Effect of Static Pressure on Friction and Wear Behavior of Aluminum Alloy Surface by Ultrasonic Rolling

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Abstract: Aluminum alloy is one of the most widely light structural materials in the aviation manufacturing industry. The fatigue strength and service life of workpiece can be effectively increased with the improvement of wear resistance. The surface quality of 7050 aluminum alloy under different static pressure (200N-1200N) is obtained by ultrasonic rolling. The effect of static pressure on the friction and wear properties of aluminum alloy surface in ultrasonic rolling process were studied by end surface friction and wear experiment, and the micro-morphology of wear surface was analysed by the super depth microscope. The research showed that the wear resistance of the material surface can be effectively elevated by ultrasonic rolling. Wear degree and wear coefficient of the material were the best, and wear resistance can be improved about 1.5% when static pressure was 600N.

1. Introduction
Aluminum alloy components’ performance is largely determined by the quality of the surface, especially in the ocean, aerospace and other fields [1]. The failure forms of mechanical workpiece mainly include wear, corrosion and fatigue, and wear is one of the main causes of mechanical equipment failure. Therefore, it is particularly important to elevate the surface quality of aluminum alloy, change the surface structure of workpiece and increase the service performance of the materials.

Wear resistance is the ability to characterized the surface of material against mechanical wear. The wear resistance of material surface [2,3] can be effectively increased by the surface treatment technology. Ultrasonic rolling technology is a new kind of surface strengthening treatment technology. During the processing, the rolling tip impacts the surface of metal workpiece by high speed, resulting in severe plastic deformation on the surface and subsurface of the material, which makes the surface grain nano-crystallization. It can also improve the hardness and wear resistance of the material [4], and realize the smoothing and strengthening of the material surface. Ye Han [5] studied the influence of ultrasonic rolling on the surface properties of 7050 aluminum alloy workpiece. Ultrasonic rolling strengthening process can greatly reduce the surface roughness of the sample, refine the grain size of sample surface, improve the surface hardness, and increase the surface wear resistance of the material. Zhao Jian [6] studied the influence of ultrasonic rolling parameters on the surface morphology of metal materials, which provided theoretical guidance for the rational selection of ultrasonic rolling parameters.

The research showed that ultrasonic rolling can refine the grain surface of the material and effectively improve the wear resistance of the workpiece. However, there are few studies on the wear resistance of the material surface by static pressure in ultrasonic rolling process. In the paper, the impact of different static pressure in ultrasonic rolling process on the friction and wear properties of
aluminum alloy surface was studied by friction and wear experiment of 7050 aluminum alloy, which provided experimental and theoretical basis for improving the wear resistance for the material by ultrasonic rolling.

2. Experiment

In this experiment, the surface rolling treatment of aluminum alloy was carried out by hawking metal surface processing control equipment, and the surface wear resistance of the treated specimens was studied with the end friction and wear tester.

2.1 Experimental materials and parameters

The chemical composition of the 7050 aluminum alloy is presented in Table 1. The tensile strength of aluminum alloy and yield strength is 524Mpa and 469Mpa, respectively. It is a high strength heat treatable alloy with high strength and corrosion resistance. Which is widely used in aircraft structural workpiece.

| Chemical component | Zn | Cu | Mg | Zr | Mn | Si | Fe | Ti | Al |
|--------------------|----|----|----|----|----|----|----|----|----|
| Mass fraction (%)   | 6.7| 2.5| 2.3| 0.12|0.1|0.12|0.13|0.06|Bal.|

The experiment was carried out by milling machine and ultrasonic tool head was installed on the machine tool through the tool holder. The machining process and experimental equipment are shown in Fig. 1 and Fig. 2, respectively.

2.2 Experimental method

The experimental principle of ultrasonic rolling equipment is shown in Fig 1. In this technique, ultrasonic vibration of a certain frequency can be applied to the surface of the material through punching, which makes the surface of the material severe plastic deformation. It can also realize the surface nano-crystallization.

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The wear experiment equipment was the end face friction and wear experiment machine. In the experiment, the aluminum alloy workpiece was in contact with Φ 20mm cemented carbide which formed the friction pair during the experiment.
The size of workpiece was limited by the size of the friction ring in the end face friction and wear tester. The workpiece can be processed into round block with Φ16mm or a square test piece with side length more than 16mm. In the friction and wear experiment, the specimen was fixed by mosaic blocks at both ends, and the specimen and mosaic blocks were adhered to the end surface of the friction ring. The specimen was 180mm×160mm×4mm as shown in Fig. 2.

In order to obtain more accurately wear quantity of the sample after friction and wear experiment, the sample around the test was weighed by electronic balance with precision of 0.001g. The measured data was processed by the "difference method". The wear rate was calculated by equation (1) and equation (2).

\[
A = \frac{V}{FD} \quad (1)
\]
\[
V = \frac{\Delta m}{\rho} \quad (2)
\]

Where, \(A\) is the wear rate (mm³/Nm), \(V\) is the wear volume (mm³), \(\Delta m\) is the quality of wear (g), \(\rho\) is the density of aluminum alloy (g/mm³), \(F\) is friction force (N), \(D\) is the friction path (m).

3. Results and analysis

3.1 Wear degree
Friction and wear on the surface of the workpiece is an important indicator to measure the surface quality. The ultrasonic rolling specimens were cleaned by ultrasonic after the friction and wear test. Finally, the specimens were taken out to dry and weigh. The variety of the quality samples in the experiment is shown in Fig. 3.

Every time the unworn friction rings were used to increase the accuracy in experiment in order to enhance the accuracy of the experiment and reduce the experiment error. The surface wear rates of the materials under various static pressures are drawn as shown in Fig. 4.
Fig. 3 Quality of specimen around friction and wear test

Fig. 4 shows that wear rate of material surface decreased first and then increased after ultrasonic rolling with different static pressures. The friction and wear properties of the material surface can’t be improved accompanied by the increase of static pressure in ultrasonic rolling. On the contrary, excessive static pressure led to the wear rate increased. When the static pressure ranged from 200N to 1200N, the wear rate reached the minimum when the static pressure was 600N, and the wear rate increased when the static pressure exceeded 600N. The difference between wear rate can reach $4.8\times10^{-4}\text{mm}^3/\text{Nm}$.

Fig. 5 Grain refinement under different static pressure

The main reasons for the above results were that the dense fine-grained structural layer was formed on the surface of material by the ultrasonic rolling. The micro-hardness of the fine-grained structure layer was higher than that of the matrix material. The surface grains gradually became finer, and the surface hardness of the material increased along with the pressure increased. The refined structure layer is shown in Fig. 5 (a). When the static pressure exceeded 600N, as the static pressure increased, the grain of the surface of the material continues to refine, but the surface integrity of the material was destroyed, which formed the certain unevenness, as shown in Fig. 5 (b), which ultimately led to reduced wear resistance of the machined surface.

3.2 Wear coefficient

Wear coefficient is the main index to evaluate the friction and wear properties of material surface. The reduction of wear coefficient can obviously improve the wear properties of material surface. Fig. 6 shows the relationship between wear coefficient and various static pressures. The wear coefficient of the material surface first decreased and then increased with in the static pressure ranged from 200N to 1200N. The wear coefficient decreased to the minimum and reached the optimal parameter design when the static pressure was 600N. The difference of wear coefficient can reach 0.135.

The main reason was that the dislocation density of the surface layer increased sharply, and grain size decreased with the increase of static pressure of ultrasonic rolling. Therefore, the hardness of the surface layer was increased, and the wear coefficient was decreased. The reduction of the wear
coefficient improved the wear condition and wear resistance of the material surface. When the static pressure of ultrasonic rolling continues to increase, the grain on the surface of the material produced large stress, which destroyed the integrity of the material surface, resulting in the friction coefficient of the material increased. The aluminum alloy material by means of ultrasonic rolling and non-rolling treatment was subjected to a friction and wear experiment, after etching (corrosion liquid ratio: 1mlHF+2.5mlHNO3+1.5ml HCL+95mlH2O) and drying. The 2D and 3D morphologies of aluminium alloy materials were observed by super depth microscope as shown in Fig.7.

![Fig. 7 Super depth of field 3D display](image)

Fig. 7 (b) shows that the average surface height difference of aluminum alloy was 25.76μm after friction and wear tests on the samples without rolling. Fig.7 (d) shows that the average surface height difference of aluminum alloy was 16.72μm after the friction and wear experiment of the specimens processed by ultrasonic rolling, it showed that the grain refinement and the wear resistance of aluminum alloy surface were obviously improved after ultrasonic rolling.

4 Conclusion
In this paper, the friction and wear properties of 7050 aluminum alloy were analysed by friction and wear tester and super depth microscope in the process of ultrasonic rolling.

1) The surface microstructure of aluminum alloy can be refined by ultrasonic rolling, and the wear resistance of the surface can be improved about 1.5% compared with the surface without ultrasonic rolling.

2) When the static pressure in ultrasonic rolling process was 200N-1200N, the wear degree and wear coefficient decreased first and then increased with the static pressure increased. The wear degree and wear coefficient of the material were the best when static pressure was 600N.

3) The reason for the above phenomenon was that the increment of static pressure caused the impact force increased on the surface of the material, then plastic deformation occurred, resulted in grain refinement, the friction and wear of the surface were reduced. The surface of the material underwent strong plastic deformation, and the surface integrity was destroyed, so as to increase the
friction and wear of the surface with the static pressure continued to increase.

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