Grease Degradation in Constant Velocity (CV) Joints

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Constant velocity (CV) joints have been widely used for modern vehicles. The sealed grease of CV joints must provide low friction and wear protection for the lifetime use of the vehicle. Grease performance affects the vibration and noise level in the vehicle. Vehicles that have traveled long distances may suffer mechanical and thermal overloads, thus causing the grease to degrade due to changes in its physical and chemical properties. In this article, the grease degradation phenomenon in CV joints is investigated by collecting grease samples from both tripod joints and Birfield joints in actual vehicles that traveled various ranges of distance. In order to analyze the property changes of grease, grease penetration and oxidation induced time are measured using a penetration meter and infrared (IR) spectrometer, respectively. Where oxygen induced time (OIT) is the point that the oxidation occurs in grease. The performance variations of grease are investigated by measuring the friction and wear using linear-oscillation (SRV, Schwingung (oscillation) Reibung (friction) Verschleiss (wear)) test machine as well as the four-ball wear tester. Degradation of properties as well as performance in CV joint grease due to physical and/or chemical changes is identified.

KEY WORDS
Constant Velocity Joint; Grease Degradation; Friction; Wear

INTRODUCTION
Constant velocity (CV) joints are positioned at the ends of the driveshaft to transfer the power from the engine to the wheels. A diagram of the CV joint, configuration within the steering system of a vehicle is shown in Fig. 1. Although CV joints provide the constant velocity rotation of the shafts, the friction inside of the CV joints usually creates generated axial force (GAF) and plunging force (PF) in CV joints, thus causing shudder vibration and idle booming noise in the vehicle (Wagner (1)). High-performance lubricating grease, in terms of friction as well as wear, is necessary to avoid problems resulting from friction. Lubricating grease used in automotive applications is a multiphase system that consists of at least two components, a thickener and a fluid lubricant. Most greases use mineral or synthetic base oil as the fluid lubricant. Additives and thickeners in grease are also important factors for the successful performance in the application. Generally, grease additives improve the lubrication properties, such as oxidative stability, corrosion protection, and anti-wear; in addition, grease thickeners determine the penetration property, which indicates the consistency (or stiffness) of grease.

In the past, various studies on CV joint grease have been conducted in the field of mechanical applications. Three principal components of the grease are base oil, thickener, and additives, which strongly influence the ability of the grease to lubricate the contacts (Fish (2)). The friction performance of CV joint grease in terms of its additives was investigated (Fish and Jisheng (3)). The tribological requirements for CV joints was described and reported as friction coefficients for the normal grease (Fish and Cole (4)). In other research, the friction of automotive driveshaft joints was measured and characterized (Lee (5)) with accurate equipment. Subsequently, a phenomenological friction model of tripod CV joints was established (Lee and Polycarpou (6)). For another sight, a series of research in grease degradation was conducted. Used grease from bearing tests was studied (Cann (7, 8); Komatsuzaki, et al. (9)), and the lubrication and reflow properties of thermally aged greases were investigated (Hurley, et al. (10)). Through experiments, the influence of grease on rolling contact wear was measured and analyzed (Mota and Ferreira (11)) and then lubricants in the rolling friction zone and its kinetics were studied (Mel’nikov (12)). In addition a new method for determining the mechanical stability of lubricating greases (Lundberg and Hoglund (13)) was established. However, this research is the first study that focused on the collected grease of CV joints from actual vehicles.

In this article, CV joint greases from actual vehicles we are collected to evaluate the grease degradation in terms of driving mileage. In order to evaluate the degradation, property and performance changes of the greases were investigated. Grease properties were analyzed using a penetration meter for changes in grease consistency and an infrared (IR) spectrometer to obtain the extent of oxidation and chemical properties. Moreover, the
performance of the used greases was evaluated and analyzed using a four-ball wear tester to measure the wear scar; linear oscillation (SRV) to obtain the coefficient of friction (COF); and pressure differential scanning calorimetry (PDSC) to record oxidation induction time (OIT).

**GREASE IN CV JOINTS**

CV joints, which can be classified as tripod joints (TJ) and birfield joints (BJ), have been widely used for modern vehicles. The sealed greases of CV joints must provide low friction and wear protection for the lifetime service of CV joints. The performance of grease affects the vibration and noise level in the vehicle. Vehicles, after travelling long distances, may experience mechanical and thermal overloads, which cause the grease to degrade due to the changes of physical and chemical properties of CV joint grease. Generally, TJ grease is made of mineral oil and lithium soap (Fish and Cole (4)). Because the TJ is usually applied to the inboard joint in the driveshaft, the structure of a TJ is designed to absorb vibration. To improve the friction and wear resistance of TJ grease, antiwear additives and friction modifiers are added. Also, antioxidants and corrosion inhibitors are added to improve the properties of grease against oxidation and corrosion. BJ greases are also made of mineral oil and lithium soap (Fish and Cole (4)). However, unlike TJ grease, BJ grease requires high load resistance because it is applied on the outboard joint. Thus, in order to increase the load resistance, extreme-pressure additives are usually added to BJ greases for improved durability.

In this work, in order to analyze degradation of CV joint greases, CV joints from Sonata 1.8 and 2.0 L passenger cars made by Hyundai Motor Company were collected for different number of miles driven. Generally, the amount of grease used in TJ is about 130 g and in BJ the amount is about 80 g. The total amount of grease used for the experiments was about 25 g for both TJ and BJ. TJ is composed of a housing, tripod, and grease, and a BJ is composed of a housing, balls, inner races, outer cages, and grease. Greases were sampled for consistency from the contact areas in the TJ housing and BJ housing of disassembled CV joints. Figure 2 shows the TJ housing and the BJ housing from which the greases were collected. Grease samples collected from the TJ housing and BJ housing are denoted by mileage, and Table 1 shows classified greases of four sections in terms of number of miles driven.

**PROPERTY ANALYSIS IN GREASE DEGRADATION**

In order to investigate grease degradation in terms of mileage, the physical properties of sampled TJ and BJ greases were analyzed first. The penetration meter and infrared spectrometer were used to analyze property changes after operation of CV joints under the different number of miles driven. A penetration meter measures the penetration of grease to evaluate the stiffness of grease, and 10 g sample is necessary. Penetration is a test method measuring the extent of viscosity of grease. The low value of penetration means high viscosity and the high one means low viscosity. The test method used was ASTM D 217 for cone penetration of lubricating grease. The penetration meter was set to experiment condition temperature of 25 °C.

![Fig. 2—Inside a constant velocity joint housing: (a) tripod joint housing and (b) Birfield joint housing. (color figure available online.)](image)

<table>
<thead>
<tr>
<th>Mileage (10^4 km)</th>
<th>0-10</th>
<th>10-15</th>
<th>15-20</th>
<th>&gt;20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of samples</td>
<td>8</td>
<td>9</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

**TABLE 1—CLASSIFIED GREASES OF CONSTANT VELOCITY JOINTS BASED ON MILEAGE**
the stiffness changes of CV joint greases were analyzed. Figure 3 shows the measurement results of penetration in TJ and BJ greases. In Fig. 3, the x-axis represents driving distance and the y-axis represents penetration. TJ grease and BJ grease are shown as circles and triangles, respectively. The results indicated that the penetration of both TJ greases and BJ greases increased with longer driving distances. The $p$ values obtained from the penetration test results for TJ grease and BJ grease showed the reliability of the penetration data. The $p$ values for TJ grease and BJ grease were 0.003 and 0.047, respectively. Because the $p$ values were less than 0.05, the penetration data obtained were proven to be reliable. The relationship between penetration and stiffness clearly shows that the stiffness of grease is decreased as the driving distance increases.

The infrared spectrometer was used to test whether the grease was oxidized, it showed the extent of the oxidation and analyzed the chemical properties. The infrared spectrometer was initialized with measurement range from 4000 to 400 cm$^{-1}$, the number of scans was 16, with a resolution of 4 cm$^{-1}$. This test was carried out to investigate the extent of oxidation of CV joint greases based on distance travelled. Peak values at around 1150 and 1750 cm$^{-1}$ indicated that the grease was oxidized. Figure 4 shows the extent of oxidation in TJ and BJ greases, where the x-axis is driving distance and the y-axis is the extent of oxidation.

It shows that the extent the oxidation in TJ greases is generally lower than that of BJ greases. In order to evaluate the trend of oxidation data, the $p$ value was determined. Obtained $p$ values for TJ and BJ grease data were 0.537 and 0.32. These values were
not within the test method’s standard of reliability, so the inclined trend of the extent of oxidation data from TJ and BJ grease was not proven. However, the extent of oxidation data for TJ greases is identifying an increasing trend in terms of the driving distance.

The infrared spectrometer was also used to analyze the grease thickener. Figure 5 shows infrared graphs that represent unused TJ and BJ greases. Generally, the peak value of Li-soap is 1580 cm$^{-1}$. The peak value obtained for both TJ and BJ greases were 1582 cm$^{-1}$ as shown in Figs. 5a and 5b; therefore, the thickener in TJ and BJ greases were identified as Li-soap. The base oil of TJ and BJ greases were measured using a refractive index tester. To measure the refractive index, light is passed through grease using a refractive index tester. Refractive index of mineral oil exists between 1.48 and 1.50. From the measured results, the refractive index of TJ grease was 1.4812 and that of BJ grease was 1.4883. Thus, the base oil of TJ and BJ grease was determined to be mineral oil.

**PERFORMANCE ANALYSIS IN GREASE DEGRADATION**

In order to evaluate performance deterioration due to grease degradation, selected TJ and BJ greases were tested using a four-ball wear tester, SRV, and PDSC. A four-ball wear tester is used to measure the wear scar of CV joint greases after different number of rules traveled. The test method used for the four-ball wear tester was ASTM D 2266 for wear characteristics of lubricating grease. The four-ball wear tester was initialized with a temperature of 75°C, rotating speed of 1,200 rpm, and load of 40 kg. The size of wear scar, which is an average value of wear length plus height, is measured by the four–ball wear test. Figure 6 shows typical examples of a wear scar with TJ greases. Figure 6a shows the wear scar of TJ grease after 45,000 km, and Fig. 6b shows the wear scar of TJ grease after 180,000 km. Comparing Figs. 6a and b, the wear scar of TJ greases becomes larger and more irregular when the CV joint experiences longer driving distances.
Figure 7 shows the measured results of wear scars from both TJ and BJ greases based on mileage. The result shows that wear size in BJ grease increases, whereas that of TJ grease remains almost constant as the driving distance increases. From the four-ball wear test results, it can be confirmed that TJ grease has better wear resistance compared to the BJ grease. Grease with antiwear additive in TJ shows the improved performance against wear in Fig. 6. Statistical analysis was conducted to obtain the p values. P Values of TJ and BJ grease were 0.601 and 0.479, respectively. Because the standard of the reliability is about 0.05, data was distributed over a wide area in the trend graph. So, p value indicating the reliability of TJ and BJ greases were not proven. However, the wear scar data for TJ greases is identifying an increasing trend in terms of the driving distance.

After measurement of the wear scar, SRV was used to measure the coefficient of friction to evaluate the friction performance. The test method used for the SRV tester was ASTM D 5707 for measurement of friction and wear properties of lubricating grease. The SRV tester was initialized with temperature of 75°C, load of 200 N, and frequency of 50 Hz. Deterioration of friction resistance in terms of mileage was evaluated. Figure 8 shows the coefficient of friction data for TJ and BJ greases versus mileage. The coefficient of friction increased in BJ greases, whereas it remained almost constant in TJ greases even when the driving distance increased. As the SRV result shows, TJ grease has better frictional behavior compared to BJ grease. It can be theorized that the better performance in frictional behavior is probably caused by the friction modifier of TJ grease. P Values were obtained from the coefficient of friction data and were 0.823 and 0.478 for TJ and BJ greases, respectively. Because the p values were greater than the reliable standard of 0.05, the trend of the coefficient of friction data was not proven statistically.

Finally, in order to measure oxidation induction time of TJ and BJ greases based on mileage, a PDSC tester was used. The test method used for the PDSC tester was ASTM D 5483 for oxidation induction time of lubricating greases. The PDSC tester
PDSC was set at temperature of 190°C and pressure of 3.5 MPa. PDSC is measured in a constant temperature process, in which when the earlier oxidation induction time is broken out and the earlier thermal resistance of grease is confirmed. Thus, oxidation induction time is related to thermal resistance, and thermal resistance can be analyzed. Figure 9 shows oxidation induction time data for both TJ and BJ greases based on mileage. It is clearly shown that the oxidation induction time of TJ greases is lower than that of BJ greases. In general, BJ generates more heat than TJ because the BJ has more contact points inside the joint. Therefore, BJ is manufactured to higher thermal resistance than TJ. Thus, the thermal decomposition time of BJ grease should be longer than that of TJ grease. It is clear from the PDSC results that BJ grease has better thermal resistance than TJ grease. It is presumed that the antioxidant additive of TJ grease has good performance with thermal resistance. Next, the \( p \) value of oxidation induction time was obtained. The \( p \) value for TJ grease was 0.006, which is less than 0.05 and the TJ grease data regarding the oxidation induction time are proven. However, the \( p \) value for BJ grease was 0.323, which is greater than 0.05, so the trend that represents oxidation induction time of TJ grease was not statistically proven.

**CONCLUSIONS**

Property analysis of greases in CV joints based on mileage was conducted using a penetration meter and an infrared spectrometer. The penetration meter was used to obtain penetration data for TJ and BJ greases. As the cone penetration increased in TJ and BJ greases with longer driving distances, it is clearly shown that the grease stiffness decreased. An infrared spectrometer was used to measure the extent of oxidation of TJ and BJ greases. From the result in Fig. 4, the extent of oxidation of grease on both TJ and BJ based on driving distance is increased. This
demonstrates that the extent of oxidation in TJ greases was lower than in BJ greases when the driving distance increased. The chemical properties of greases were tested using an infrared spectrometer and refractive index measurement. The base oil of TJ and BJ greases were identified as mineral oil, and the thickener was determined to be Li-soap. After property analysis of CV joint greases based on mileage, performance was tested using a four-ball wear tester, SRV, and PDSC. First, the four-ball wear tester was used to measure the wear scar of TJ and BJ greases. The result showed that as the driving distance increased, wear increased in BJ greases, whereas the wear was constant in TJ greases. From the result of four-ball wear tests, it was concluded that the antiwear additive of TJ grease had better wear resistance. Next, SRV was used to measure the coefficient of friction in TJ and BJ greases. The coefficient of friction increased in BJ greases when the driving distance increased, but the coefficient of friction was almost constant in TJ greases. By considering the measurements of coefficient of friction in TJ and BJ greases as well as the result of SRV, the friction modifier of TJ grease showed good performance in terms of frictional behavior. Finally, PDSC was used to measure oxidation induction time of TJ and BJ greases. The oxidation induction time of TJ greases was lower than that of BJ greases; therefore, BJ grease has better thermal resistance compared to TJ grease. It can be theorized that the antioxidant additive of TJ grease had good performance with thermal resistance. From property and performance analyses of TJ and BJ greases based on mileage, it clearly is seen that used TJ and BJ greases of CV joints are degraded as the driving distance increased. Thus, the measurement of grease degradation was represented by the property and performance of grease in present status, and then through an analysis, the development of the grease can be discussed. Moreover, the results obtained can be applied to the development of optimized greases to remanufacture the CV joint after use. The relationship between the actual vehicle performance and grease degradation requires further research.

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REFERENCES