Study on the film-forming ability of water in oil emulsion with water concentration

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Abstract. This paper mainly explores the influence of different loads on the lubrication performance of point contact under pure rolling conditions and the abrasion phenomenon of water-containing emulsion on the contact area under pure sliding condition. The laboratory apparatus is point contact lubrication friction test equipment and the lubricant is water-containing emulsion.

1. Introduction

With the development of industry, food processing technology has been rapidly improved. At the same time, people pay more attention to hygiene, health and food safety. Therefore, it is important for food processing industry to use cleaning, sterilization, disinfection and other cleaning technologies. But during the process of cleaning, the cleaning fluid will penetrate into the bearing internal lubrication system, resulting in serious damage to the bearing. The common cleaning fluid in the Surfactant is amphiphilic molecules (hydrophilic and oil) which can make water and lubricating oil mixed together to form an emulsion[1].

In 1959, Whetzel and Rodman firstly measured the roll friction coefficient. They found that the amount of emulsifier have has a significant effect on the friction behaviour of the contact surfaces, but the film film-forming ability could not be studied at that time[3]. Nakahara et al. studied the effect of line contact velocity on the thickness of emulsion liquid membrane by means of optical interferometry[4]. Barker made a preliminary measurement of the size of the oil pool in the entrance area under line contact and pointed out that the increase of the film thickness at low velocity resulted from the full oil pool formed by the full oil storage in the entrance area, and w. When the velocity increased, the lack of oil caused the film thickness to collapse[5]. In 2006, Cambiella studied the effect of ionic and nonionic Surfactant concentrations on the film-forming properties of emulsions. The results showed that the type and content of emulsifiers affected the interfacial adsorption behavior of emulsions. The emulsion with stronger more vital adsorption ability at the interface of solid/oil/water interface has the stronger film-forming ability[6]. Liran Ma and Chenhui Zhang studied the mechanism of oil film formation in water and the effects of emulsifier concentration and oil concentration on film formation by means of optical interferometry[7]. The behaviour of emulsion in point-contact and line-contact was observed by Haixia Yang and Schmid. It was found that oil droplets in point-contact were easily squeezed out of the contact zone, which was impossible in line-contact[8]. Based on the characteristics of smooth and continuous transition of viscosity coefficients from thick
film region to thin film region, Sy-wei lo and Tzu-chun Yang established an oil-in-water emulsion model. It is found that the critical volume fraction of oil depends on the viscosity of oil and the factors such as emulsifier, pH value, droplet size and shear rate[9]. Wenyi Liu and Daming Dong et al. [10] found that the thickness of EHL film of w/O emulsion decreased slightly with the increase of water concentration.

2. Experimental equipment and testing principle

2.1. Test equipment

The point contacts lubricating oil film measuring tester is shown in Fig1, which can realize on-line accurate measurement of accurately measure lubricating oil film. It mainly realizes the smooth movement of the steel ball and the disk and the stable capture of the oil film image by the supporting camera. The system includes a ball drive system, disk drive system, image acquisition system and loading system. Because the ball and disk are driven by two systems, the fixed-point control and sliding-roll ratio control, the ball and disk can run respectively. The synchronous belt drive can effectively reduce the vibration caused by the direct connection between the motor and the spindle, and obtain the accurate transmission ratio. The image acquisition system collects the interference image by microscope and camera, the light intensity of each pixel is obtained by computer and the oil film thickness is calculated according to the principle of relative light intensity.

2.2. Principle of optical interferometry in film thickness measurement

The principle of the optical interference principle measuring system is shown in Fig2. When a single-colour incident light reaches the surface of the coating, it will be reflected by two beams on the surface of the coating and steel ball, respectively. Then the two beams of light interfere. The interference captured by high-speed CCD light passes through the microscope. Then transferred to the computer to display the interference fringe, and the thickness of the lubricating film is calculated digitally by the principle of light interference relative intensity.

3. Experimental study on point contact lubrication performance of cleaning agent under the pure rolling condition

In a pure rolling state, the water content of lubricating oil will reduce the film thickness. Now We will explore the influence of different loads of cleaning agents on the point contact lubrication performance under the water-bearing condition.

3.1. Test materials and conditions

In this section, a glass disc-steel ball is selected to carry out pure rolling experiments. The chrome plating on the surface of the glass disc is mainly to increase the refractive index of the material so as to acquire good interference images of a lubricating oil film. The lubricating oil was a mixture of PAO4
and PAO40 with a ratio of 1:1. The viscosity of PAO was 119 mpa s at 25℃. The cleanser was formulated with Surfactant (OAE-12). Before the experiment, the surfactant was mixed with water at a ratio of 1% (OAE-12) + 99% water. The prepared mixture is added to PAO oil and stirred uniformly to form an emulsion. The properties of the emulsion are shown in table 1.

| Sample | Proportion | Viscosity of 25 ℃ (mPa s) |
|--------|------------|--------------------------|
| 1      | 5%(1%OAE-12+99%water) + 95% PAO | 133.1 |
| 2      | 20%(1%OAE-12+99%water) + 80% PAO | 140.0 |

3.2. Test procedures and phenomena

Loading 8.3 N and 24.9 N, respectively, the oil film interference images and data obtained by the experiment. The data lines of emulsion liquid film thickness are drawn by double logarithmic coordinates. The thickness of two different concentration emulsion lubrication films under different loads is compared:

3.3. Analysis of test results

Through analysis and comparison, the test shows that the film thickness of the same emulsion decreases with the increase of load, and it has a good linear relationship with the entrainment velocity. The general trend is the same.

4. Experimental study on point contact lubrication performance of cleaning agent under the pure sliding condition

4.1. Test materials and conditions

In a pure rolling state, the water content of lubricating oil will reduce the oil film thickness. Then, the effect of the water content of lubricating oil on lubrication properties under pure lubrication conditions is studied. It is found that the contact area will be worn when the lubricant is an emulsion. In order to study the abrasion phenomenon, a sapphire plate with higher elastic modulus will be used to replace the glass plate in this section.

The test condition is that the sapphire disc rotates while the steel ball remains stationary, the pure disc sliding contact condition. The contact area is completely immersed by emulsion during the test. The sliding speed was 160 mm/s. The emulsion was 5% (1% OA-E-12 + 99% water) and 95% PAO. The load was 8.3 N and 24.9 N.
4.2. test procedures and phenomena

Fig. 5 shows the dimensions of static contact interference rings between steel ball and sapphire disc under different loads. The actual pressure and diameter of the contact zone are calculated by Hertz contact theory.

The duration of the test was 20 seconds, from the start to the stop of the Sapphire disk. At the end of the test, different degree of abrasion was found on the surface of the steel ball. When the load is 8.3 N, 5% (1% OAE-12 + 99% water) + 95% pao emulsion from rest to the end of the test, the contact area is shown in Fig.6. As can be seen from the diagram, the contact area is surrounded by water at rest, and the surface of the steel ball is abraded when the sapphire disc stops.

At the end of each set of tests, the sapphire disc was removed, the ball was cleaned with alcohol, the surface of the ball was grazed by CCD and marked under a microscope. Fig.7. and 8 show the surface abrasions of steel balls at different concentrations of emulsion under different loads.
4.3. Test procedures and phenomena

The test results show that when the lubricant is an emulsion, the contact area will be worn, and the surface area of the steel ball will become larger and more serious severe with the increase of load.

5. Observation of water drop in contact area under oil-in-water lubrication

Because the sapphire plate can only observe the emulsion flow around the contact area. The thermal imager is used to observe the emulsion droplet flow in the contact area through the temperature change of the contact area. Based on the characteristics of different specific heat capacity and emissivity of water and oil, the difference of specific heat capacity of water and oil in the contact zone is caused by the difference of water and oil in the water-in-oil condition. The emissivity of the droplet is much higher than oil. So if the droplet enters the contact zone, it is bound to see two different and steep temperature rises. With distinct temperature boundaries, the temperature is not like the natural flattening of the temperature rise under pure oil lubrication. In order to increase the contact temperature, the oil-in-water combination of 80% PAO40 + 20% H2O was selected and the load was 24.9 N.
The process of water droplets entering the contact zone is clearly seen in the four images. In the start-stop phase, the phenomenon in the diagram will occur. After a smooth operation, it is difficult to see the water droplets into contact.

6. Conclusion
In this paper, the influence of water-containing emulsion on lubrication performance of contact zone was studied by using point-contact lubrication film measuring instrument, steel ball-glass plate and steel ball-sapphire plate respectively. The main conclusions of this study are as follows:

1) Under the pure rolling condition, the water content of lubricating oil will decrease and the oil film thickness will decrease if load increases;
2) Under the pure sliding condition, when the lubricant is the emulsion, the surface of the steel ball will be abraded, and the degree of abrasion increases with the increase of load;
3) The difference of emissivity between the water droplet and oil is used to verify that the water droplet will enter the contact zone during the start-stop phase and break the oil film so that causes the contact zone wear.

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