12 Extreme-pressure and anti-wear additives

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12.1 Introduction

To understand the nature and function of extreme-pressure and anti-wear additives, it is useful to consider again the fundamental nature of lubrication by fluids, and of wear. In an ideal situation, lubricated surfaces are separated by a thick film of lubricant, and all the forces between the surfaces are transmitted by the lubricant. If, for any reason, the thickness of the lubricant film decreases, a point will be reached such that the contact stresses are carried increasingly by direct solid/solid contact between the surfaces or, at best, by interposed films of lubricant or other materials which are so thin that they behave as if they were solid.

The situation can be explained most simply in terms of the diagram in Figure 12.1, usually known as a Stribeck curve, but in fact first presented in this form by McKee and McKee (1929). The diagram was first used in connection with a plain journal bearing, but is equally appropriate for any bearing in which a ‘pressure wedge’ contributes to the formation of the lubricant film. The figure shows the relationship between the friction in the bearing and the expression $\eta N/P$, which is sometimes called the Hersey number. $\eta$ represents the lubricant viscosity, $P$ the bearing pressure, and $N$ the speed of rotation of the shaft or, more generally, the relative speed of movement of the bearing surfaces. The zone in which a thick film of lubricant

![Figure 12.1 Relationship between lubrication regime and Hersey number. Reproduced with permission from A.R. Lansdown.](image-url)
is present is termed 'hydrodynamic lubrication'. In this zone the lubricant film is thick enough to prevent any solid/solid contact between the bearing surfaces, and the friction is entirely due to the viscosity of the lubricant. The bearing load is carried more or less uniformly over the whole of the load-bearing area, and the stresses are therefore low. Since there are no high local stresses on the asperities of the bearing surfaces, there is no wear.

Three factors can lead to a reduction in the thickness of the lubricant film. These are: (i) a reduction in the lubricant viscosity, for example due to increasing temperature; (ii) a reduction in speed; or (iii) an increase in bearing load. Any of these changes causes a decrease in $\eta N/P$ and, therefore, a move towards the left-hand side of the diagram.

As the lubricant film becomes thinner, it reaches a stage at which its thickness is similar to the height of the microscopic roughness, or asperities, on the bearing surfaces. At this stage the thickness of the film and the load distribution are no longer uniform, but vary with the shape of the asperities. Where asperities on the opposing surfaces come close together, the film thickness will be low and the stress high. There will also be lateral stresses on the asperities because of the pressure variations, and these lateral stresses will begin to contribute to the friction. If the combined perpendicular and lateral stresses on an asperity are high enough, then repeated stress cycling can cause fatigue. This leads initially to surface or sub-surface microcracking and, eventually, to a particle breaking away from the surface: this is the first manifestation of wear, called fatigue wear.

Any further progressive reduction in $\eta N/P$ will further decrease the film thickness until there is actual solid/solid contact between the bearing surfaces. In the earliest stages this contact will only take place at the higher asperities, while a high proportion of the bearing load continues to be carried by the fluid. With further reduction in film thickness, an increasing proportion of the load will be carried by solid/solid contact between the asperities. This situation is represented by the 'mixed lubrication' zone shown in Figure 12.1. In this zone the friction is increasingly due to the solid/solid interactions and decreasingly due to the fluid viscosity.

Finally, the situation is reached in which solid/solid interactions carry all the load and generate all the friction. This is the zone called 'boundary lubrication' in Figure 12.1.

When solid/solid interactions occur between asperities, the asperities tend to adhere and the friction thus produced is called adhesive friction. The stresses on the asperities are sufficient to remove material, and this material loss is called adhesive wear. If the asperities of metal surfaces were purely metallic, the adhesion between them would be very strong, and would cause high friction and severe wear. In practice, bearing surfaces are normally covered with a film of metal oxide. Adhesion between asperities that are oxide-coated tends to be much milder and leads to lower friction and mild wear. Mild wear generally represents removal of metal oxide and, if the