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A MASTER-CURVE FOR THE SHEAR DEGRADATION OF ROLLING BEARING GREASES

CATEGORY: GREASE

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INTRODUCTION

Most rolling bearings are lubricated by grease, a multi-phase visco-elastic material with a high consistency. The relatively stiff grease creates a lubricant reservoir inside the bearing from where the supply of lubricant towards the contacts takes place [1]. During operation, the grease may mechanically age due to the thickener breakage and oil loss [2]. Chemical degradation is mainly caused by oxidation [3]. The aged grease may lose its original lubricity, ultimately resulting in surface damage and failure of the bearings [1]. This can be prevented by bearing re-lubrication well before the 'end of the grease life'. This end of grease life can be calculated using models. For the further development of these models a good understanding of the grease degradation mechanism is required.

In this work, grease mechanical degradation was studied by shearing fresh grease samples at controlled shear rates and temperatures for different periods of time. Shear softening was observed due to the breakage of the thickener micro-structure. This was quantified through the rheological properties. Based on this, a Master Curve was developed and applied to grease aging inside a rolling bearing.

COUETTE AGING TESTS

Fresh lubricating greases thickened by lithium, lithium complex and polyurea were sheared in an in-house made Couette Aging Machine (Figure 1). Atomic Force Microscopy (AFM) measurements showed that all fresh greases have a fibrous thickener micro-structure. Inside the Couette Aging Machine, a uniform (apparent) shear field was created between the rotating bob driven by a magnetic coupling and the stationary housing case immersed in a thermal bath. The input work W was calculated from the drag torque and the rotating speed. The aging temperature T was recorded by a thermocouple. To prevent grease leakage, the aging head was sealed by an O-ring. Rheological measurements were performed for the grease samples, where the zero-shear viscosity η_0 was obtained from the Flow Curve test [4] and the yield stress τ_y was obtained from the Oscillatory Strain Sweep test [5]. Fourier Transform Infrared Spectroscopy confirmed the absence of oxidation.

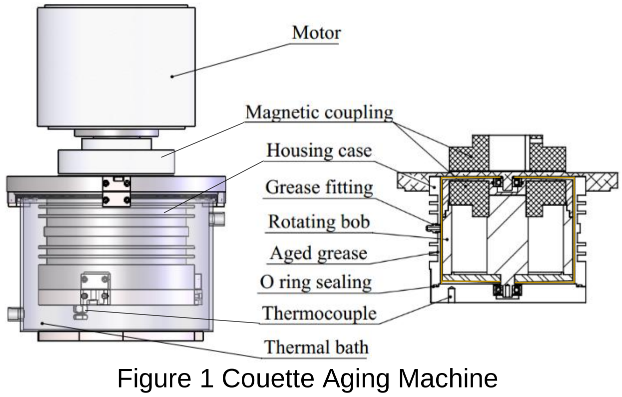

Figure 1 Couette Aging Machine

GREASE AGING MASTER CURVE

Figure *2* shows the grease aging behavior for lithium based grease with mineral oil as base oil (denoted as Li/M) and polyurea based grease with ester as base oil (denoted as PU/E) at different aging shear rates and temperatures. To take both shear and temperature effects into account, grease aging was analyzed from an energetic point of view, where a 'modified energy density E_m' was introduced. It was calculated as the product of the input work and an 'Arrhenius correction factor' per unit of grease volume:

$$E_m = \frac{C_T \cdot W}{V}, \quad (1)$$

where V is the aged grease volume in mm^3, W is the input work in J and C_T is the Arrhenius correction factor, which was derived from the time sweep isothermal aging tests: for lithium greases, $C_T = 2^{\frac{T-T_0}{15}}$; for polyurea greases, $C_T = 2^{\frac{T-T_0}{10}}$. Here T_0 is the reference temperature 25℃. This factor is in line with the temperature impact on the reduction of grease life [1,6].

According to Figure *2*, the change of grease rheological properties (η_0 and τ_y) with E_m shows a two-phase behavior, which is closely related to the change of the thickener micro-structure during aging. As shown in the AFM images in Figure *2*-a, in the first phase, the original thickener network is broken by shear, along with fiber re-orientation and cutting. This leads to a progressive shear softening. Afterwards, the aging is dominated by the scission of smaller fiber fragments, resulting in an asymptotic behavior.

A Master Curve was developed, which describes this two-phase degradation behavior under different shear rates and temperatures:

$$Y = \frac{Y_i - Y_\infty}{1 + K \cdot {E_m}^n} + Y_\infty. \quad (2)$$

In this equation, Y represents a rheological property (η_0 or τ_y), with the index i denoting the initial rheological value for fresh grease and ∞ the ultimate aging value; K and n are fitting constants. This equation fits well with the tested greases, see the black fitting curve drawn in Figure *2*. Derived from the Couette aging tests, this Master Curve was validated by aging PU/E inside a grease worker, where E_m was calculated by summing the product of the drag force and the plunger displacement divided by the aged grease volume [7]. The grease worker aging results show a good agreement with the Master Curve (see Figure *2*-b), which suggests that the Master Curve is generally applicable for prediction/describing the mechanical aging of grease.

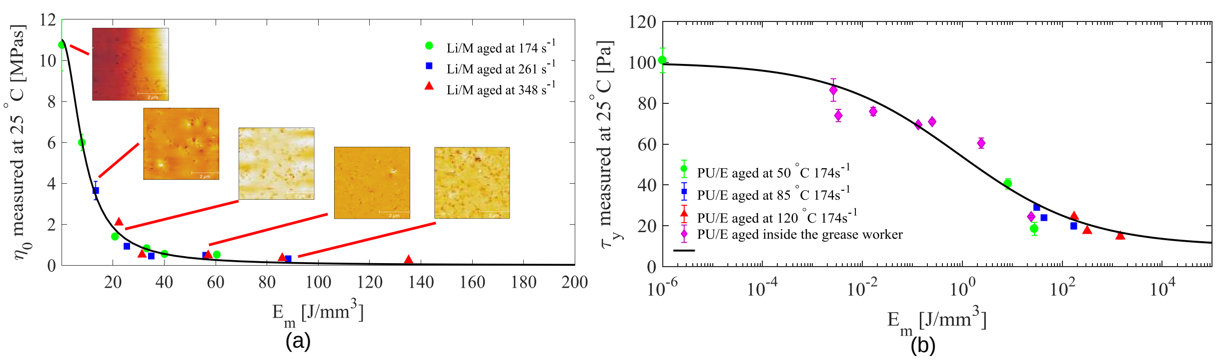

Figure 2 Grease aging Master Curve for (a)Li/M; (b)PU/E

To apply the Master Curve on the aging of grease inside a rolling bearing, fresh PU/E was worked inside shielded deep groove ball bearings (30% filling of the bearing free volume) using an R0F+ test rig at specific running conditions: 10000rpm and 15000rpm, $C/P = 40$, $T = 120$℃ for different periods of time. Afterwards, the aged grease inside the bearing was collected and evaluated using the rheometer.

In Figure *3*, the yield stress τ_y for fresh and aged PU/E was plotted versus the bearing friction energy density E_b, which was calculated by multiplying the bearing frictional power loss [8] with the running time divided by the filling volume. The R0F+ results shows a similar aging trend as the PU/E Master Curve in Figure *2*-b. However, to reach a similar yield stress value, there is a large energy discrepancy between E_b in the bearing and E_m in the Couette Aging Machine. This is because of the inhomogeneous aging condition inside the bearing, where only a fraction of grease will be aged [9], whilst the evaluated volume for the rheological test was collected as a mixture of the grease from various parts of the bearing. In addition, E_b

was calculated from the bearing frictional power loss, which combines the bearing sliding and rolling friction moment and is larger than the energy dissipated by aging the grease. To compensate for the uncertain aging conditions inside the bearing, E_b was multiplied by a correcting factor C_e. When plotted versus $E_b * C_e$, the R0F+ results show a good agreement with the Master Curve (blue squares in Figure *3*). Therefore, this concept is also applicable for the grease aging inside a rolling bearing.

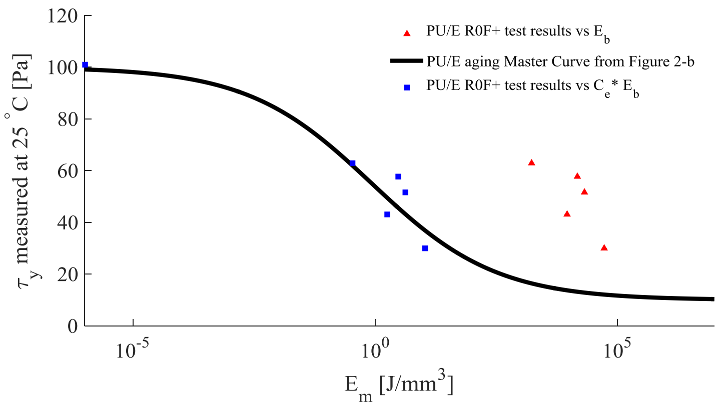

Figure 3 PU/E grease aging curve based on the R0F+ bearing results

CONCLUSION

In this work, grease mechanical degradation was studied by shearing fresh greases using an in-house made Couette Aging Machine. Two-phase aging behavior was observed, which is closely related to the change of the thickener micro-structure under shear. A Master Curve was developed to describe this grease aging behavior from an energetic point of view, which was subsequently validated in a grease worker. It was shown that this concept is also applicable for grease aging inside a rolling bearing and could be used as a potential building block for grease life prediction.

ACKNOWLEDGMENTS

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KEYWORDS

Lubricant degradation, rheology, greases