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FILM FORMING CHARACTERISTICS OF OIL-IN-WATER EMULSIONS IN ELASTOHYDRODYNAMIC CONTACTS

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INTRODUCTION

Oil-in-water emulsions are the most widely used lubricants in metal rolling, as they provide a combination of cooling and lubricating properties. These avoid severe metal-to-metal contact by forming a separating (elastohydrodynamic) film between the metal strip and the rolls so as to prevent scuffing, limit wear and control friction.

Oil-in-water emulsions show a complex pattern of behaviour which can be described in three stages (see Figure 1) [1]. At low speeds (Stage I), the oil-in-water emulsion forms a small pool of oil phase in the contact inlet and the elastohydrodynamic film thickness has the same value as that formed by neat oil and increases with increasing speed. At some critical speed (first critical speed) however, the rate of pool formation becomes insufficient to balance the rate at which it passes through and around the contact and starvation ensues, causing the film thickness to fall quite sharply with increasing speed (Stage II) [2]. The film thickness, however, does not fall to zero, and at a still higher rolling speed (second critical speed), it starts to rise again and Stage III behaviour ensues. Very little experimental work has been done at speeds above 4 ms^{-1} [3], where stage III behaviour is prevalent, therefore this behaviour is still not understood. This is unfortunate for metal rolling lubrication, since the entrainment speeds in metal rolling are generally greater than 5 ms^{-1} (can reach 20ms^{-1}) and it appears that there is a marked change in emulsion behaviour above this speed.

In this paper, experimental film thickness measurements for speeds of up to 20 ms^{-1} and visualization of the contact region for oil-in-water emulsions have been carried out. This was done to investigate the composition of the fluid entrained inside the contact and to better understand the lubrication mechanisms which occur at various speeds.

EXPERIMENTAL TECHNIQUES AND PARAMETERS

The main experimental equipment used in this investigation was a conventional optical EHL test rig which was modified to operate at high speeds (up to 20 ms^{-1}) under controlled sliding conditions. A reflective steel ball is loaded against a rotating glass disc with a semi-reflective coating and is half immersed in the lubricant. During testing, the oil-in-water emulsion is continuously circulated to prevent it from separating.

Optical interferometry was used together with a spectrometer to measure the mean film thickness over a small central region of the circular contact. Film thickness measurements were stable with time (within ±5nm) for the whole range of speeds.

Laser induced fluorescence (LIF) was used to image the contact. The oil phase in the oil-in-water emulsion was dyed using an oil soluble fluorescer, so that, when illuminated with laser light, a fluorescence intensity map which reveals the oil content at the inlet of the contact and in the inlet itself could be achieved. To date, the use of the LIF technique has been limited to low speeds (up to 1 ms^{-1}).

Tests were carried out in nominally pure rolling conditions, with the disc and ball being driven independently at speeds of up to 20 m s^{-1}. The emulsion had an oil-in-water concentration of 3% emulsifiable ester oil.

RESULTS AND DISCUSSION

Figure 1 shows film thickness measurements of the emulsifiable oil in neat and emulsion form compared to predicted film thickness values for water. Up to a speed of 0.2 ms^{-1}, film thickness measurements of neat oil and emulsion are very similar. After this speed, starvation ensues and the film thickness falls sharply with increasing speed. Above 3 ms^{-1}, the film thickness rises and seems to be slightly higher than the predicted value for water, suggesting that the water phase of the emulsion predominates in the film formed under these conditions.

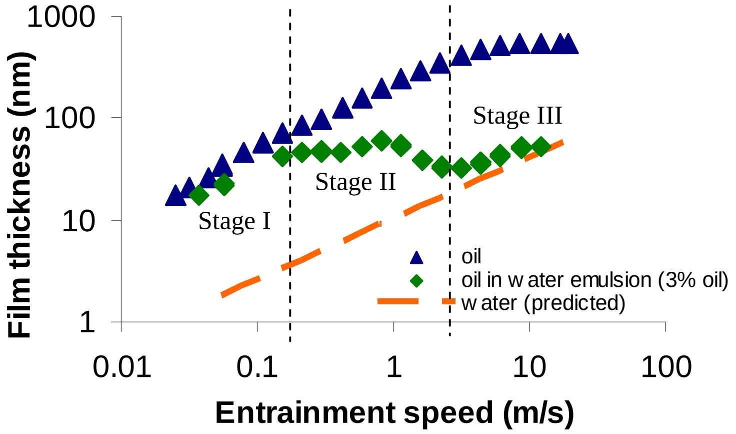

Figure 1 – Plot showing film thickness measurements obtained using neat oil and oil-in-water emulsion (3% oil) compared to predicted film thickness values for water (test parameters: load= 20N, *T*= 40℃, p_0= 0.5GPa, *E'*= 110GPa)

Figure 2 shows how the average oil intensity both within the contact and at the inlet varies with entrainment speed. The values plotted in this figure are obtained from fluorescent images obtained using LIF.

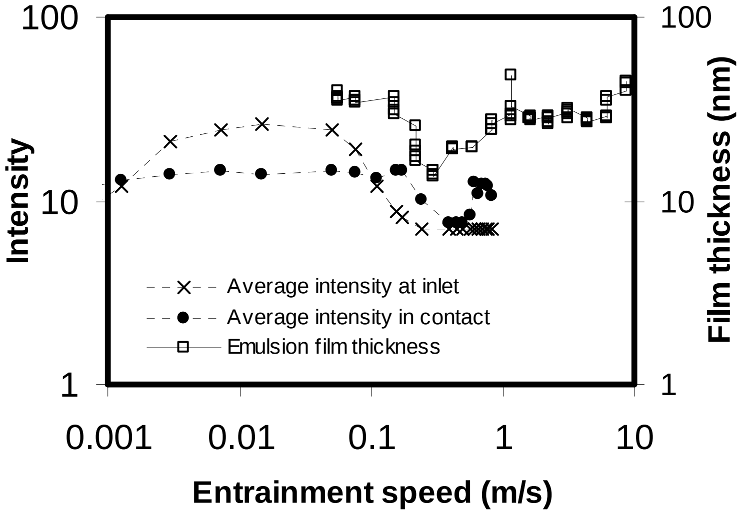

Figure 2 – Intensity plots of contact and inlet compared to film thickness values obtained using optical interferometry under the same conditions (test parameters: load= 20N, *T*= 20℃, p_0 = 0.5GPa, *E'* = 110GPa)

The contact region appears to be less intense than the inlet due to the fact that, the film thickness inside the contact is smaller than that at the inlet. As the speed increases, the intensity inside the contact changes (see Figure 2). The fluorescent intensity within the contact correlated well with optical film thickness measurements under the same conditions. One important observation is that, as the emulsion goes beyond the second critical speed (0.4 ms^{-1}), the intensity of the central film seems to increase more rapidly, suggesting that some oil is entrained in this stage.

Figure 3 shows a snapshot of the contact obtained using LIF at low speeds. Dark areas denote the presence of water (or air) while bright areas denote the presence of oil. As the emulsion approaches the inlet (top side on Figure 3), the oil droplets are preferentially drawn into the conjunction while most of the water is squeezed out (concentration region). The emulsion then inverts and a pool of mainly oil is seen at the inlet. This behaves like undiluted oil and builds up the pressure necessary for film formation (pressurization region).

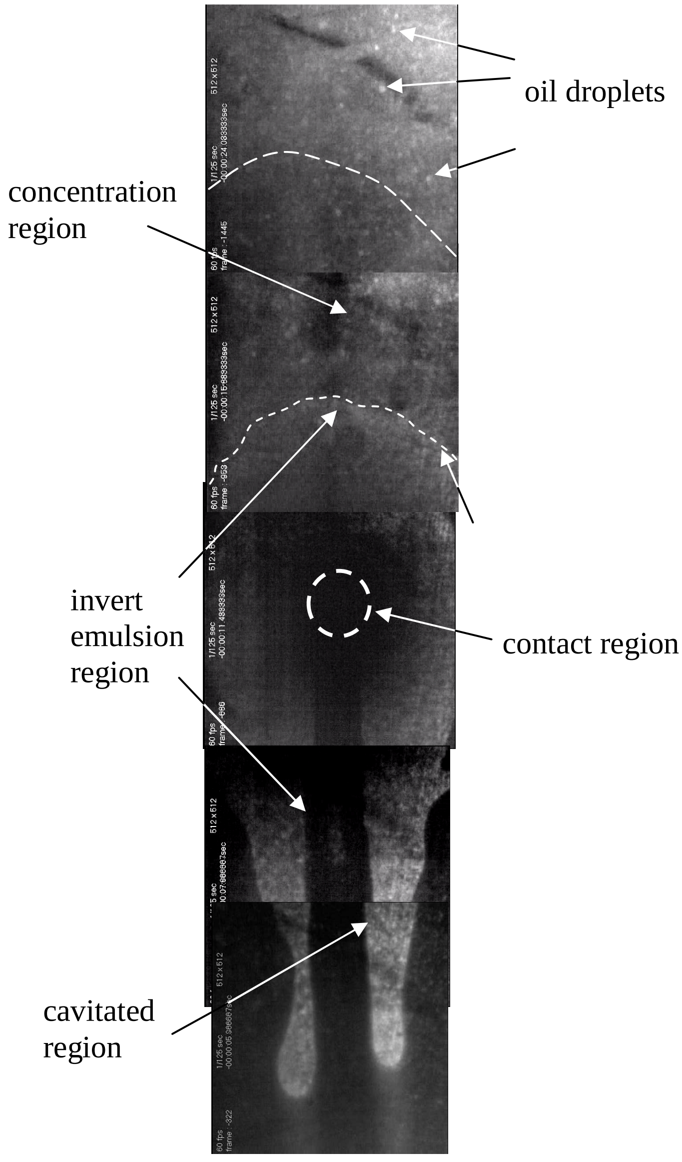

Figure 3 - Images of contact at low speed obtained using LIF technique (inlet on top) (test parameters: entrainment speed= 0.002 ms^{-1}, load= 20N, *T*= 20℃, p_0 = 0.5GPa, *E'*= 110GPa)

CONCLUSIONS

An optical rig has been modified to measure the thickness of the film formed by oil-in-water emulsions in a rolling contact at speeds of up to 20 ms^{-1}. In addition to this, laser induced fluorescence has been used to visualize the contact at low speeds.

The film thickness results show that, at low speeds, the emulsion behaves in a similar way to neat oil. Images of the contact obtained using LIF support this, as it can be seen that, at low speeds, most of the water is squeezed out of the contact inlet and a pool mainly of oil is present at the inlet. At high speeds, film thickness results suggest that the water phase of the emulsion predominates in the film formed under these conditions. Beyond the second critical speed, the fluorescent intensity of the central film increases more rapidly, suggesting that some oil is still entrained in this stage.

ACKNOWLEDGMENTS

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