oxide film of aluminum alloy after hard oxidation treatment, and the surface roughness Ra value is 0.366. Figure 5(b) shows that the surface of the hard anodized film becomes smoother after polishing, and the surface quality has been improved significantly from the microscopic point of view, the linear protrusions and small air holes have disappeared, but a small amount of linear grooves appear, and the situation of large craters has not changed much. The surface polishing removal amount of the oxide film is about 11 μm, and the surface roughness Ra value is 0.08. At this time, most of the small pores on the surface of the hard anodized film have disappeared, which shows that the depth of small pores on the surface of hard oxide film on the surface of aluminum alloy is within the majority of 11 μm.

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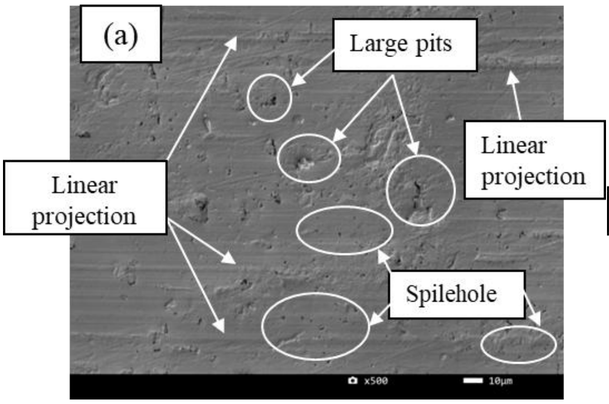

Fig. 5 Comparison of hard anodized film before and after polishing (500x): (a) Before polishing (roughness Ra 0.366) (b) After polishing (roughness Ra 0.082)

3.3 Effect of polishing force on the roughness of aluminum alloy hard oxide film

Under the conditions of polishing speed v=56m/min, feed rate f=0.3mm/r, particle size of sandpaper n=15 μ m, and the average initial roughness Ra value of the aluminum alloy hard anodized film of 6 test pieces is about 0.36, the comparison of hard anodized film roughness under different polishing forces is shown in Figure 6, and the comparison of the thickness of hard anodic oxide film under different polishing forces is shown in Figure 7.

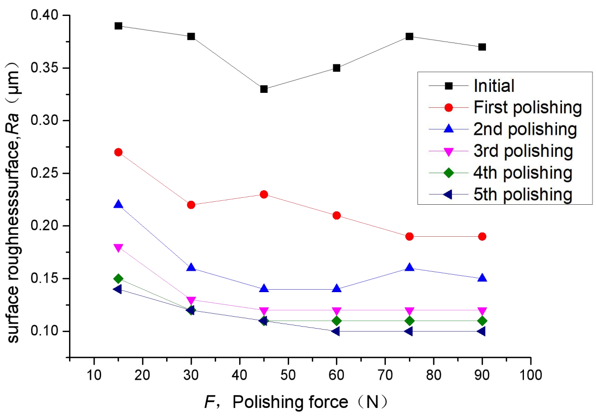

Fig. 6 Comparison of roughness of hard anodized film under different polishing forces

As can be seen from Figure 6, the roughness value of the oxide film keeps decreasing after each round of polishing. The decreasing trend of roughness gradually slows down with the increase of polishing times, and the decreasing trend of roughness value also increases gradually as the polishing force increases.

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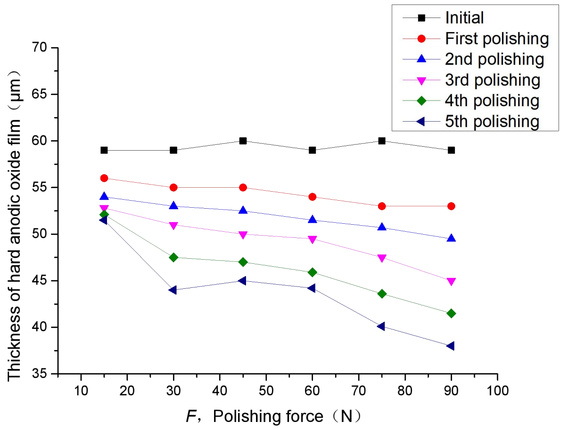

Fig. 7 Comparison of thickness of hard anodic oxide film under different polishing forces

From Figure 7, it can be seen that the thickness of the oxide film keeps decreasing after each round of polishing. With the increase of polishing times, the decreasing trend of the thickness of oxide film is basically the same, and the decreasing trend of the thickness of hard anodic oxide film gradually increases with the increase of polishing force.

3.4 Effect of polishing speed on the roughness of aluminum alloy hard oxide film

Under the conditions of polishing force F=30N, feed rate f=0.3mm/r, particle size of sandpaper n=15 μ m, and the average initial roughness Ra value of the aluminum alloy hard anodized film of 5 test pieces is about 0.38, the comparison of hard anodized film roughness under different polishing speeds is shown in Figure 8, and the comparison of the thickness of hard anodic oxide film under different polishing speeds is shown in Figure 9.

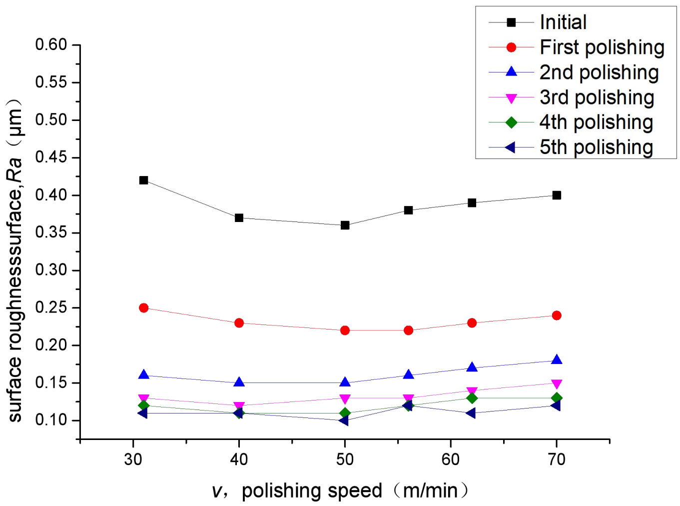

Fig. 8 Comparison of roughness of hard anodized film under different polishing speeds

It can be seen from Figure 8 that the roughness value of the oxide film keeps decreasing after each round of polishing. The decreasing trend of roughness gradually slows down with the increase of polishing times, and the trend of decreasing roughness value is not obvious as the polishing speed increases.

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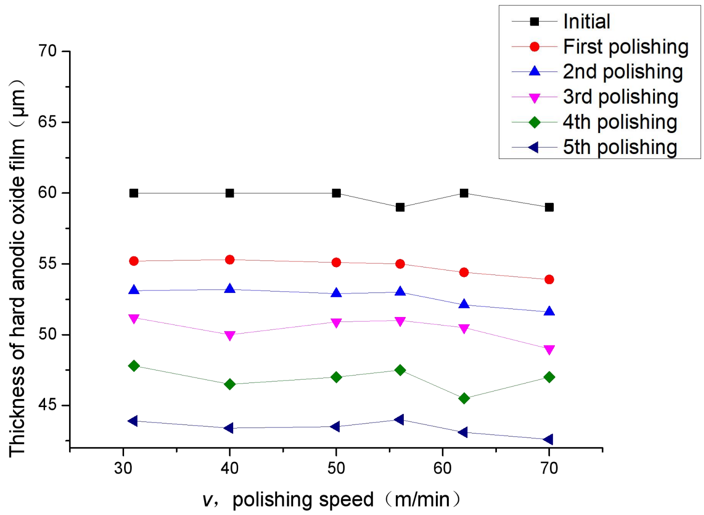

Fig. 9 Comparison of thickness of hard anodic oxide film under different polishing speeds

It can be seen from Figure 9 that the thickness of the oxide film keeps decreasing after each round of polishing. With the increase of polishing times, the decreasing trend of the oxide film thickness is basically the same, and the thickness of hard anodic oxide film has no clear tendency to decrease with the increase of polishing speed.

3.5 Effect of feed rate on the roughness of aluminum alloy hard oxide film

Under the conditions of polishing speed v=56m/min, polishing force F=30N, particle size of sandpaper n=15 μ m, and the average initial roughness Ra value of the aluminum alloy hard anodized film of 6 test pieces is about 0.38, the comparison of roughness of hard anodized film under different feed rates is shown in Figure 10, and the comparison of the thickness of hard anodic oxide film under different feed rates is shown in Figure 11.

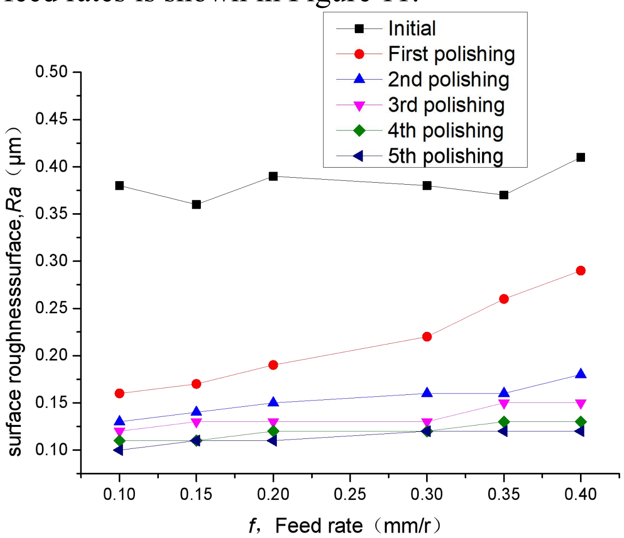

Fig. 10 Comparison of roughness of hard anodized film under different feed rates

As can be seen from Figure 10, it can be seen that the roughness value of the oxide film keeps decreasing after each round of polishing. As the number of polishing times increases, the decreasing trend of roughness decrease under different feed rates conditions gradually slows down, and the decreasing trend of roughness value also decreases gradually as the feed rate increases.

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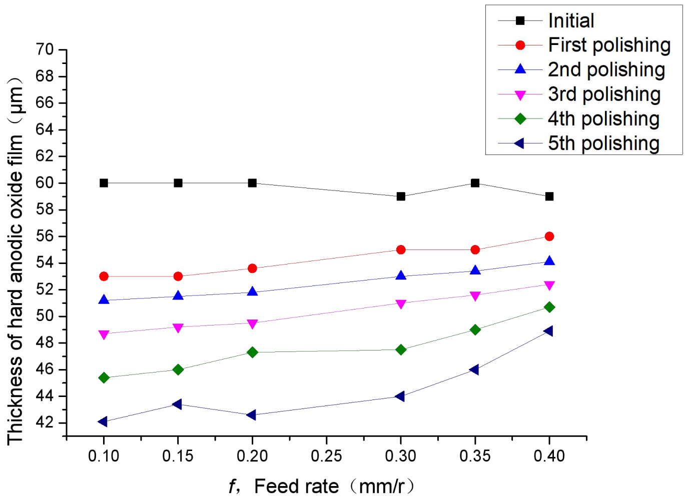

Fig. 11 Comparison of the thickness of hard anodized film under different feed rate

It can be seen from Figure 11 that the thickness of the oxide film keeps decreasing after each round of polishing. With the increase of polishing times, the decreasing trend of oxide film thickness decreases with the increase of feed rate, and the decreasing trend of the thickness of hard anodic oxide film gradually decreases with the increase of feed rate.

3.6 Effect of particle size of sandpaper on the roughness of aluminum alloy hard oxide film

Under the conditions of polishing speed v=56m/min, feed rate f=0.3mm/r, polishing force F=30N, and the average initial roughness Ra value of the aluminum alloy hard anodized film of 4 test pieces is about 0.38, and the comparison of roughness of hard anodized film under different particle sizes of sandpaper is shown in Figure 12, and the comparison of the thickness of hard anodized film under different particle sizes of sandpaper is shown in Figure 13.

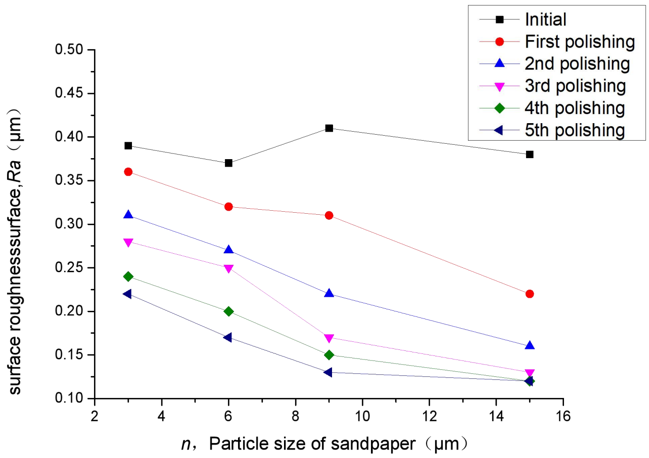

Fig. 12 Comparison of roughness of hard anodized film under different particle sizes of sandpaper

In Figure 12, the roughness value of the oxide film keeps decreasing after each round of polishing. With the increase of polishing times, the decreasing trend of the roughness gradually slows down; and with the increase of the particle size of the sandpaper, the decreasing degree of roughness value gradually increases.

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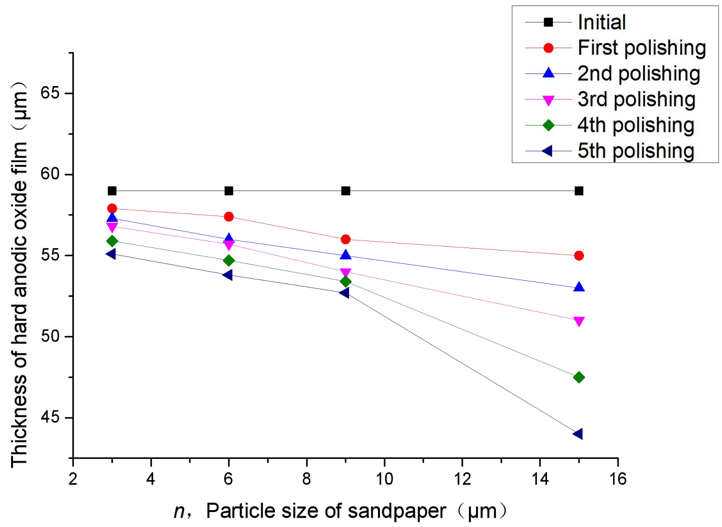

Fig. 13 Comparison of thickness of hard anodic oxide film under different particle sizes of sandpaper

The thickness of the oxide film keeps decreasing after each round of polishing in Figure 13. When the particle sizes of sandpaper n=15 μ m, the decreasing trend of the thickness of oxide film increases with the increase of polishing times. When the particle sizes of sandpaper n=9 μ m, the decreasing trend of the thickness of oxide film decreases with the increase of polishing times. When the particle sizes of sandpaper n=6 μ m, the thickness of hard anodic oxide film has no clear tendency to decrease with the increase of polishing times. When the particle sizes of sandpaper n=3 μ m, the thickness of hard anodic oxide film has no clear tendency to decrease with the increase of polishing times. With the increase of particle sizes of sandpaper, the decreasing trend of the thickness of hard anodic oxide film increases gradually.

4. Conclusion

(1) The surface roughness of 2D70 aluminum alloy decreases by one grade on average after hard oxidation.

(2) The surface of hard anodized film has more linear protrusions, large pits and a large number of small pores, etc. After polishing, the linear protrusions and small pores disappear, a small number of new linear grooves appear, and the situation of large pits does not change much.

(3) With the increase of polishing force, the decreasing trend of roughness value also gradually increases, and the decreasing trend of the thickness of hard anodic oxide film gradually increases.

(4) With the increase of polishing speed, the decreasing trend of roughness value and the thickness of hard anodic oxide film are not obvious.

(5) As the feed rate increases, the decreasing trend of roughness value gradually decreases, and the decreasing trend of the thickness of hard anodic oxide film decreases gradually.

(6) With the increase of particle size of the sandpaper, the decreasing degree of the roughness value increases gradually and the decreasing trend of the thickness of the hard anodized film increases.

(7) The surface roughness value of the hard anodized film decreases gradually with the removal of a certain amount of residual for each polishing. Under the same polishing parameters, with the increase of polishing times the removal residual of hard anodized film is very close each time and the amount of each decrease in the surface roughness value of the hard anodized oxide film is gradually reduced.

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