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Observation of Contact Area of Rubber Wheel Using an Ultraviolet-Induced Fluorescence Method

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ABSTRACT – An ultraviolet-induced fluorescence method was used to measure the contact area between a cylindrical rubber wheel and flat glass. The experiment was carried out using pyranine as the fluorescence dye, and three variants of load in static and dynamic conditions. The contact area was captured by high-speed camera and analyzed using s software. Results showed that the contact area became wider as the applied load increased from 39.2 to 117.6 N in the static condition; in the dynamic condition, however, the contact area decreased as speed increased from 22.5 to 90 mm/s.

1. INTRODUCTION

Over the last several decades, the study of thin film thickness in elastohydrodynamic lubrication (EHL) has become the focus of many researchers. In 1996, a group study presented an experimental technique that could provide very high-resolution thickness measurement in the horizontal and vertical directions at around 1.4 µm and 0.5 nm respectively [1]. This technique was called relative optical interference intensity (ROII). In addition to ROII, other techniques have been used to measure thin film thickness. One called the fluorescence technique, was introduced in the 1970s by Ford et al. [2 - 3]. This technique was the first to apply fluorescence in tribology. The advantage of the fluorescence technique is that it can measure the actual amount of lubricant that exists between two surfaces. Thus, this observation approach is well suited to investigating the contact area between a rubber wheel and flat surface.

The purpose of this study is to identify the contact area (in this case contact width) between a rubber wheel and flat glass using a fluorescence technique, specifically, the ultraviolet-induced fluorescence method. As fluorescence dye, water-soluble dye pyranine with density of 3200 mg/l, was used in this experiment.

2. METHODOLOGY

2.1 Experimental apparatus

The contact area for the fluorescence image was produced using a rubber wheel on a surface of flat glass covered by fluorescence fluid. The rubber wheel was shaped in the form of a cylinder, with a diameter and width of around 80 mm and 32 mm, respectively; the flat glass was a square, 100mm in length and 5mm thick. In this apparatus, the contact area was observed with a digital high-speed camera (HAS-U2; DITECT, Ltd, Japan) with 18 different effective image sizes and a maximum frame rate of 7500 frames per second (fps). The camera was located beneath the flat surface, where the distance of camera and observed contact area could be changed as desired. The fluorescence excitation was provided by an ultraviolet (UV) light, which produced a 367nm maximum wavelength high-power UV light.

2.2 Experimental method

The contact condition was captured with the high-speed camera under static and dynamic conditions. In the static condition, the rubber wheel was pressed by 3 different applied loads. Meanwhile, in the dynamic condition, the loaded rubber wheel moved on the flat fluorescence -liquid-covered glass at 3 different speeds. The experimental conditions are listed in Table 1. Pyranine is a chemical compound ($C_{16}H_7Na_3O_{10}S_3$) that is often used for optical analysis in bioscience and medical science. The captured images were then analyzed with software using a grayscale to differentiate the contact area and its surrounding.

Table 1 Experimental conditions

No	Contact condition	Moving speed (mm/s)	Applied load (N)
S1	Static	-	39.2
S2	Static	-	78.4
S3	Static	-	117.6
D1	Dynamic	22.5	78.4
D2	Dynamic	45	78.4
D3	Dynamic	90	78.4
D4	Dynamic	180	78.4

3. RESULTS AND DISCUSSION

3.1 Contact area due to load

Figure 1 shows the contact area between the cylindrical rubber wheel and flat glass covered by fluorescence liquid at three selected applied loads in the static condition. The point 0 mm on the x-axis indicates the central position of the contact area, while the y-axis signifies the value intensity of the fluorescence image in the range of 0 (min) to 254 (max). This figure proves that the present method can clearly differentiate the contact area from the surrounding area without contact. It can be seen that the contact area became wider as the applied load increased. The contact width increased by 3.4 mm (from 6.2 to 9.6 mm) as the applied load increased from 39.2 to 117.6 N. A low amount of fluorescence was observed inside the contact area, which was assumed to be due to noise or dirt.

Figure 2 compares the contact area obtained using the present method and the Hertz theory for parallel cylindrical rubber wheel and flat glass (equation 1). It can be seen that the contact width measured using the fluorescence method was more than a 95% match for the Hertz theory calculated-contact width.

According to the Hertz theory, contact area for cylindrical materials can be calculated using the following equation,

$$a = 2\sqrt{\frac{4WR}{\pi E^*}} \quad (1)$$

where,

a = contact width
W = applied load per unit width
R = relative radius of curvature
E^* = reduced modulus

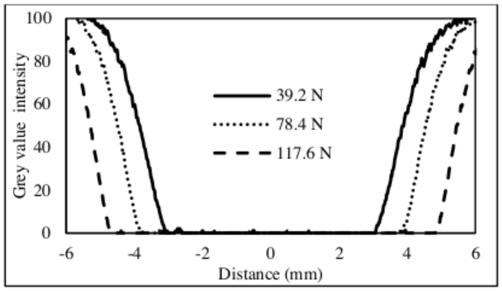

Figure 1 Contact width due to loads.

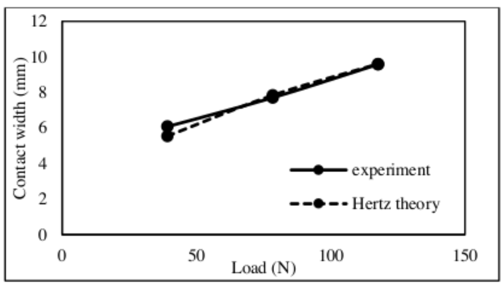

Figure 2 Contact width comparison.

3.2 Contact area due to rotating speed

Figures 3 and 4 show the effect of rotating speed on the contact area between a rubber wheel loaded with 78.4 N and a flat glass. It is evident that rotating speed affects the contact area, with the contact area becoming significantly smaller in the first 3 speed variants (from 22.5 to 90 mm/s), and then subsequently becoming slightly smaller. Looking at the rubber contact deformation in Fig. 3, there appears to be some fluorescence liquid between the rubber wheel and flat glass when the wheel moved at high speed. It seems that there is a complete separation by a thin layer of fluorescence liquid between the wheel and flat glass at higher speeds. Myant at al. [4] found a similar contact area tendency in an experiment using a hemisphere elastomer on glass disk at 5 different speeds, ranging from 2.19 to 579 mm/s.

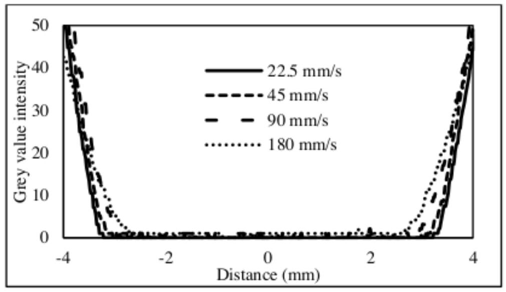

Figure 3 Contact width due to moving speeds.

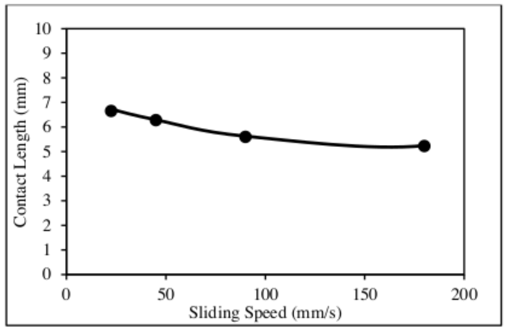

Figure 4 Contact width reduction due to moving speed.

4. CONCLUSIONS

An ultraviolet-induced fluorescence method using a pyranine dye of 3200 mg/l was used to observe the contact area between a cylindrical rubber wheel and flat glass. We found that the contact area became wider as the applied load increased under static condition. In the moving condition, however, the contact area between the loaded rubber wheel and flat glass was reduced as moving speed increased.

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