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LUBRICITY AND RETENTIVITY PERFORMANCE OF SEVEN RAILROAD GREASES

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LUBRICITY AND RETENTIVITY PERFORMANCE OF SEVEN RAILROAD GREASES

INTRODUCTION

At the request of CP Rail, seven different types of greases were tested in NRC's Vancouver lab to determine their comparative performance in the wheel/rail interface. Two test apparatus were employed:

a) a 1/10th-scale rail/wheel wear apparatus to establish the retentivity in the top of the rail/wheel tread interface, and

b) an Amsler wear apparatus to establish the retentivity in the gauge face/wheel flange interface.

These apparatus closely simulate the rates of rail/wheel wear and lubricant deterioration experienced in the field.

Rail Wear

Rail wear is governed by the following relationship:

$$Rail\,Wear \propto Lubrication \times \frac{Load \times Slip}{Hardness}$$

In this relationship, load, slip and rail hardness can influence wear several-fold, but no more than 10-fold each. On the other hand, the lubrication constant changes the wear rate by a factor of at least 100-fold. Thus, when lubrication is absent, the wear rate is 200 to 300 times larger than when it is present. Since

- there is little hope of reducing axle loads in the heavy haul wheel/rail interface (indeed they continue to rise steadily),
- slip can only partially be reduced by a specific choice of wheel/rail profile and
- hardness affects the wear rate by no more than a factor of 6,

lubrication represents the last line of defense against rail wear. Comparing the cost of grease to the cost of worn rail, it is readily apparent that maintaining thorough lubrication (i.e., having fresh grease in the wheel flange/rail gauge face interface at all times) is of prime economic importance. The best possible way to maintain good lubrication is to prevent lubrication breakdown.

Lubrication breakdown can occur for numerous reasons. Some of the most prominent causes are broken lubricators, grease that does not pump through the pipes, late pumping of the grease, poor stirability, etc. If all these problems are eliminated, then the presence/absence of lubricant at any specific spot in the track is a function of the ratio between the rates of grease inflow and lubricant consumption at that spot. In other words, any given consumption rate of lubricant should ideally be matched by the delivery rate. The consumption rate is governed by the complex interaction of several wheel/rail variables including friction force and creepage, and by the properties of the grease, the most important being lubricity and retentivity.

Grease Properties

Lubricity refers to the grease's capacity to reduce friction. It is essentially proportional to the coefficient of friction under fully lubricated conditions. Poor lubricity is usually associated with higher wear rates but, compared to dry wear rates during lubrication breakdowns, the overall effect of lubricated wear rates on the life of the rail is insignificant. For example, if Grease A yields a coefficient of friction of 0.06, while Grease B yields a coefficient of friction of 0.1, Grease A can be said to have better lubricity. The wear rates with Grease B may be about twice those of Grease A. If there are any break downs in lubrication, the dry wear rates will completely "swamp" the tiny lubricated wear rates, whether it be Grease A or Grease B. The most important point, therefore is to ensure that the rail is at all time lubricated. The lubricity is of secondary importance.

As will be seen from the results below, all the greases tested had about the same lubricity and all resulted in wear rates so low that they were immeasurable.

Retentivity is a measure of the time (or number of cycles, or MGT's) that the grease is able to retain its lubricity. Since grease, which operates under boundary lubrication conditions, can only partially separate the surfaces of the wheel and rail conditions, the individual microscopic protrusions on each surface – referred to as asperities – are engaged with each other. The frictional heat generated by any such encounter can yield a "flash temperature" measured in hundreds of degrees Celsius. Flash temperatures of 600 to 800ºC are typical of rail/wheel contacts. The lubricant is consumed at these microscopically localized hot spots, literally being "burned up". Once all the lubricant is gone, the coefficient of friction quickly climbs from its "lubricity" coefficient of friction of about 0.05 to its "dry lubrication" coefficient of friction of about 0.6. Compared to lubricated wear rates, dry wear rates are at least 100 times higher.

Like wear rates, retentivity is a function of load and creepage. Laboratory tests have shown that retentivity decreases with increasing load and increasing lateral creepage (angle of attack). The practical implication of this is that loaded trains consume ("burn") grease at a much higher rate than empties, and sharp curves consume ("burn") grease much faster than mild curves.

Wheel/Rail Interface

Under well-lubricated conditions, the wheel flange/gauge side of the rail experiences coefficients of friction as low as 0.05. Some of the grease inevitably spreads from the well-lubricated gauge side to the top of the rail. The contaminated top of the rail typically experiences friction coefficients of about 0.3 $\pm$ 0.1. At this friction level, the flange force on the leading wheel sets of 3-piece North American trucks in sharp curves is about 30% of the axle load (or about 60% of the wheel load on the high rail if the vehicle travels at the balanced speed). By contrast, when the rail is dry, the coefficient of friction is about 0.6 at both the gauge face and top of the rail. With friction this high, the flange force is 60% of the axle load (120% of the wheel load on the high rail). Therefore, a lubrication breakdown occurring for any reason is influenced more strongly by the state of contamination at the top of the rail than the state of lubrication at the gauge face.

The interval between potential lubrication breakdowns depends on the retentivity at both the wheel tread/top of the rail and wheel flange/gauge side. As the top of the rail creepage is at most 1/20 that at the gauge face, the top of the rail contamination, as a rule, has a much higher retentivity rate than the gauge face. As long as the top of the rail is contaminated, the flange force and the rate of "burn up" of grease at the gauge face are moderate. Once the flange force increases, i.e., the top of the rail is dry, the "burn up" of grease at the gauge face accelerates rapidly. For this reason, a breakdown in gauge face lubrication is always preceded by "contamination breakdown" at the top of the rail. Therefore, knowledge of the retentivity at the top of the rail contamination is just as important as the retentivity at the gauge face.

TEST METHODS

Two different test methods were used to evaluate the retentivity of the grease. The rail/wheel wear apparatus was used to evaluate the retentivity on top of the rail because it can operate at any preset angle of attack and simulate curving as it occurs in the field. The disc on disc Amsler wear apparatus was used to simulate the flange contact because of its ability to operate at high creepage rates which are typical at that location

Rail/Wheel Wear Apparatus

The photo of the rail wheel wear apparatus and its schematics, including the motions of its main component, are shown in Figure 1. This test rig enables a wheelset to negotiate a pair of rail discs at any angle of attack. Since the rail shafts are driven, the "wheel set" in this apparatus represent a wheel set of a railroad car rather than that of a locomotive. The cross-sectional profiles of wheel or rail discs are machined on a numerically controlled lathe to field worn wheel and rail profiles (at 1/10th scale). This allows for exact reproduction of longitudinal, lateral and spin creepages as they occur in the field. The angle of attack on the apparatus can be set to the same set of average angels of attack as experienced by the leading and trailing wheel sets in the field on a curve of any degree of curvature (including tangent track). Setting the angle of attack to positive or negative values simulates right or left-hand curves.

To simplify testing, all greases were tested at an angle of attack of –40 minutes of arc. This value represents the average angle of attack on leading wheel sets of North American freight car trucks. At this setting, the lateral creepage is fully saturated and the ratio of lateral to vertical load represents the coefficient of friction at the low rail/wheel disc interface. The wheel set is loaded by a levered, dead weight loading system. A load of 5 kg to the lever system produced a contact pressure of 1500MPa between each pair of wheel/rail discs, which is the typical value for a 100-ton car low rail/wheel interface. Load cells at the high and low rail/wheel disc interfaces measure the lateral load. Rotation speed of the rail discs was set at 240 or 480 rpm. The entire wheel/rail wear apparatus is computer controlled, which includes settings of most test conditions and collection of all data including longitudinal, lateral and spin creep forces.

Grease was applied with a syringe onto the wheel discs through a 0.1mm inner diameter needle. Three half-inch long grease beads were placed equidistantly onto each disc. This represented a minimum amount of grease to lubricate the discs well with no excess grease pilled up at the edges of contact wear band.

Amsler Wear Apparatus

The photo of the Amsler wear machine and the arrangement of the discs (about 1.25" to1.75" in diameter) are shown in Figure 2. By changing the disc diameters one can select any desired value of creepage in disc to disc contact patch. To simulate saturated slip conditions at the rail gauge-face/wheel-flange interface we have selected a creepage value of 22%. Furthermore, to obtain a good simulation of the flange contact with rail we manufactured the upper disc from intermediate (320BHN) rail steel and the lower disc from class B wheel steel. A record the friction history was acquired by computer for all tests. The discs were subject to a 90kg load, yielding a contact pressure of 900MPa.

To establish a sufficient film of lubricant, a generous amount of grease was applied to the discs under fully loaded conditions. Following a few revolutions of the discs, which established thickness of the film, any "squeezed-out" grease was wiped off to prevent re-lubrication of the contact band.

TEST RESULTS

Seven greases were tested in the rail/wheel wear and Amsler apparatus to establish their retentivity in the wheel-tread/top-of-rail and wheel-flange/gauge-face contact, respectively. The greases and a partial list of their properties are provided in Table 1.

Wheel/rail Wear Apparatus

The retentivity measurements, as relates to contamination of the top running surfaces of the rail, are summarized in Figure 3. The retentivity curves for individual greases are shown in Figures 4 – 10.

Amsler Apparatus

The retentivity measurements, as relates to lubrication of the gauge face of the rail, are shown in Figure 11. The retentivity curves for individual greases are shown in Figures 12 –18.

DISCUSSION

The retentivity and lubricity differ appreciably between the top-of-rail and gauge-face testing conditions.

Firstly, most greases have a retentivity in excess of 5000 cycles at the top-of-rail and 500 cycles at the gauge face (please note the difference in scales in Figures 3 and 11). Consider a train consisting of about one hundred and twenty 100-ton cars negotiating a sharp curve. Including the locomotives, it has about 250 leading wheel sets in saturated lateral creepage (i.e. high angle of attack). With a retentivity of 5000 cycles, the grease on top of the rail would "burn" after passage of twenty trains while the grease at the gauge face, with the retentivity of 500 cycles and the top of the rail uncontaminated, would "burn" after the passage of only two trains. This clearly demonstrates the importance of re-establishing the top of the rail contamination immediately following rail grinding or shutdown of track side lubricators prior to Sperry inspection. In the winter, when top-of-rail contamination may be flushed from the rail head by melted snow, gauge face wear can be reduced by top of the low rail contamination (i.e. lubrication).

Secondly, there is little difference in lubricity at the top-of-rail and gauge face. The lubricity at the gauge face, as measured by Amsler, is in the range of 0.09 to 0.11 for all greases. This essentially is the lowest coefficient of friction to be expected at the gauge face. Once wear particles or other matter, such as clay or soil deposited at rail crossings, contaminates the grease, the coefficient of friction at the "well lubricated" gauge face may be higher, up to 0.2. As measured by the wheel/rail wear apparatus, the top of the rail lubricity of all the tested greases is in the range of 0.05 to 0.07. Of course at a coefficient of friction this low, the locomotives would not be able to pull the train and sand would be applied. However, let us assume that at the same mix of lubricant and debris (wear debris, soil, etc) and the same coefficient of friction, it is the lubricant portion of the mixture which governs its retentivity. Although all the retentivities of all the greases would be lower than those shown in Table 2, we also assume that the rating of the retentivity of the individual greases would not change.

With the exception of Shell Cardura Plus, which exhibits high retentivity on top of the rail (see Table 2), and Prolab Pro-Rail, which exhibits high retentivity at the gauge face (see Table 3), there are no substantial differences in top of the rail and gauge face retentivities between the rest of the greases. The reason for this may be that all the grease manufacturers formulated their products with a good knowledge of the severity of wheel/rail contact conditions. Although Table 1 lists the content of some of the extreme pressure (EP) additives, such as graphite and molybdenum disulfide, the content of chemical EP additives which the greases may contain, is not known to us.

As there are no notable differences in the lubricity, the protection against the rail wear of any of the tested greases is about the same, so long as it is present in the rail/wheel interface. Because the differences in "burn-up" rate between the greases tested are not large, it will not be practical to consider varying the lubrication interval (on-board or high-rail vehicle lubricators) or the dispensing rate (track side mounted lubricators). The test results do not, for example, justify the implementation of a 3-fold more expensive lubricant on the basis of a 3-fold reduction in consumption.

The importance of technical variables and actions to ensure a continuous delivery of lubricant to the wheel/rail interface cannot be overemphasized. Preventing gauge face wear in curves thus depends greatly on the pumpability (which is affected by, among other things, the stirability of the grease) and ensuring that lubricators are not allowed to go dry or be shut down for a prolonged periods of time. Although not a subject of our investigation, the stirability of the tested greases was evaluated by Don B. Coveney at the NRC's Center for Surface Transportation Technology in Ottawa. The results are shown in the Appendix A. Any unavoidable lubrication shutdowns can be appreciably compensated for by lubrication of the locomotive flanges with solid lubricant sticks. During recent tests at FAST in Pueblo, Colorado, it was demonstrated that the usage of sticks prevented the roughening of the gauge face surface. This not only reduces the wear rates, but facilitates the establishment of the lubricant film once the track side lubricators are turned on again. Once the film of lubricant originating from track side lubricators is established, the sticks glide on that film and do not wear, i.e. there is no double lubrication. Providing reduced flange wear on locomotive wheels would pay for the sticks while any reduction in rail gauge face wear would represent net savings in rail replacement costs.

RECOMMENDATIONS

A thorough lubrication policy that minimizes gauge face wear requires:

- Application of the grease which has the best pumpability and retentivity. The lubricity of the grease, in practical terms, is barely significant.
- Minimizing the non-lubricated periods and the lubrication breakdowns.
- Usage of the solid sticks throughout the year to carry the rail over any unavoidable lubrication breakdowns.
- "Lubrication" (friction management) of the low rail during the winter period to reduce the extent of lubrication breakdowns.

No.	Grease	Color	Chemical			
			$CaCO_3$	Li St.	MoS_2	C
1	Texaco Molytex RL-W	Light gray	0.047	2.264	2.970	Nil
2	Imperial Oil Galena Moly EP	Dark gray	7.491	0.306	3.41	11.5
3	Whitmore Railmaster #1	Black	0.251	Nil	0.070	1~2
4	Maryn Marinus RC Grease	Yellow	2.434	Nil	Nil	Nil
5	Shell Cardura Plus	Dark gray	0.067	0.087	Nil	Nil
6	Chemtool Chemcal CRG-1MG	Dark gray	4.801	1.889	3.81	11.5
7	Prolab Pro-Rail	Light gray	15.449	Nil	3.64	Nil

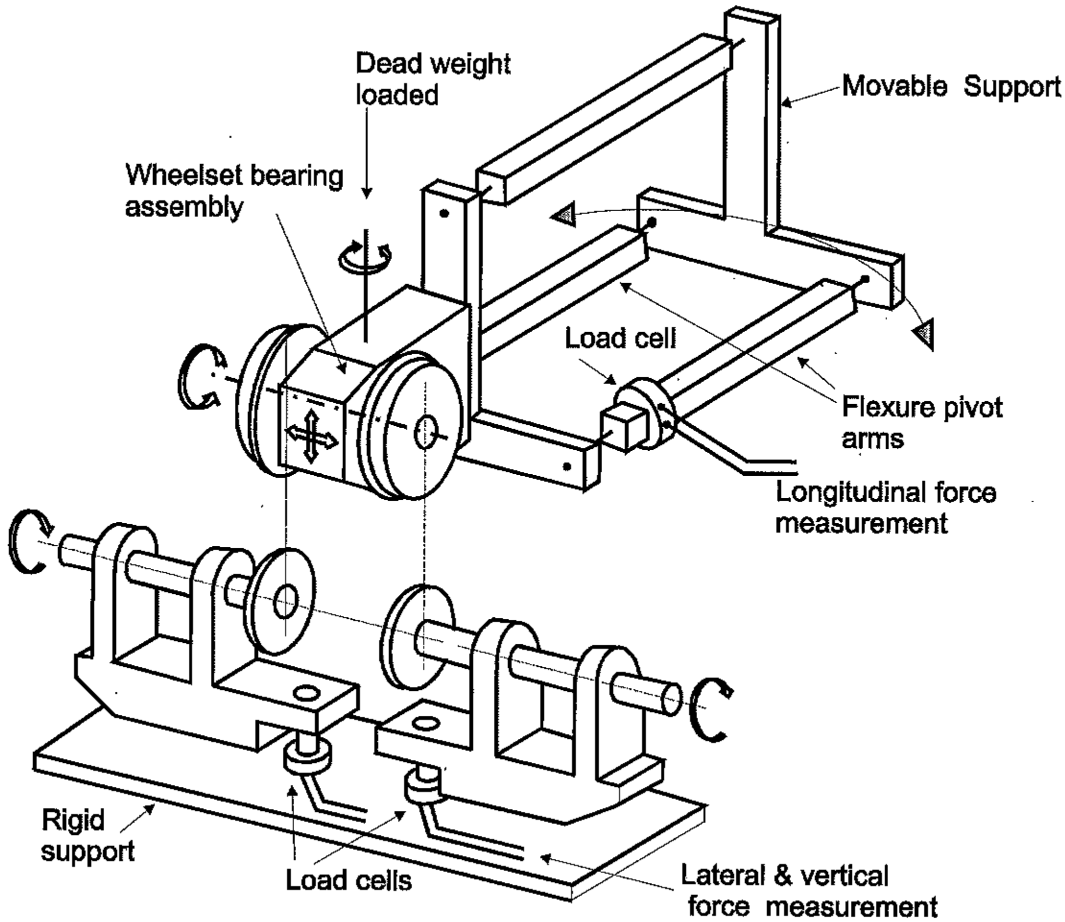
Table 1. List of greases supplied by CP Rail for retentivity testing

NAME OF GREASE	AVERAGE RETENTIVITY	RANKING
Texaco Molytex RL-W	5140	6
Imperial Oil Galena Moly EP	8900	5
Whitmore Railmaster #1	17800	2
Maryn Marinus RC Grease	4960	7
Shell Cardura Plus	41500	1
Chemtool Chemcal CRG-1MG	12300	4
Prolab Pro-Rail	17210	3

Table 2. Average retentivity of greases in the rail rig tests.

NAME OF GREASE	AVERAGE RETENTIVITY	RANKING
Texaco Molytex RL-W	1500	2
Imperial Oil Galena Moly EP	560	6
Whitmore Railmaster #1	1040	3
Maryn Marinus RC Grease	350	7
Shell Cardura Plus	650	5
Chemtool Chemcal CRG-1MG	960	4
Prolab Pro-Rail	23500	1

Table 3. Average retentivity of greases in the Amsler tests.



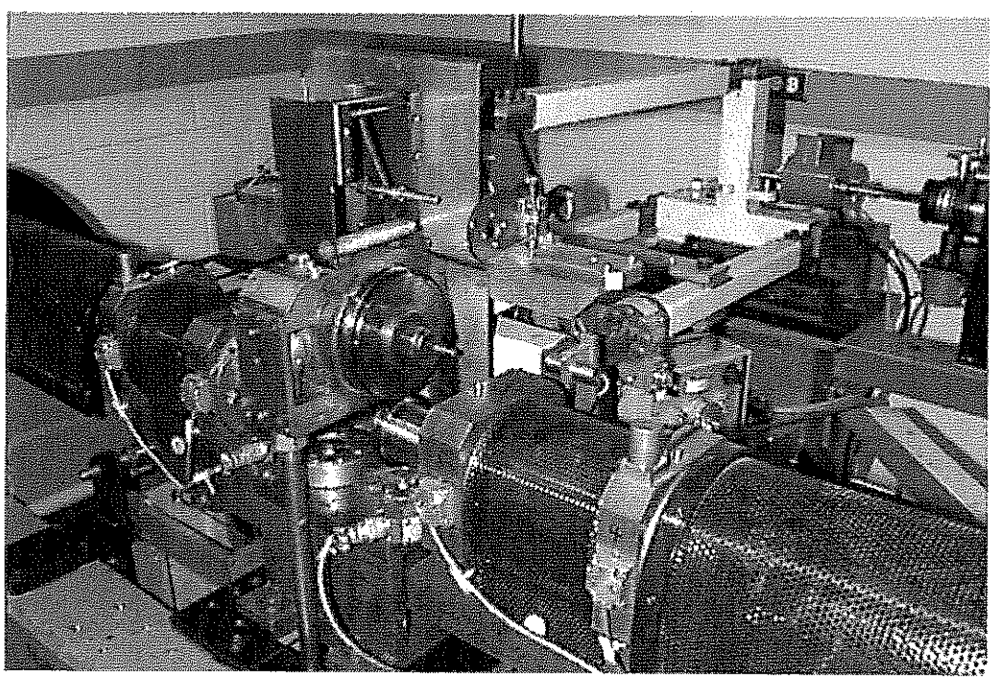
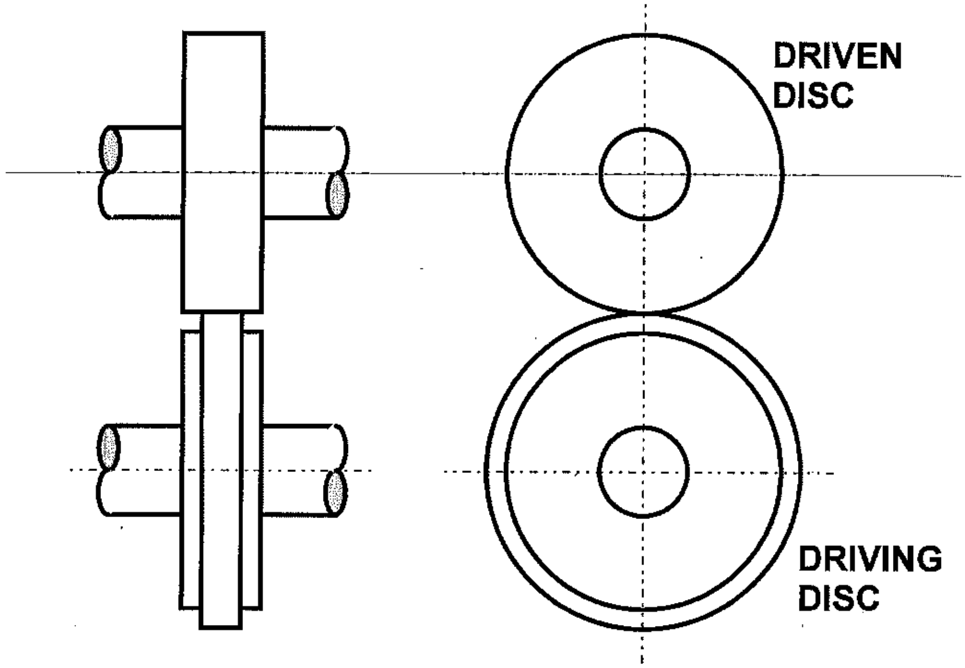


Figure 1. Schematic and photo of the rail/wheel wear apparatus.



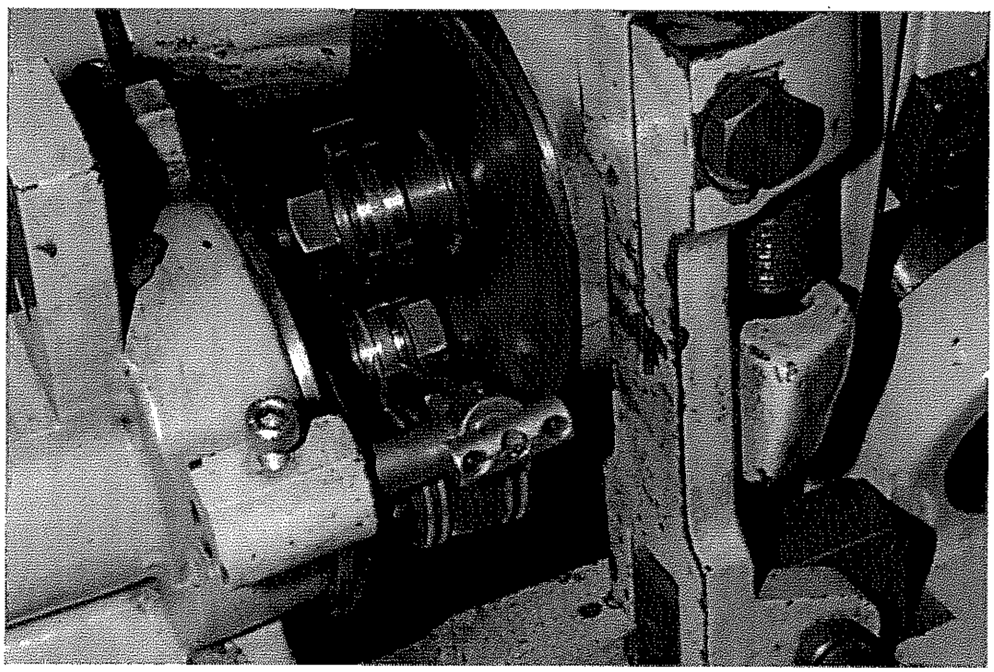


Figure 2. Schematic and photo of the Amsler wear apparatus.

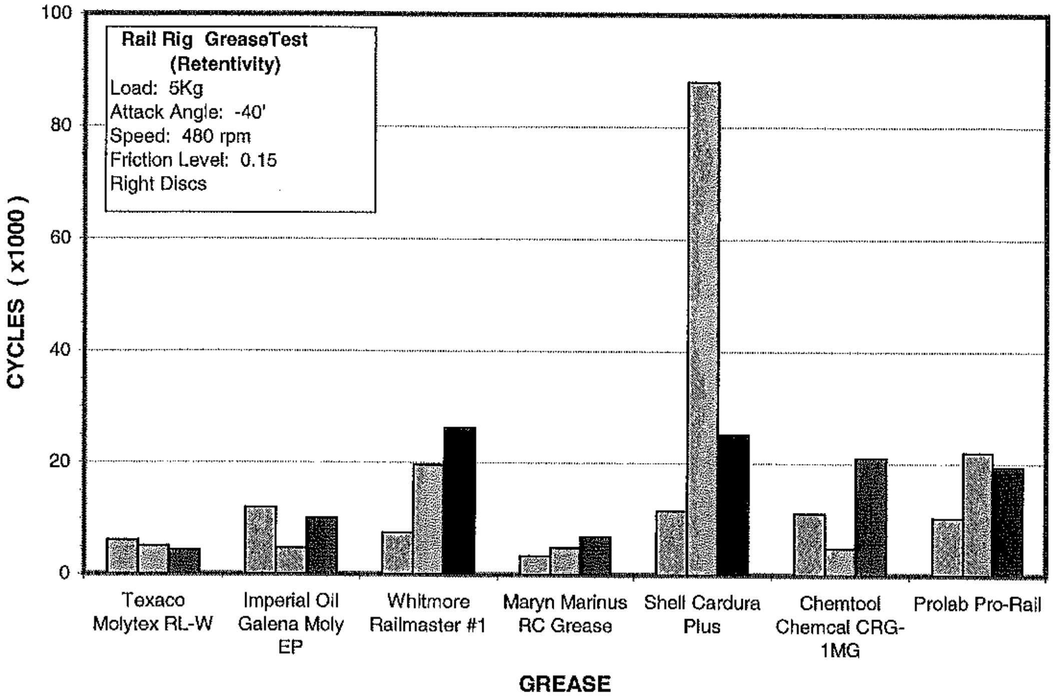


Figure 3. Summary of the rail/wheel wear apparatus grease retentivity tests.

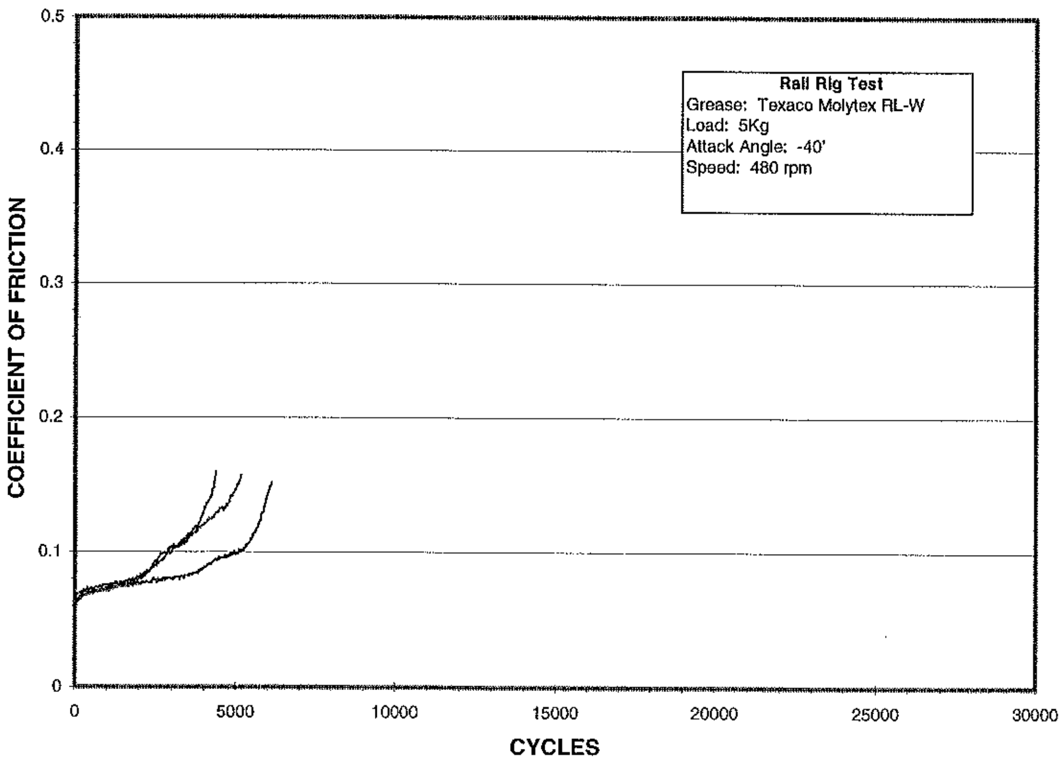


Figure 4. Rail rig retentivity tests of Texaco Molytex RL-W grease.

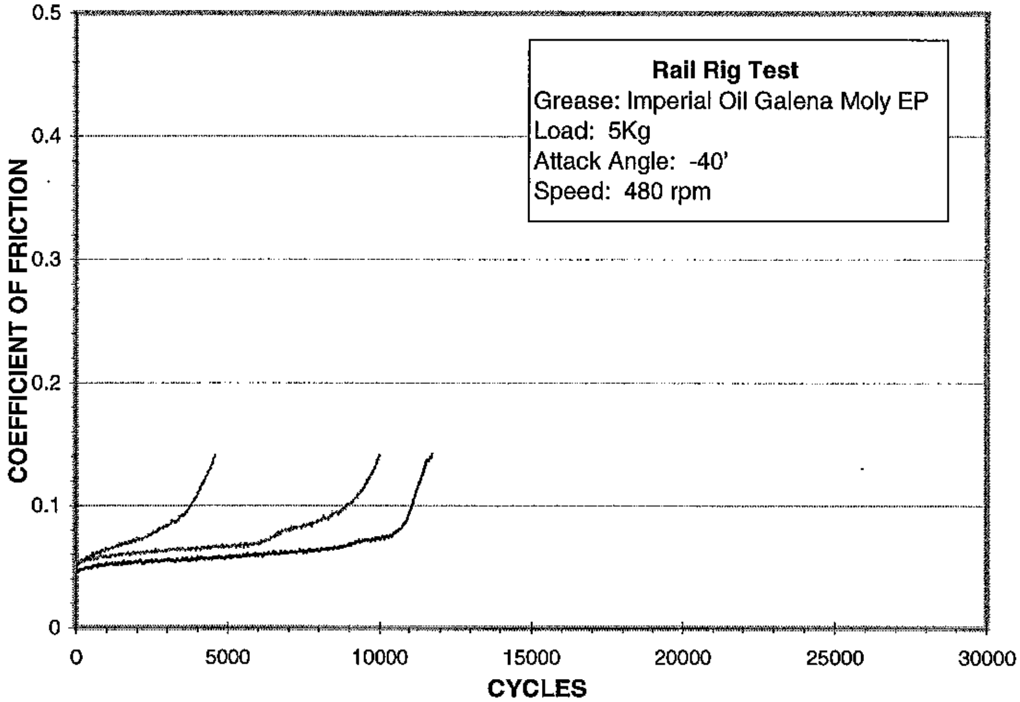


Figure 5. Rail rig retentivity tests of Imperial Oil Galena Moly EP grease.

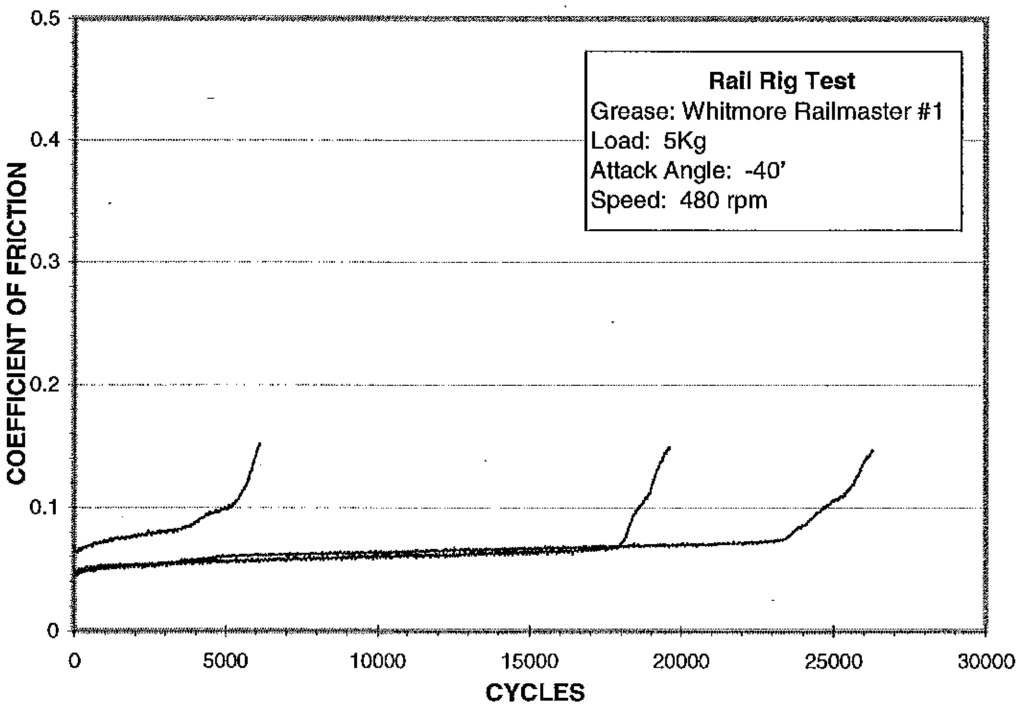


Figure 6. Rail rig retentivity tests of Whitmore Railmaster #1 grease.

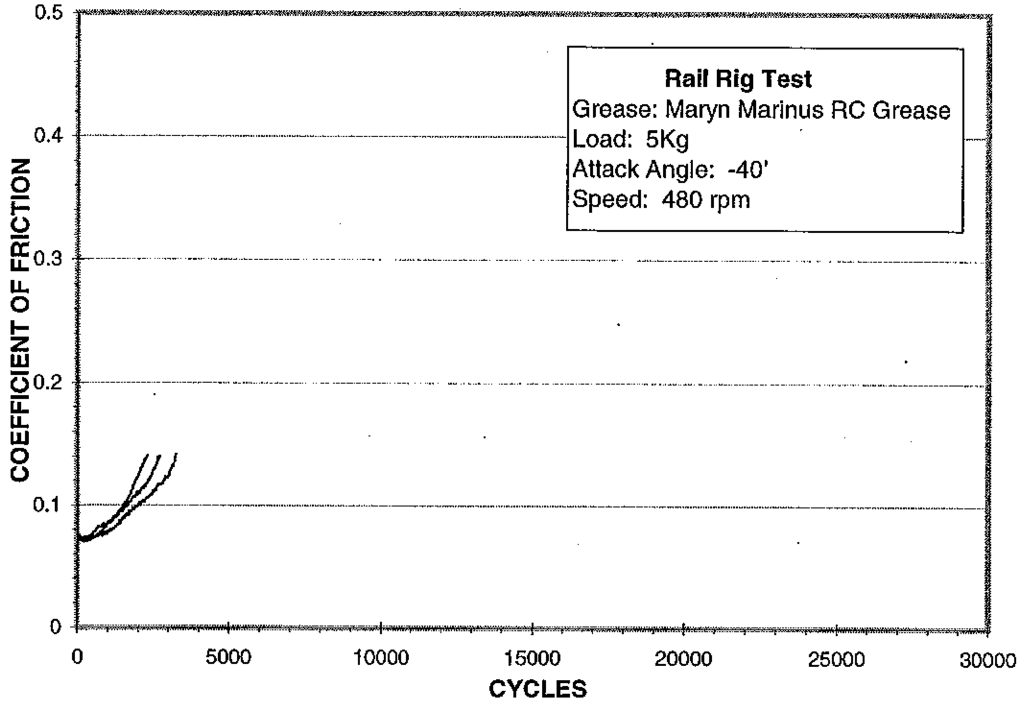


Figure 7. Rail rig retentivity tests of Maryn Marinus RC grease.

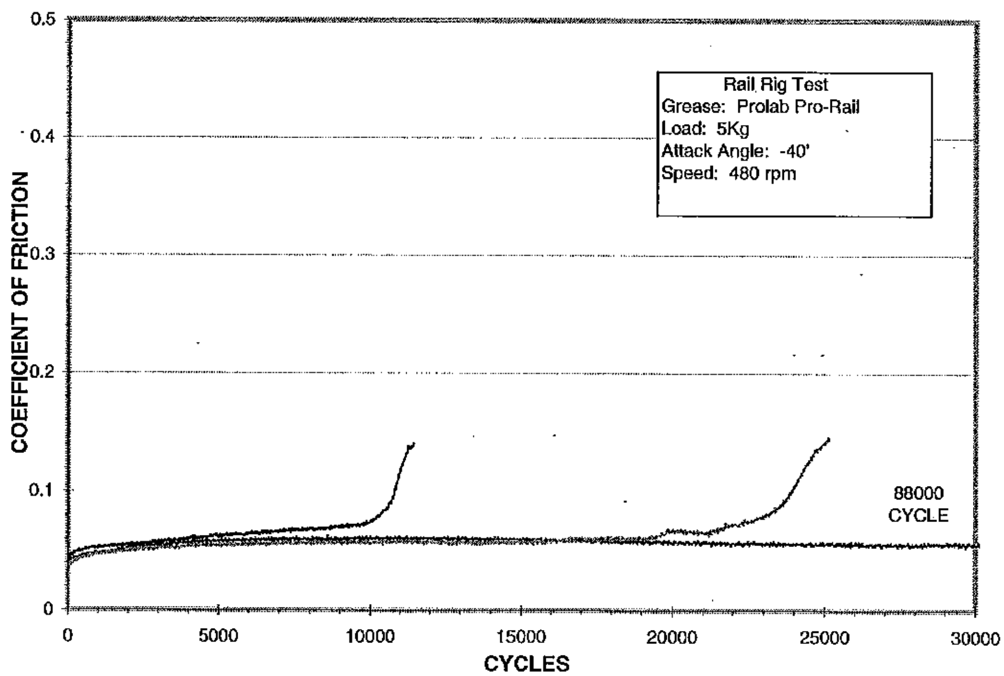


Figure 8. Rail rig retentivity tests of Shell Cardura Plus grease.

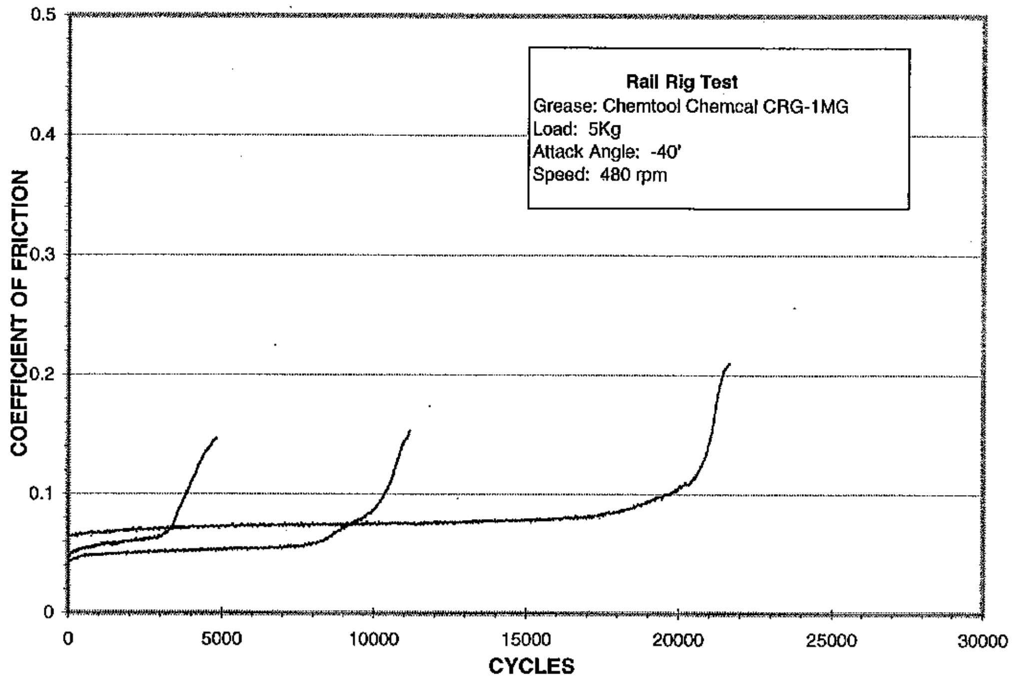


Figure 9. Rail rig retentivity tests of Chemtool Chemcal CRG-1MG grease.

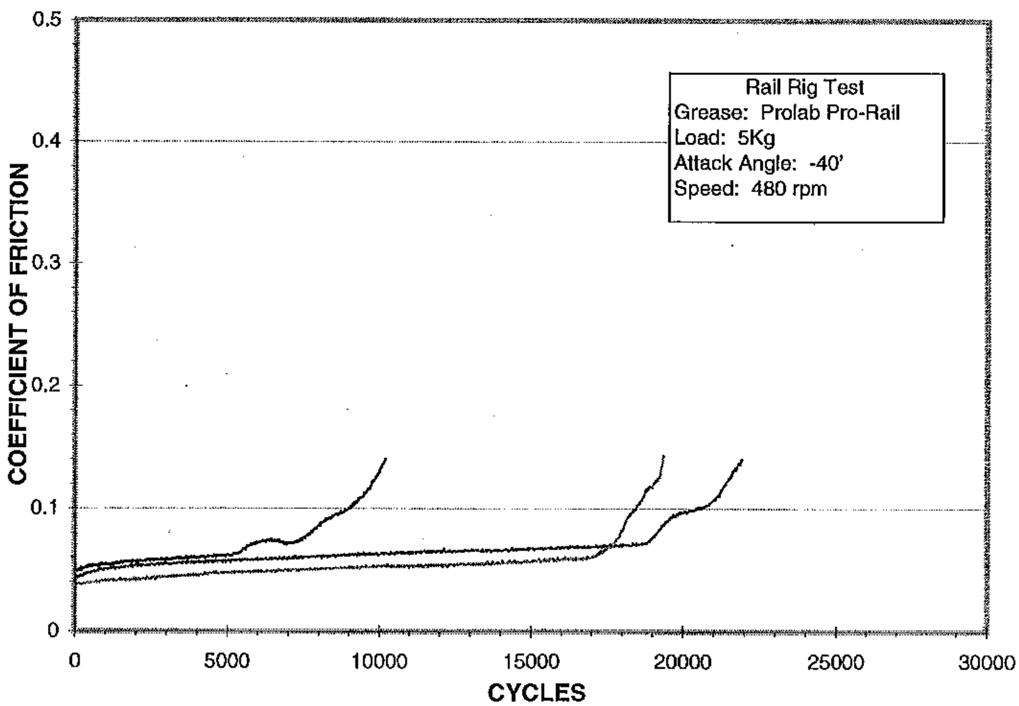


Figure 10. Rail rig retentivity tests of Prolab Pro-Rail grease.

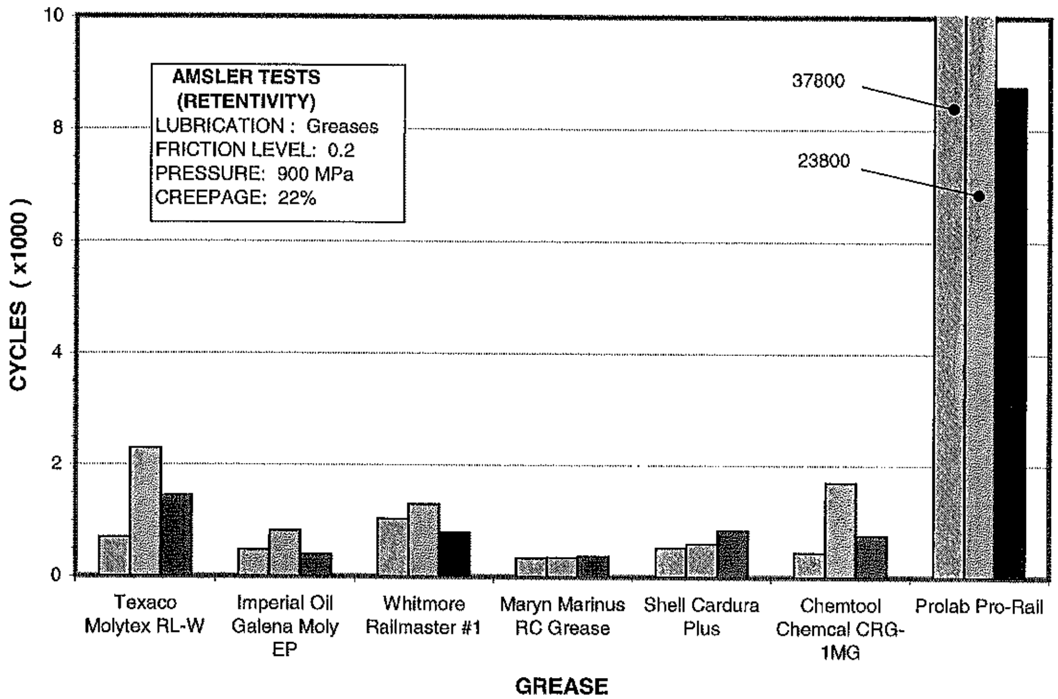


Figure 11. Summary of the Amsler wear apparatus grease retentivity tests.

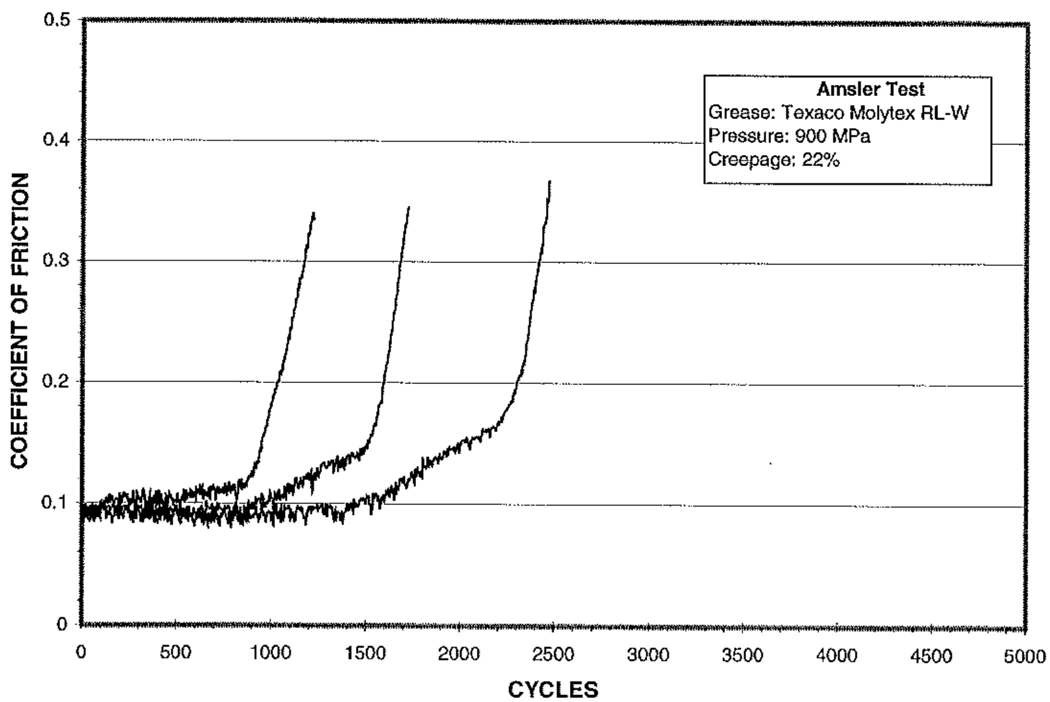


Figure 12. Amsler retentivity tests of Texaco Molytex RL-W grease.

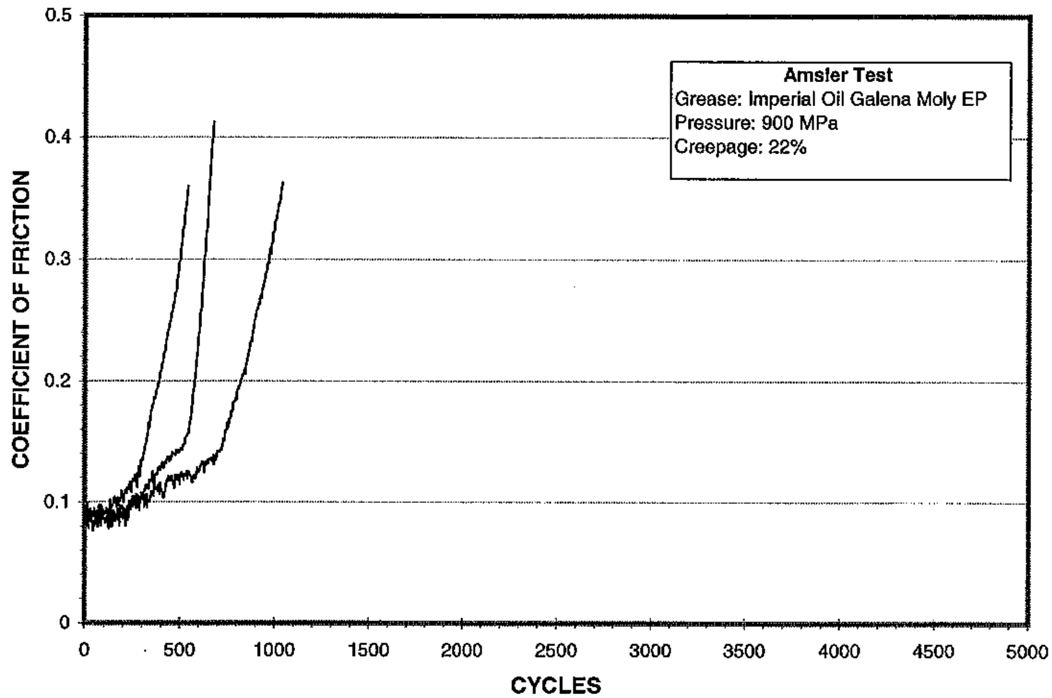


Figure 13. Amsler retentivity tests of Imperial Oil Galena Moly EP grease.

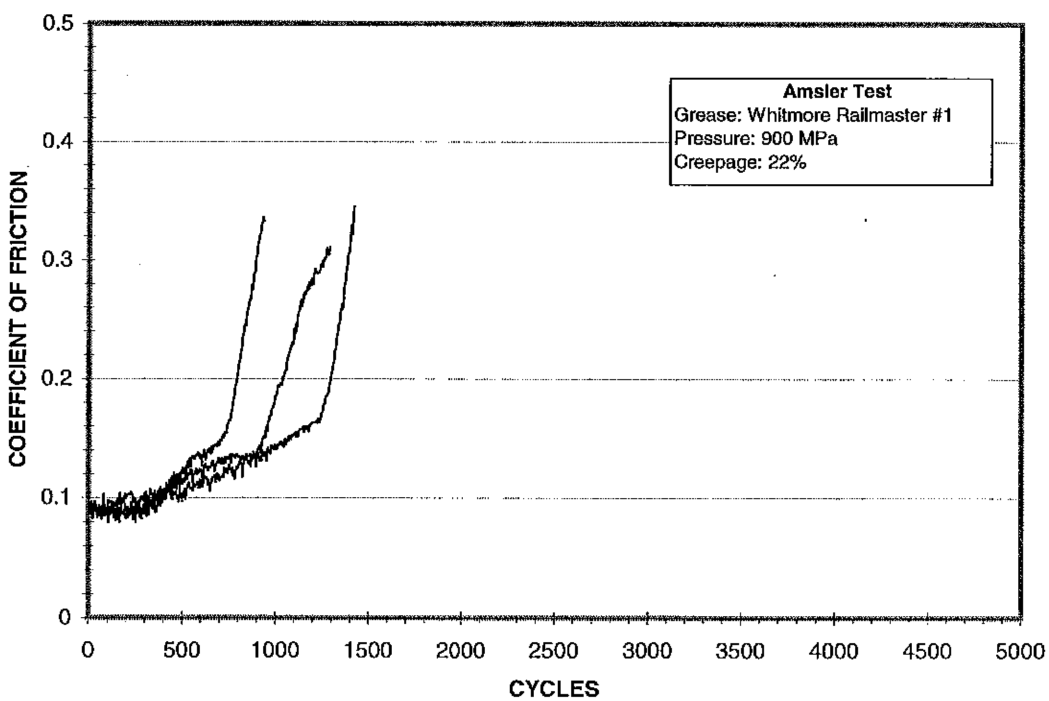


Figure14. Amsler retentivity tests of Whitmore Railmaster #1 grease.

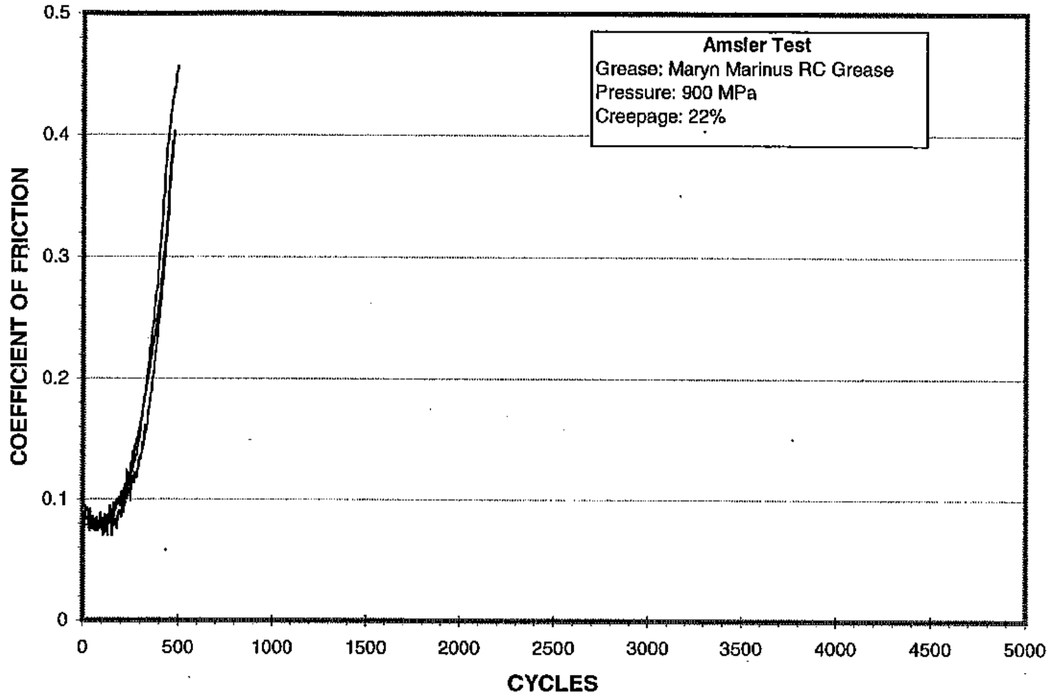


Figure 15. Amsler retentivity tests of Maryn Marinus RC grease.

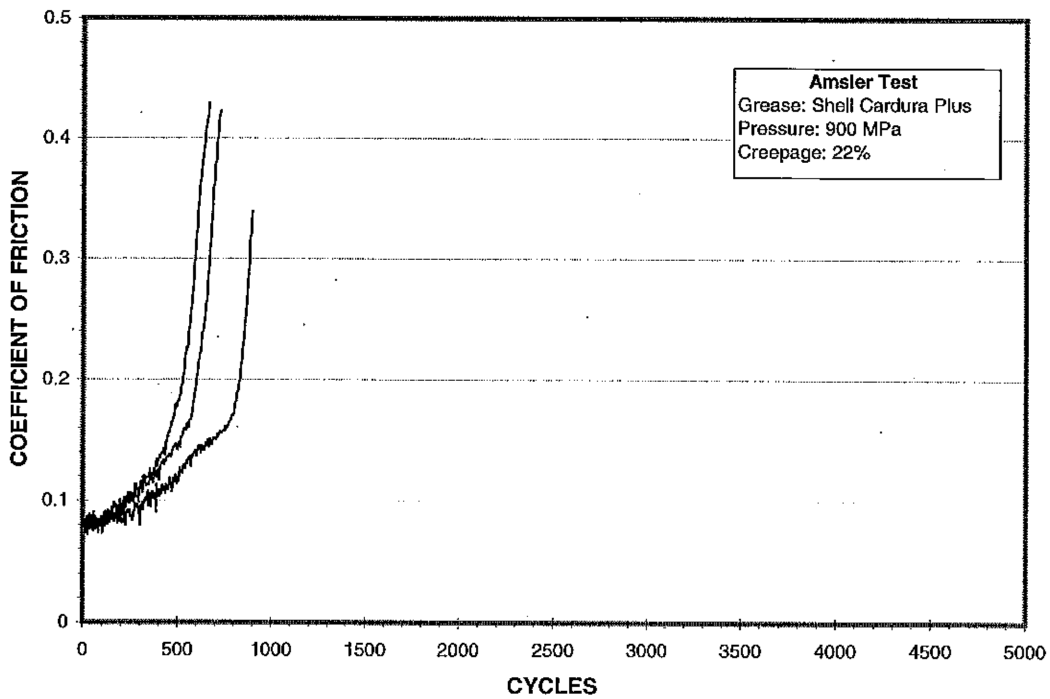


Figure 16. Amsler retentivity tests of Shell Cardura Plus grease.

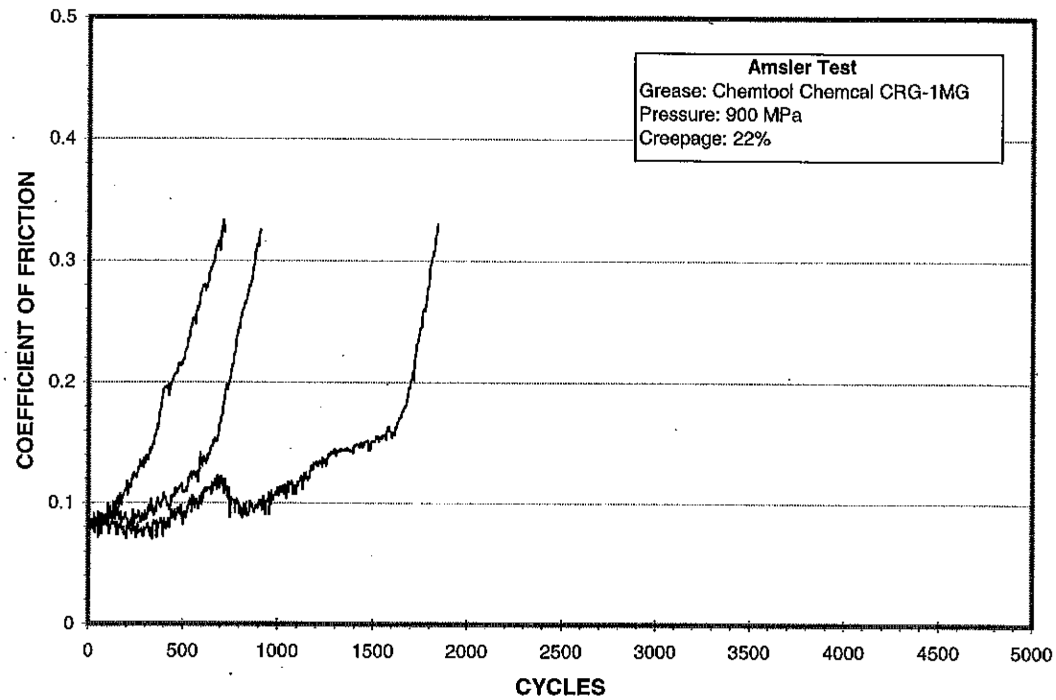


Figure 17. Amsler retentivity tests of Chemtool Chemcal CRG-1MG grease.

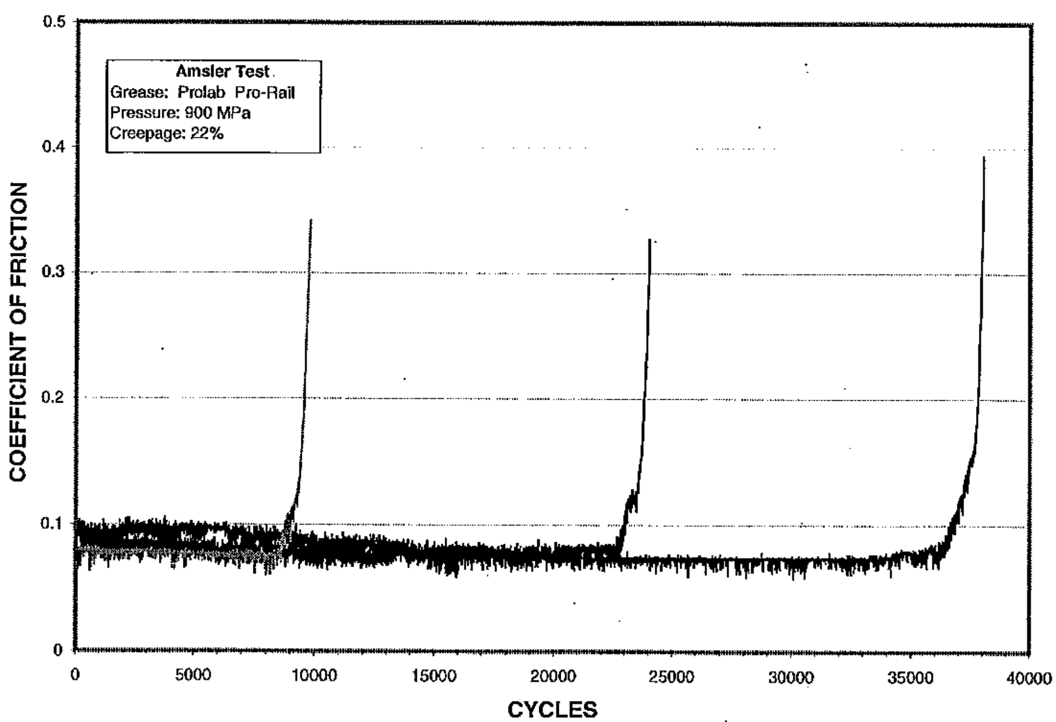


Figure 18. Amsler retentivity tests of Prolab Pro-Rail grease.

APPENDIX

RAIL LUBRICANTS
"STIRABILITY" TESTS AT VARIOUS TEMPERATURES
CEC 25 CP RAIL

By Don B. Coveney
CSTT, NRC
Ottawa

Stirability Tests

A) ≈ -40°C

Samples of the seven candidate greases supplied by the Rolling Contact Tribology Business Unit of CSTT were placed in the Blue M cold chest at M-17 on Friday 98/01/16. At 08:00h on Sunday 98/01/18 the chest refrigeration was started and the controls were set for a temperature of -40°C. At 15:30h on Monday 98/01/19 measurements of the sample temperatures yielded an average of -43°C. Subsequently, an attempt was made to stir each sample. Below is the list of sample greases arranged in order of "STIRABILITY". Note that this is a subjective assessment of the ease with which the samples could be stirred.

1	IMPERIAL OIL GALENA MOLY EP	easily stirred - should slump well
2	MARYN LUBRICANTS	
3	CHEMTOOL CHEMICAL CRG-1MG	stirable - may not slump adequately
4	SHELL CARDURA - PLUS	
5	TEXACO MOLYTEX RL-W	
6	WHITMORE RAILMASTER #1	hard - could not be stirred
7	PROLAB PRO-RAIL	

B) ≈ 0°C

Samples were left in a car overnight reaching a temperature of 0°C. Subsequent stirring tests on Tuesday 98/01/20 showed that all could be stirred easily. However it was noted that samples 6 and 7 were slightly stiffer.

C) ≈ +20°C

Samples were then left to warm-up to room temperature (21 °C). All could be stirred easily with no perceptible differences on Wednesday 98/01/21.

D) ≈ +60°C

On Tuesday 98/01/27 samples were placed in an oven until they reached 65°C. After removal from the oven, the samples had cooled to 62°C when a subjective comparison of the hot "STIRABILITY" commenced. They had cooled further, to about 60°C, by the end of these tests. Below is a list of the samples in order of hot stiffness.

1	IMPERIAL OIL GALENA MOLY EP	stiffest
2	MARYN LUBRICANTS	relatively stiff
3	CHEMTOOL CHEMICAL CRG-1MG	sag but do not drip
4	SHELL CARDURA - PLUS	
5	TEXACO MOLYTEX RL-W	
6	WHITMORE RAILMASTER #1	
7	PROLAB PRO-RAIL	separated

Comments

At low temperature the IMPERIAL OIL GALENA MOLY EP and the MARYN LUBRICANTS greases appeared to be about equal and most easily stirred; the CHEMTOOL CHEMICAL CRG-1MG, the SHELL CARDURA - PLUS and the TEXACO MOLYTEX RL-W appeared about equal but somewhat less stirable; the WHITMORE RAILMASTER #1 and the PROLAB PRO-RAIL were both hard and could only be cut like hard butter.

At moderate temperatures from 0°C to 20 °C all greases were subjectively much the same. More sophisticated test methods would be needed to differentiate between them.

At high temperature the IMPERIAL OIL GALENA MOLY EP remained the stiffest with the TEXACO MOLYTEX RL-W close behind; the CHEMTOOL CHEMICAL CRG-1MG, the SHELL CARDURA - PLUS the WHITMORE RAILMASTER #1 and the PROLAB PRO-RAIL all were less stiff but did not drip; the MARYN

LUBRICANTS grease separated.

Summary

1) IMPERIAL OIL GALENA EP has the best overall flow characteristics from -43°C to +60°C.

2) MARYN LUBRICANTS grease has good flow characteristics at the lowest temperatures and at moderate temperatures but is not suitable for use at the highest temperatures because of its tendency to separate in the +60°C range.

3) TEXACO MOLYTEX RL-W has the second best overall flow characteristics. It holds up at the hottest temperatures and may be adequate at the lowest temperatures.

4) CHEMTOOL CHEMICAL CRG-1MG and SHELL CARDURA - PLUS may be adequate throughout the temperature range.

5) WHITMORE RAILMASTER #1 and PROLAB PRO-RAIL are not suitable for use at the lowest temperatures because of their stiffness but may be adequate for use at warmer temperatures up to the highest temperatures.