Method for Designing Lubricant Life

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Abstract

Lubricants degrade over time due to operating conditions and aging, leading to a loss of their initial performance. While degradation is known to accelerate with high lubricant temperatures and the presence of metal catalysts, no quantitative studies have been conducted to evaluate the impact of each factor on lubricant degradation. This paper presents degradation tests of lubricants, where lubricant temperature and the amount of metal catalysts were varied to quantitatively assess the effects of these factors on the remaining service life. The insights gained are valuable for the development of new lubricants and for planning optimal lubricant-change intervals.

1. Introduction

The function of additives in lubricants is to enhance the properties of the base oil and provide performance characteristics that the base oil alone does not offer, thereby improving the overall performance of the lubricant. In particular, transmission lubricants contain various additives that help control the friction characteristics of clutches, prevent the seizing of gears and other sliding parts, and improve durability. However, lubricants degrade over time and under specific operating conditions. Degradation refers to the change in the properties of lubricants, resulting in the loss of their initial performance. Because degradation can interfere with the operation of vehicle components or damage them, proper design of the lifespan of lubricants is crucial.

Lubricant is well known to deteriorate more rapidly at higher temperatures[(1)]. Additionally, the presence of metal catalysts accelerates lubricant degradation[(2)]. In real-world scenarios, lubricants are used under conditions where both of these factors change in a complex manner. However, no quantitative studies have been reported on how each of these factors affects lubricant degradation.

This paper presents an investigation into the sensitivity of automotive transmission lubricants to lubricant temperature and the amount of metal catalysts. The study involved comparing lubricants degraded under various conditions by varying both the lubricant temperature and the amount of metal catalyst.

2. Experimental Methods

In transmission lubricants for automotive applications, the most significant effect of lubricant deterioration is the depletion of additives that control the friction characteristics of the clutch. As the lubricant deteriorates, issues such as shocks during clutch release and engagement become a concern[(3)]. To address this, our company mathematically estimates the remaining lifetime of the lubricant based on the depletion of additives that contribute to clutch friction characteristics. In this model, a value of 100 represents the lifetime of new lubricant, and 0 represents the lifetime of lubricant completely depleted due to degradation. In this paper, the remaining lubricant lifetime is used as an indicator of lubricant degradation.

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Table 1 ISOT Test Conditions

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Temperature, ℃	50	80	110	110	120	140	140	160	175	180
Time, h	144	144	144	1,152	280	144	576	144	216	144

First, to determine the relationship between lubricant temperature and degradation rate, ISOT tests were conducted under the conditions listed in Table 1, and the remaining lifetime of the degraded lubricant was examined.

Existing AT lubricant was used. Next, the influence of metal catalysts was investigated by examining the remaining lifetime of lubricant samples that underwent the heating test without a metal catalyst (Table 2) and the unit-durability test (Table 3), which involved a significant amount of metal catalysts, such as unit components and their wear powder.

Table 2 Heating Test Conditions

	Test 1	Test 2	Test 3	Test 4
Temperature, ℃	100	100	120	140
Time, h	1,000	3,000	3,000	2,000

Table 3 Unit Durability Test Conditions

	Test 1	Test 2	Test 3	Test 4
Driving Conditions	A	B	C	D
Distance, km	37,000	5,000	38,000	18,000

3. Results and Discussion

3.1 Relationship between lubricant temperature and degradation rate

Table 4 lists the results of the lubricant analysis after the ISOT tests. The reaction rates and rate constants were calculated based on the remaining lubricant lifetime.

To examine the relationship between lubricant temperature and degradation rate, the reaction rate constants are plotted starting from 110° C, the temperature at which the progression of degradation was first observed.

Notably, when the temperature difference from 110° C is x° C, the reaction rate multiplier is $e^{0.0471x}$ (Fig. 1).

By applying this analysis, the heat-damage level of lubricant exposed to 110°C for 1 h can be defined as 1, which is considered the unit number for the magnitude of heat damage. This allows us to summarize the experiments conducted at different lubricant temperatures, as shown in Fig. 2.

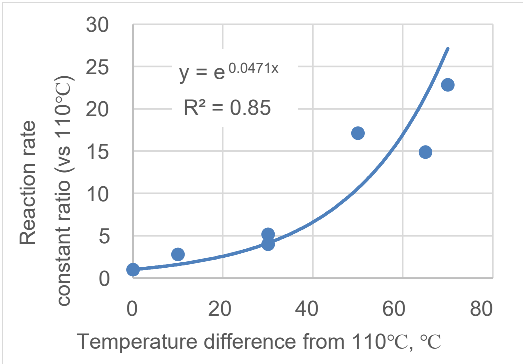

Fig. 1 Relationship between Lubricant Temperature and Reaction Rate Constant

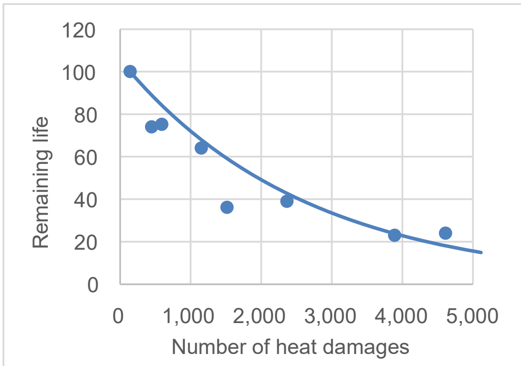

Fig. 2 Sorting Remaining Life Based on Number of Heat Damages

Table 4 Results of ISOT Test

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Remaining life	100	100	100	64	74	75	39	36	24	23
Reaction rate	0	0	0	0.031	0.093	0.172	0.106	0.444	0.352	0.535
Reaction rate constant	0	0	0	0.0004	0.0011	0.0020	0.0015	0.0065	0.0057	0.0087

3.2 Effect of metal catalysts

The remaining lubricant lifetime after each test was calculated and plotted against the number of heat damages (Fig. 3). The lubricant from the heating test without the metal catalyst exhibited a longer remaining lifetime compared to the lubricant from the ISOT test with the metal catalyst, despite experiencing the same number of heat damages.

In contrast, the lubricant containing a large amount of metal catalysts, such as unit components and their wear powder, exhibited a shorter remaining lifetime, indicating a higher degradation rate. Metal catalysts, such as iron and copper, are believed to accelerate the depletion of the additives.

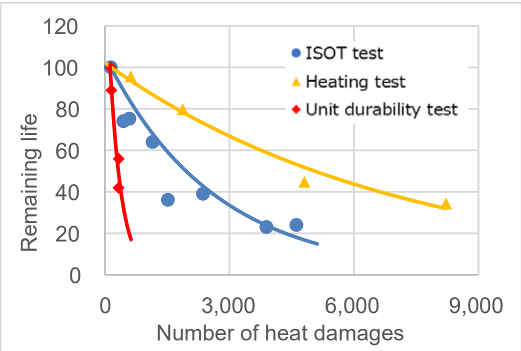

Fig. 3 Sorting Remaining Life
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3.3 Examination using multiple regression analysis

To calculate the degree of influence of each factor, a multiple regression analysis was performed on the results. The remaining lubricant lifetime served as the objective variable, the number of heat damages as the explanatory variable, and the amounts of iron and copper elements in the lubricant as the variables representing metal catalyst content. The obtained correlation coefficient was 0.83, indicating a strong correlation.

In Fig. 4, the horizontal axis represents the remaining lubricant lifetime, calculated using the prediction equation from the multiple regression analysis, while the vertical axis represents the remaining lubricant lifetime measured experimentally. The calculated values exhibited a strong correlation with the measured values, suggesting that the quantitative relationships between the duration of lubricant exposure at each temperature, the amount of metal catalysts, and lubricant degradation were successfully established.

The standardized partial regression coefficients for each factor were also compared. The results demonstrate that the strength of influence on lubricant degradation follows this order: number of heat damages, amount of copper in the lubricant, and amount of iron in the lubricant.

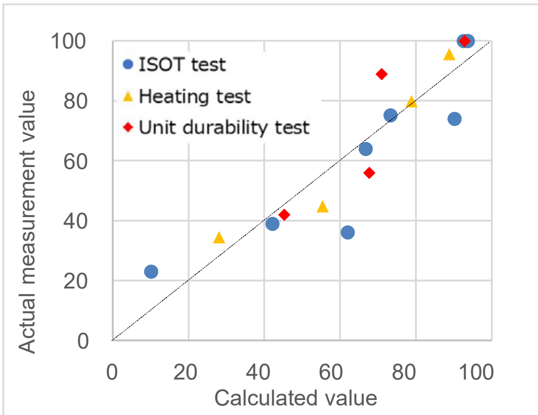

Fig. 4 Multiple Regression Analysis Results

4. Summary

The degradation of lubricants is influenced by metal catalysts as well as the duration for which the lubricant is subjected to various temperatures. By comparing the remaining lifetime of the lubricant after degradation under different conditions, the degree of influence of each factor was quantitatively determined.

The findings provide essential knowledge for designing new lubricants with a service life suitable for real operating environments, as well as for establishing an appropriate lubricant-change frequency. Future improvements include increasing the design accuracy of lubricant lifetime by considering the effects of local heat generation in the unit and the additive depletion due to lubricant adsorption on the sliding surfaces. This will help establish a more accurate design for lubricant lifetime under actual operating conditions.

5. References

(1) Mitsuru Toyoguchi: On antioxidants for lubricating oils, Synthetic Organic Chemistry, 13, 11, 512–516 (1955).
(2) Katayama: Oxidation of lubricating oil, Journal of Oil Chemistry, 5, 5, 261–270 (1956).
(3) Toshihiko Ichihashi: Action of friction modifier on clutch and its degradation mechanism, The Japan Petroleum Institute, 41st Petroleum and Petrochemical Conference, 2F13 (2011).
(4) Mochizuki, Kato, Maeda: Lubricant Life Design Method, Proceedings of Tribology Conference Fall 2024 Nago, 2024, A31

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