Experimental Research on Rubber Compatibility of Drive Train oils used in Construction Machinery

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Abstract. The compatibility of oil and rubber in the drive train system of construction machinery plays an important role in the safe and reliable operation of the system. In order to investigate the rubber compatibility of drive train system oil of construction machinery, the changes of rubber sheet volume and hardness before and after immersion of standard fluororubber (FKM2) and hydrogenated nitrile rubber (HNBR1) with 9 kinds of drive train system oil were tested. The results show that FKM2 has good rubber compatibility with drive train oil, and HNBR1 is only compatible with some drive train oil; The volume change rate and hardness change range of FKM2 are smaller than those of HNBR1.

1. Introduction

The transmission and drive axle are core components of the drive train system applied to the construction machinery. In the process of the operation, the working oil temperature of the transmission and drive axle can reach up to 120°C. The high-temperature lubricating oil and rubber seal contact for a long period. On the one hand, the interaction between lubricant molecules and rubber matrix will cause the volume change of the rubber and decrease the mechanical properties, which will lead to seal failure and lubricating oil leakage. On the other hand, the additives of rubber dissolving in the lubricating oil will make the color of the oil darker, aggravate the aging process, result in abnormal operation of the lubricating components, and even bring out serious wear of bearings, gears and other parts [1-2]. Therefore, when the drive train oils are used, they must have good compatibility with the rubber sealing materials to ensure well system seal and normal lubrication.

At present, the evaluation of rubber compatibility mostly adopts the static immersion test method. It determines the compatibility by investigating the changes of the performance parameters of the rubber pieces before and after immersion in the lubricating oil. The rubber types and test methods used in different drive train oil specifications are diverse, and the evaluation indicators are also varying. The Caterpillar TO-4 specification mainly examines the compatibility of Caterpillar 1Y0530 and Caterpillar 1E2827 rubber materials with the drive train oils. The Allison TES 439 specification focuses on the investigation of the compatibility of polyacrylate, nitrile rubber, fluorine rubber with the drive train oils [3].

The sealing material used in the drive train system of construction machinery is mostly fluorine rubber, and the pipeline or external sealing is mostly made of nitrile rubber. It has been reported that after nitrile rubber is immersed in transmission oil at the temperature of 100°C, its volume shrinks significantly and hardness increases signal, which cannot meet the requirement of practical application[4]. Therefore, standard hydrogenated nitrile rubber with excellent oil and high temperature resistance is adopted instead of nitrile rubber, and its compatibility tests are carried out simultaneously.
with standard fluorine rubber under the same conditions in this paper. By comparing the volume and hardness of the rubber sheets before and after immersion, the compatibility of the drive train oils and rubbers is evaluated, which provides a basis for the matching and selection of oils and rubber types.

2. Test part
This paper selects nine commonly used lubricants for construction machinery drive train system and standard fluorine rubber and hydrogenated nitrile rubber meeting ISO 6702 requirements to conduct compatibility test. The dumbbell-shaped rubber test pieces meeting the requirements of Table 1 and Figure 1 are cut out, and their volume \( V_0 \) and hardness \( H_0 \) before the test are checked. As shown in Figure 2, the test pieces are putted into a tube containing 160 mL oil and soaked at 150°C for 168h. The volume \( V_1 \) and hardness \( H_1 \) of the rubber test pieces after the test are measured and averaged to investigate the performance change of the rubber pieces before and after immersion in the test oil. The volume change rate and hardness change are calculated according to the following formula:

\[
\text{volume change rate: } \Delta V = \frac{V_1 - V_0}{V_0} \times 100\% 
\]

\[
\text{hardness change: } \Delta H = H_1 - H_0 
\]

| Test piece type | \( A \) total length/mm | \( B \) end width/mm | \( C \) length of narrow part /mm | \( D \) width of narrow part /mm | \( E \) outer transition edge radius /mm | \( F \) inner transition edge radius /mm |
|-----------------|--------------------------|-----------------------|---------------------------------|-------------------------------|---------------------------------------|---------------------------------------|
| type 1          | 115                      | 25.0±1.0              | 33.0±2.0                        | 6.0±0.4                       | 14.0±1.0                             | 25.0±2.0                              |

Figure 1. The shape of a dumbbell-shaped rubber test piece.

Figure 2. Test diagram of soaking device.
3. Test results and analysis

3.1. FKM2 (Fluorine Rubber)
Fluorine rubber is a synthetic polymer elastomer containing fluorine atoms on the main chain or side chain, and it has excellent oil resistance. The introduction of fluorine atoms makes the rubber have excellent heat and oxidation resistance, as well as higher hardness. It is a rubber owning the best resistance to media among all elastomers. The compatibility results of nine drive train oils with FKM2 are shown in Table 2 and Figure 3.

| Oil sample number | Volume change rate /% | Hardness change / HAM |
|-------------------|------------------------|-----------------------|
| 1                 | 1.1                    | 0.3                   |
| 2                 | 1.2                    | -0.2                  |
| 3                 | 1.0                    | 0.3                   |
| 4                 | 1.2                    | -0.2                  |
| 5                 | 0.5                    | -0.3                  |
| 6                 | 0.6                    | 3.3                   |
| 7                 | 0.4                    | 3.8                   |
| 8                 | 2.2                    | -0.5                  |
| 9                 | 0.8                    | -0.2                  |

Figure 3. Compatibility results of drive train oils with FKM2.

As can be seen from Table 2 and Figure 3, the fluorine rubber pieces all have a certain degree of expansion, and the volume change rates are concentrated within 2.5% after soaking. Generally, slight expansion of the rubber sheets can achieve better sealing effect. The change trends of the hardness are widely different. Related literature[4] recommends the compatibility evaluation reference index that the volume change rate of fluorine rubber is 0~+4%, and the hardness change (-2~+4) HAM. The fluorine rubber compatibility test data all meet the evaluation index requirements, indicating that fluorine rubber seals can play a good sealing effect during usage, effectively prevent oil leakage of the system, and ensure the normal operation of the equipment.

3.2. HNBR1 (Hydrogenated Nitrile Rubber)
Hydrogenated nitrile rubber is prepared by the catalysis of precious metals for hydrogenation of carbon-carbon double bonds in nitrile rubber. It has better mechanical strength. And the heat, chemical corrosion and ozone resistance are excellent. Therefore, its overall performance is brilliant. The results of the compatibility of nine drive train oils with HNBR1 are shown in Table 3 and Figure 4.
Table 3. Compatibility results of drive train oils with HNBR1.

| Oil sample number | Volume change rate /% | Hardness change / HAM |
|-------------------|-----------------------|----------------------|
| 1                 | 8.4                   | 3.0                  |
| 2                 | 7.0                   | 4.0                  |
| 3                 | 6.8                   | 2.0                  |
| 4                 | 3.7                   | 3.0                  |
| 5                 | 2.8                   | 7.3                  |
| 6                 | 3.8                   | 3.3                  |
| 7                 | 3.3                   | 1.0                  |
| 8                 | 4.8                   | 3.7                  |
| 9                 | 4.6                   | 3.3                  |

Figure 4. Compatibility results of drive train oils with HNBR1.

From Table 3 and Figure 4, it can be seen that after hydrogenated nitrile rubbers immersed in the oils, the volume values expand to different degrees. The volume change rate is between 2.8% and 8.4%, which is higher than the one of fluorine rubber. The rubber pieces all become harder, and the hardness is in the range of 1.0 to 7.3. The hardness change of NO. 5 oil sample is the largest, and the rest are all within 5 HAM. Related literature[4] recommends the compatibility evaluation reference index that the volume change rate of hydrogenated nitrile rubber is -2%~+6%, and the hardness change is (-5~+6) HAM. The compatibility data of HNBR1 has obvious differences, and only a few oil samples meet the requirements of the evaluation index. Therefore, in actual usage, the rubber materials that have good compatibility with drive train oils should be selected.

3.3 Correlation analysis

It can be seen from Figure 5 and Figure 6 that the greater the volume change rate of fluorine rubber is, the smaller the change in rubber hardness. This is because when the oil and fluorine rubber act, the oil molecules will penetrate into the network structure of the rubber to soften it. Therefore, the greater the rubber swelling degree is, the more severe the hardness decreases. There is no obvious correlation between the volume change rate and the hardness change of hydrogenated nitrile rubber. In addition, as the FKM2 owns stronger polarity than HNBR1, it has better compatibility with drive train oils, and the volume change rate and hardness change range are relatively smaller.
Figure 5. Correlation of volume change rate and hardness change of FKM2.

Figure 6. Correlation of volume change rate and hardness change of HNBR1.

4. Conclusions
In this paper, the compatibility of nine drive train oils with standard fluorine rubbers and hydrogenated nitrile rubbers used in construction machinery are tested. The results show that under 150°C and 168h:

(1) FKM2 has good rubber compatibility with the drive train oils, which can meet the sealing requirement of the drive train system.

(2) HNBR1 can only be compatible with a few common drive train oils. If HNBR1 is used as drive train system seal material, the compatibility of rubber and oil needs to be investigated in advance.

References
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