Study on the Anti-friction properties of Chemically Etched surface texture and its synergistic Anti-friction properties with nano-lubricating oil in sheet metal deep drawing process

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Abstract. In sheet metal deep drawing process, the sliding contact between mold and sheet metal will cause friction and wear between sheet metal and die, resulting in tensile breaking and die wear, which will not only shorten the service life of die seriously, but also lead to quality decline and the rising costs of the forming process. In this paper, an anti-friction method using chemically etched surface texture collocated with graphene nanoparticles added lubricating oil was proposed to reduce the COF between sheet metal and die during sheet metal deep drawing process. Several surface textures with different parameters were obtained by surface chemical etching treatment on the die. The surface texture was observed by Laser Confocal Microscope. The results show that the surface texture after corrosion consists of micron-scale convex and concave, in the process of friction, when the pressure is higher than 72 MPa, the concave in the surface texture forms a closed oil concave because of plastic deformation, lubricating oil provides static pressure bearing capacity in the closed oil concave, sheet metal was separated by the oil from die contact surface, which effectively reduced the COF. In addition, the anti-friction properties were tested, which showed that when the mass fraction of graphene nanoparticles added is 0.3%, stable deposited film in the friction contact interface can be formed, and a good filling effect of the lubricating oil in the sealed oil concave can be guaranteed, which can preserve a better integrity of the surface texture.

1. Introduction

Sheet metal deep drawing process is a kind of metal plastic processing method as stamping, which is widely used in automobile manufacturing, rail transit, aviation and so on. But the friction and wear between sheet metal and die during the processing has become the most serious problem hinders the development of sheet metal drawing process[1-4]. Sulaimana et al.[5] studied the performance and physical properties of the DLC/TiALN-coated die surface. The results showed that the presence of a thin oil film reduces the sliding-originated surface tensile stresses of the DLC/TiALN coating. Costing models[6] investigated the tribological behavior of conventional and modified surfaces at the critical radii area with a strip bending rotation test to investigate the cause-effect relations as well as wear mechanisms. Flegler et al.[7] found out that a reduction of the roughness of a mill-finished sheet results in a significant improvement with regard to the friction and wear behaviour in the strip drawing test.

In this paper, the surface texture with different surface characteristics is prepared by chemical etching on C12. Through the friction experiment, the influence of different texture on the friction of die under different pressure is studied, and the nano-lubricating oil with graphene nanoparticles were used in the friction and wear tests to investigate the anti-friction properties in sheet metal deep drawing processing.

2. Chemical etching experiment

2.1. Sample Preparation
Cr12 die steel is selected as the test material, and prepared into Φ10 × 5 mm cylinder. The surface of all specimens was grinded and polished, and the initial surface was obtained after ultrasonic cleaning for 2 min (the surface roughness was about 0.08 μm). Samples were etched by a mixture of ferric chloride, nitric acid (a mass fraction of 65%) and distilled water, with a proportion of 20 g: 30 ml: 10 ml. The etching process was carried out in a 30° constant temperature water bath of 2.5 min, 5 min, 7.5 min, 10 min, 12.5 min, 15 min, 17.5 min and 20 min respectively.

2.2. Sample Characterization

In the experiment, ISO25178 were used to characterize the surface texture observed by laser confocal microscope (LSCM, model: OLS4000) under 50 times magnification.

2.3. Analysis of Corrosion test results

As shown in Figure 1, it is a three-dimensional appearance when the etching time is 17.5 min. After etching, the surface appeared obvious gully appearance with concaves and convexes. At the same time, there formed many oil concaves (closed concaves) convenient for storing lubricating oil, which will squeeze the lubricating oil in the friction process, providing support force and reducing surface friction by hydrostatic effect.

According to the following parameters to evaluate the quality of corrosion surface: Sa and Vvv + Vvc as the main parameters to characterize the surface quality, Ssk and Sku as auxiliary parameters. The specific values are as follows:

As shown in Figure 2, following parameters selected to evaluate the quality of corrosion surface are Sa, Vvv, Vvc, Ssk and Sku. Sa mainly represents the roughness of the surface, Vvv + Vvc reflects the surface storage oil lubrication effect, Ssk and Sku reflects the bearing capacity and undulation degree of rough surface. With the increase of the time of corrosion, Sa presents a wavy change, which is because the corrosion on the surface layer by layer during the time of corrosion. When the time of corrosion reached a certain time, the surface layer is gradually corroded completely, then the surface gradually tends to be smooth, and the next layer continues to be etched.

When the time of corrosion is 7.5 min, the surface is smoother than the other samples with the Sa of 0.67 μm; when the time of corrosion is 17.5 min, the surface is rough with the Sa of 2.546 μm. Vvv + Vvc showed the same change rule as Sa, and the consistency between them ware good. When the time of corrosion is 15 min and 17.5 min, the Ssk is lower than 0, the Sku is lower than 3, the Vvv + Vvc is larger, which means there are more convexes than concaves on the surface after corrosion.
3. Friction experiments

3.1. Test specimen

Five groups of etching samples with different gradients were selected as samples for friction experiment, which were recorded as samples 1, 2, 3, 4, 5 (0 min, 7.5 min, 12.5 min, 15 min, 17.5 min). The lubricating oil used in this test is water-soluble emulsion oil.

3.2. Friction and wear experiments

The experiments verified the effect of surface texture on friction. The actual contact pressure is 9 MPa, 18 MPa, 36 MPa, 54 MPa, 72 MPa (706.5 N, 1413 N, 2826 N, 4239 N, 5652 N); the relative velocity rate is 10 mm/min.

3.3. Results of the friction and wear experiments

As shown in Figure 3, the results showed that after the run-in, the COF curve is stable and the data is efficacious.

Figure 3. Friction experiment of samples 1~5: (a) tensile force curve; (b) COF curve.
As shown in Figure 4, the results showed that with the increase of pressure, the COF of sample 1 increases gradually while the COF of sample 2-5 decreases. At low pressure, the COF of etching sample is generally higher than that of non-etching sample, while at high pressure, the COF of etching sample is generally lower than that of non-etching sample. The lowest COF is 0.095 at the pressure of 72 MPa, which is 49.5% lower than that of 0.188, and the average value of COF of sample 2-4 is 0.644 times of sample 1.

Figure 4. Friction experiments: (a) COF curve; (b) ratio of COF of each sample to sample 1.

4. Anti-friction properties of nano-lubricating oil

4.1. Preparation of the nano-lubricating oil

The nano-lubricating oil is prepared through the method of mechanical agitation and ultrasonic vibration. The graphene nano-particles (as shown in Figure 5) were mixed with water-soluble emulsion oil by the weight percentage of 0, 0.1, 0.3 and 0.5.

Figure 5. SEM graph of graphene nano-particles

4.2. Results

As shown in Figure 6, after selecting the average value of all the points (a total of 50 data points) in 5 s with stable friction, the average friction coefficient curve of each experiment was obtained, which first rapidly increased to the maximum value, then gradually decreased, and finally reached the stable value, that is, changed from static friction to sliding friction, and finally became stable gradually.
The average COF curve of each lubricating oil group on different pressure were shown in Figure 8. The results showed that, with the increasing of the pressure, the COF decrease for all oil samples. Meanwhile, when the percentage of weight achieve 0.3% (sample c), the COF (0.12) is lower than the other samples at the same pressure of pump. But when the pressure is more than 4 MPa, the COF of sample c is higher than pure lubricating oil. That’s because when the low pressure is strong, graphene acts as a solid lubricant, and the oil is not completely extruded by the contact surface, and the combination can be effectively reduced. Because the fabric gap is filled with graphene particles, the lubricating oil is greatly squeezed by the contact surface, the liquid lubrication is greatly reduced, and the partial graphene reduces the effect of the friction effect, so the friction coefficient is still less than the friction coefficient of the friction coefficient of the oil sample c.
Conclusion

According to the results of friction and wear experiments, we can obtain the conclusion as below:
1) With the increase of the load, the COF between die and sheet metal with the surface texture prepared by chemical etching decrease gradually.
2) The surface texture prepared by chemical etching can effectively reduce the COF between die and sheet metal under high load condition (actual contact load $\geq 72$ MPa), with an average reduction of 35.6%.
3) When the $S_s$ of the surface is about 1.3, the effect of reducing friction of the surface texture is the best, and the maximum reduction is 49.5% (actual contact load is 72 MPa);
4) The nano-lubricating oil with graphene nano particles show definite anti-friction and anti-wear performance during the friction and wear test against under the pure lubricating oil condition. When the graphene percentage is 0.3%, the anti-friction performance of the nano-lubricating oil is the best.

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