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An engineering model to estimate consistency reduction of lubricating grease subjected to mechanical degradation under shear

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ABSTRACT

A model is presented that uses the principles of irreversible thermodynamics to predict the reduction in consistency of a lubricating grease undergoing mechanical shearing action. Here we restrict our attention to operating temperatures far below the initial activation energy needed to initiate chemical degradation or base oil evaporation. Thus, mechanical degradation is the dominant degradation process. The predictions of the model are validated using the experimental results obtained by testing three greases subjected to different shear rates and temperatures. Illustrative examples are presented to demonstrate the application of the model.

1. Introduction

Estimation of grease life is essential for determining the lubricant suitability for specified operating conditions and for predicting re-lubrication intervals in a bearing. Currently, only empirically-based models – developed primarily by bearing manufacturers – are available for estimation of grease life [1]. A good summery of the state-of-the art on the available empirical models is presented by Lugt [1]. The non-empirical models primarily pertain to: chemical models that predict the thermal oxidation life of the grease based on antioxidant depletion time using different approaches such as the FTIR techniques [2,3]; application of the Arrhenius activation energy law using PDSC [4]; and thermogravimetric analysis [5]. Chemical models are applicable in high temperature applications where chemical degradation is dominant. In low and moderate temperatures, however, mechanical degradation may prevail and must be properly taken in consideration.

The life of a grease with a low mechanical stability is affected by Mechanical degradation. A summary of the importance and effectiveness of different mechanical stability tests is presented by Lundberg and Höglund [6]. Mechanical degradation of grease has been studied from an energy point of view. By analogy to the model of solid body wear, Kuhn [7] defined an apparent rheological frictional energy density which is the energy per volume unit of grease wasted by frictional force between the layers of the grease during a shearing process. Utilizing this concept, he went on to define a mechanical dissipation function to characterize the structural degradation of grease. Further, considering the irreversibility of the mechanical degradation, Kuhn suggested the application of thermodynamic entropy in the study of mechanical degradation of lubricating grease [7,8].

In a recent paper [9], The principle of irreversible thermodynamics [10] was successfully applied to the mechanical degradation of grease. This type of a treatment has been applied to different degradation processes such as wear and fatigue [11–16]. According to the degradation entropy generation theory [10] any irreversible degradation associated with dissipative processes can be related to the thermodynamic entropy generation. The results revealed the existence of a linear correlation between the changes in the net penetration of the grease (caused by mechanical degradation under shear stresses) and the production of thermodynamic entropy unit volume. This was identified as the grease characteristic line [9]. It was shown that, in the absence of high temperatures responsible for initiating chemical degradation, this linear correlation remains valid regardless of the applied shear rate. Based on [9] any grease has its own characteristic line and the slope of the characteristic line – called "degradation coefficient" – can be measured and reported as a mechanical property of the grease. A grease with smaller degradation coefficient is expected to have a longer service life under mechanical shear.

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In this paper we explore how the concept of degradation coefficient can be used to quantify the consistency reduction and mechanical life of a grease.

2. Theoretical

2.1. Mechanical degradation under shear

A lubricating grease consists of a base oil for lubrication, and a thickener which is responsible for containing the base oil in the contact. A thickener possesses a microscopic mechanical structure. This structure can be seen using a Scanning Electron Microscope (SEM). Fig. 1 shows an SEM image of thickener's structure of a fresh grease sample (labeled Grease A) with Li-Complex soap thickener.

As shown in Fig. 1, the structure consists of many particles that take on the shape of long tangled-ropes. Similar to any other mechanical structure, the thickener's structure is prone to gradual break down under load and stress. Fig. 2 shows the SEM image of the same grease after 15 hours of shearing at the rate of 5000 1/s at 25 °C in a rheometer.

Also described by other researchers [1,17], mechanical degradation is a physical process that destroys the thickener structure and decreases the grease consistency. As a result, during long-term applications, the grease leakage and bleeding rate tend to increase, thus reducing the lubricating effectiveness of the grease [18] .

A grease can also suffer from other types of degradations such as base oil evaporation and chemical degradation which accelerate dramatically with temperature rise and become dominant in higher temperatures. However, in the temperature range tested in this study (between 25 °C to 45 °C), the greases tested are chemically stable, and mechanical degradation is considered to be the most dominant degradation mode.

2.2. Mechanical degradation and entropy generation

Research shows that consistency reduction resulted by mechanical degradation is linearly related to the entropy generation

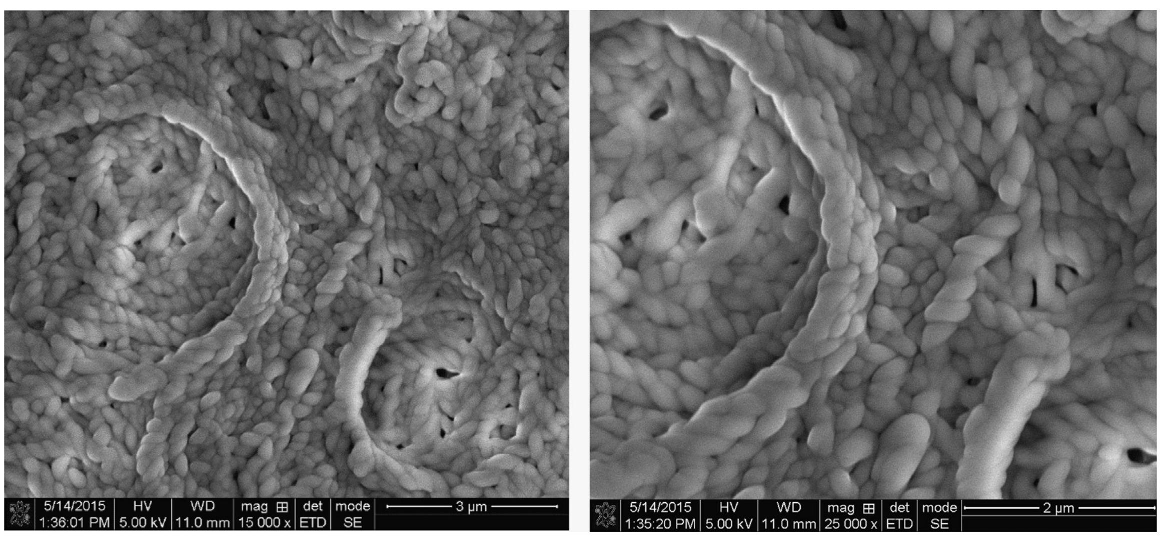

Fig. 1. SEM images of Grease A soap network after washing out the base oil with a volatile solvent (Right and left pictures have taken with magnifications of 25000 X and 15000 X, respectively).

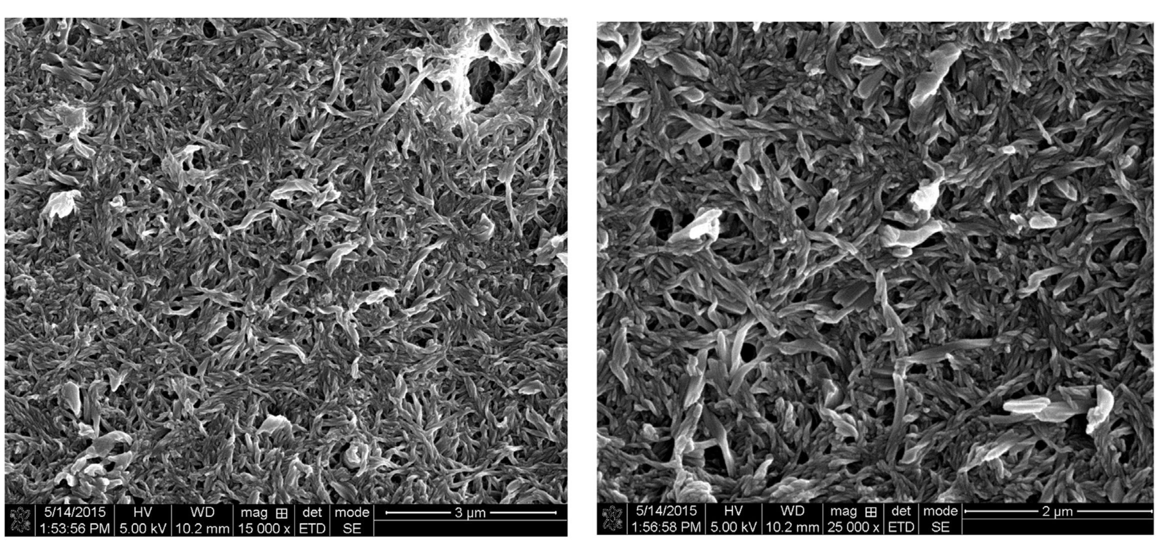

Fig. 2. SEM images of Grease A soap network after 15 hour shearing with a shear rate of 5000 1/s in 25 °C (Right and left pictures have taken with magnifications of 25000 X and 15000 X respectively).