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Understanding Grease Retentivity in Wheel-Rail Contact

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Abstract

This study investigated wheel flange grease retentivity, defined as the distance or duration over which grease can efficiently lubricate a contact surface. The grease analyzed was BECHEM EcoRail 2009, which consists of a bentonite thickener and a synthetic ester base oil. Experiments were conducted using a Mini-Traction Machine in a ball-on-disc configuration. The effects of temperature, air humidity, load, slip, speed, and lubricant quantity on retentivity were examined. The results indicated that increasing load and slip led to a decrease in retentivity, which could be attributed to the frictional energy absorbed by the lubricant. An increase in velocity resulted in a decrease in retentivity when measured over time, but an increase in retentivity when measured by sliding distance. A linear increase in retentivity was observed with a higher amount of lubricant. Temperature increases led to an enhancement in retentivity, provided the temperature stayed within the operational range of the grease. Air humidity impacted retentivity only when condensation occurred, which resulted in an increase in retentivity.

Keywords: friction, grease, flange lubrication, retentivity, tribology, wheel-rail contact.

1 Introduction

Optimizing the lubrication process in wheel-rail contact is critical to maintaining the desired coefficient of adhesion (CoA) while avoiding over-lubrication, which can lead to lubricant waste and potential safety risks. Optimal flange lubrication can be achieved through interval lubrication, GPS-based systems for location-specific lubrication, and digital twins that use sensor data to determine when to apply lubricant. These methods aim to optimize lubrication, reducing energy consumption, lubricant use, wheel and rail wear, and noise.

A key factor in these systems is understanding the retentivity of lubricants, or how long they can maintain the desired CoA. The wheel-rail contact is an open tribological system influenced by environmental factors (temperature, humidity, contamination) and operational conditions (load, speed, slip, lubricant quantity, and type). Previous studies have shown that grease retentivity is influenced by the properties of the grease [1–3], particularly base oil viscosity [4,5], and to a lesser extent, the type of thickener. The evolution of the CoA typically follows an S-curve [1,6] or an exponential curve if only the initial phase is recorded [3].

Studies have demonstrated that retentivity decreases with increasing temperature [7], load [8], and slide-to-roll ratio [1], while increasing the amount of applied lubricant enhances retentivity [1,8,9]. However, these studies often measured limited parameter values or used different testing devices and greases, making it difficult to generalize the results.

This research aims to provide comprehensive retentivity data for grease under a wide range of rolling-sliding contact conditions and summarize the findings. The goal is to unify current knowledge and offer a description of the effects of load, slip-to-roll ratio, velocity, applied grease amount, temperature, and relative humidity on grease retentivity.

2 Methods

For the main experiments, the Mini-Traction Machine (MTM) from PCS Instruments was used. Operating in a ball-on-disk configuration as seen in Figure 1, it can achieve contact pressures up to 1.25 GPa and velocities of 4 m/s. The MTM allows independent control of ball and disk motion, enabling the adjustment of the slide-to-roll ratio. The ball (19.05 mm diameter) and the disk (46 mm diameter) are both made of AISI 52100 steel. It measures loading force (±0.3 N accuracy), friction force, temperature, and wear, with data sampled at 1 Hz and averaged. For tests with different relative humidity, a humidity generator was used, and a heat gun was employed for tests at higher temperatures. All MTM parameters are summarized in Table 1.

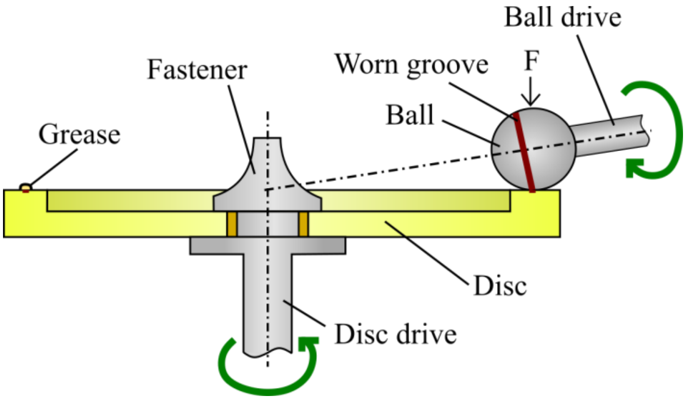

Figure 1: Schematic illustration of the MTM device.

Parameter	MTM
Ball diameter	19.05 mm
Disc diameter	46 mm
Material	AISI 52100
Velocity	0–4 m/s
Contact pressure	0.8–1.25 GPa
Slide-to-roll ratio (SRR)	0–200 %
Temperature	Ambient–150 °C

Table 1: Parameters of experimental devices.

A 60-minute wear-in was conducted on each new pair of test specimens to ensure a stable evolution of the worn groove, following literature recommendations [10]. Samples were cleaned with acetone and subjected to a 5-minute run-in before each test to remove residual grease and stabilize the CoA, also bringing the specimens to approximately 40°C. Grease was applied in 1 µl increments, squashed to leave 0.1 µl in the track, and validated using an analytical balance. The grease layer thickness and volume were verified with a profilometer. Tests were performed on the MTM using the OFAT (one-factor-at-a-time) methodology, where one parameter was varied while others remained constant, and each experiment was repeated at least three times. Default test conditions and values are provided in Table 2.

Parameter	Default test conditions	Values for OFAT testing
Load	37 N	19 N, 37 N, 65 N
Slip	10 %	5 %, 10 %, 20 %, 30 %, 50 %
Amount of applied grease	0.2 µl	0.1 µl, 0.2 µl, 0.3 µl, 0.4 µl, 0.5 µl
Velocity	1 m/s	0.5 m/s, 1 m/s, 2 m/s
Relative air humidity	35 %	25 %, 35 %, 75 %, 100 %
Temperature	40 °C	40 °C, 55 °C, 70 °C

Table 2: Default test conditions and values for OFAT testing.

In the MTM experiments, the evolution of the CoA over time was recorded. From these data, retentivity was evaluated at two thresholds: the time at which the CoA exceeded $\mu = 0.15$ and $\mu = 0.25$. Each experiment was repeated at least three times, and from these repetitions, the mean retentivity and variance were calculated for both

CoA thresholds. Consequently, each combination of tested parameters is described by four values: two means and two variances.

3 Results

In this part, there are two types of graphs. The first type is a graph showing mean values of retentivity and variances of results as described in the previous chapter. The second type shows the best-fitting mathematical dependency of the examined parameter.

The results for the influence of temperature on retentivity (Figure 2a) showed that higher temperatures led to increased retentivity, contrary to expectations based on the influence of temperature on base oil viscosity described in previous studies [4,5]. This discrepancy might be due to temperature affecting grease consistency, allowing it to flow back into the contact path after the ball passes, and potentially enhancing flow from the inner side due to centrifugal forces. A linear dependency was used to describe the influence of temperature (Figure 2b), but it has limitations, predicting zero retentivity around 30°C, which implies an unlikely initial coefficient of adhesion above $\mu = 0.25$.

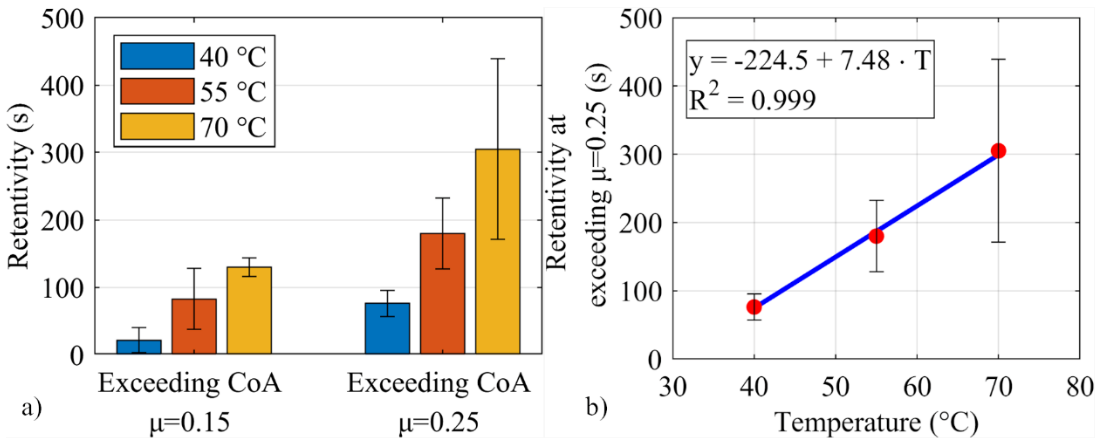

Figure 2: Results of influence of temperature a) mean results, b) mathematical model.

The data for relative humidity (Figure 3) indicate that retentivity remains consistent at 25% and 75% relative humidity. At laboratory humidity (~35%), retentivity is slightly lower but within statistical error. When RH was set to 100% for 5 minutes, water condensation occurred, resulting in a significant increase in retentivity, consistent with literature findings [11]. This suggests that the bentonite thickener, similar to lithium thickener [12], provides higher film thickness in the presence of water. The water itself does not provide as low CoA as grease. However, it can aid in altering the consistency of applied grease and help replenish the contact overcoming the removal of applied lubricant. It should be noted that the observations are made with a contact that is not fully flooded by the lubricant. In fully flooded conditions, the behavior may be very different.

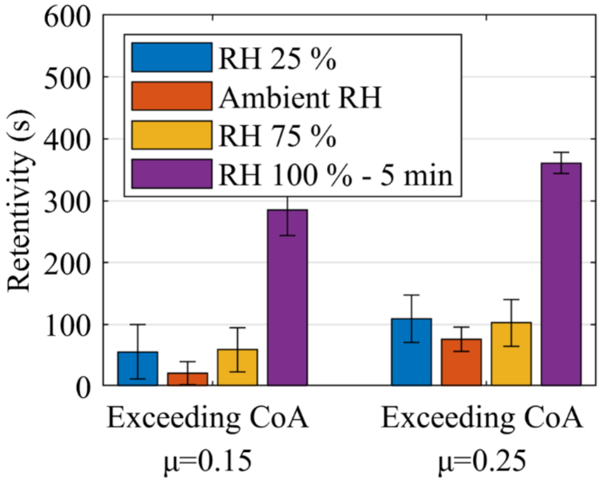

Figure 3: Results of influence of relative humidity.

The graphs for load dependency (Figure 4a) show that increasing load decreases retentivity, consistent with previous studies [6,8]. This decrease is more pronounced at the higher CoA (μ = 0.25). At 19 N, the variance of retentivity for μ = 0.15 drops below zero, indicating some tests start at a CoA higher than μ = 0.15, resulting in zero retentivity. Figure 4b demonstrates that the influence of load follows a decreasing power law, similar to grease life in rolling bearings [13]. This model suggests infinite retentivity at zero load, and no upper load limit for zero retentivity. This physically makes sense as at zero load nothing is acting towards removal of the grease. However, the tested loads correspond to contact pressures of 800, 1000, and 1200 MPa, which are at the lower bounds for wheel-rail contact at the flange/gauge interface. So, a wider generalization is not available.

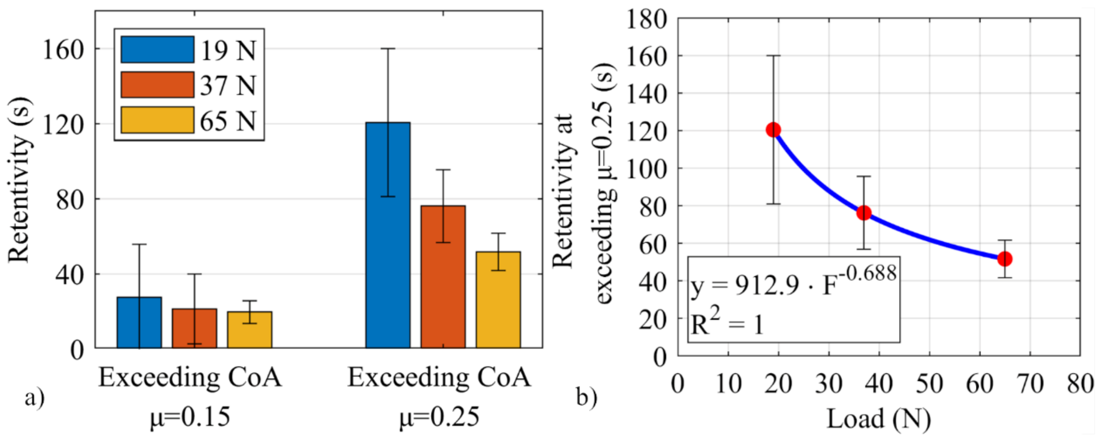

Figure 4: Influence of load on retentivity, a) mean results, b) mathematical model.

The tests varying slip (Figure 5a) show that increasing the slip decreases retentivity, aligning with existing literature [1,6,14]. Some error bars drop below zero, similar to the observations in the load influence tests. This can be described as the CoA after application starting above the value of 0.15. The mathematical dependency graph (Figure 5b) indicates that the influence of SRR on retentivity can be effectively described by a power law function.

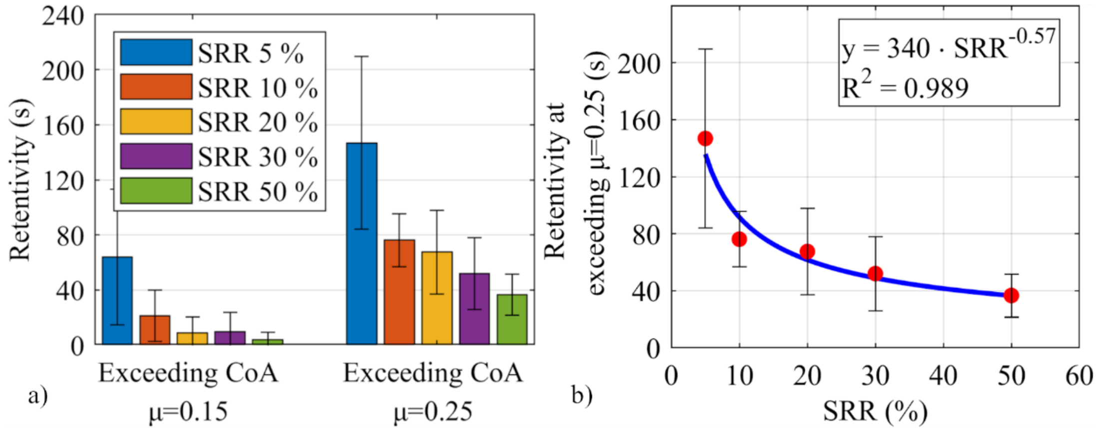

Figure 5: Influence of SRR on retentivity. a) mean results, b) mathematical model.

The results describing the change in velocity indicate that retentivity, when evaluated over time, decreases with increasing velocity (Figure 6a). However, retentivity evaluated over sliding distance will increase with velocity. These results are consistent with previous studies [8]. The time-based retentivity exhibits a power law decay (Figure 6b). Notably, for velocity's influence on sliding distance retentivity has a power coefficient similar to the Hamrock-Dowson prediction for film thickness.

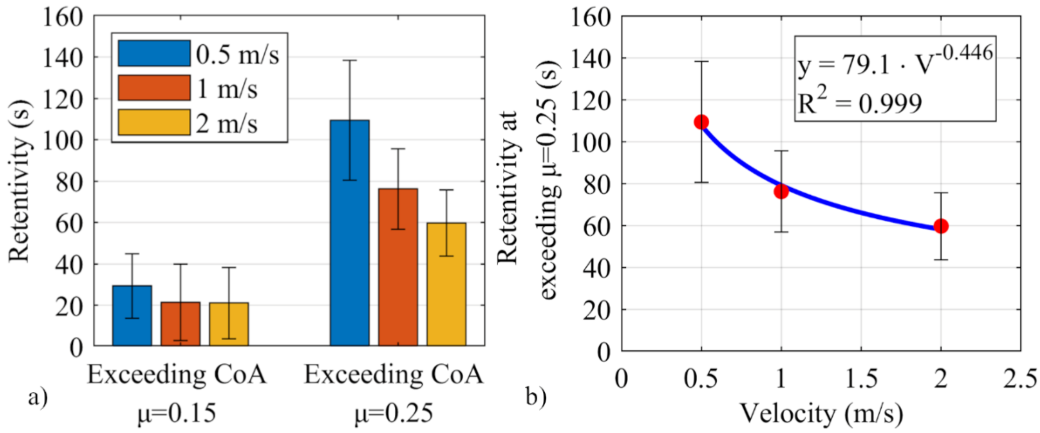

Figure 6: Influence of velocity on retentivity a) mean results, b) mathematical model.

4 Conclusions and Contributions

This study investigated several parameters affecting grease retentivity, including load, slip, velocity, amount of applied grease, relative humidity, and temperature, using experiments on the Mini-Traction Machine. The results were described by mathematical functions. The key findings are:

- Temperature: An increase in temperature linearly increased retentivity within the range of 40–70 °C. However, exceeding the grease's upper temperature limit significantly reduced retentivity. These findings do not align with literature on base oil viscosity effects.

- Relative Humidity: Retentivity was unaffected by relative humidity but significantly increased with condensed water, consistent with previous research. Future research should replace relative humidity with the amount of condensed water.
- Load and Slip: Both parameters followed a decaying power law relationship with retentivity, consistent with existing literature.
- Velocity: The impact of velocity on retentivity varied with the evaluation method. Evaluated over time, increasing speed decreased retentivity, while evaluated over sliding distance, it increased retentivity. This dual behavior is consistent with prior findings in sliding contact and aligns with film thickness predictions.
- Amount of Applied Grease: Retentivity increased linearly with the amount of applied grease, consistent with other studies. Low grease quantities could result in zero retentivity.

These insights provide a comprehensive understanding of the factors influencing grease retentivity and aid in the development of predictive models for lubrication optimization. Further steps require validating the presented results on a real scale and designing a model for the redistribution of lubricant. This will lead to the application of a prediction model to railway vehicles and the estimation of necessary lubrication needs.

Acknowledgements

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