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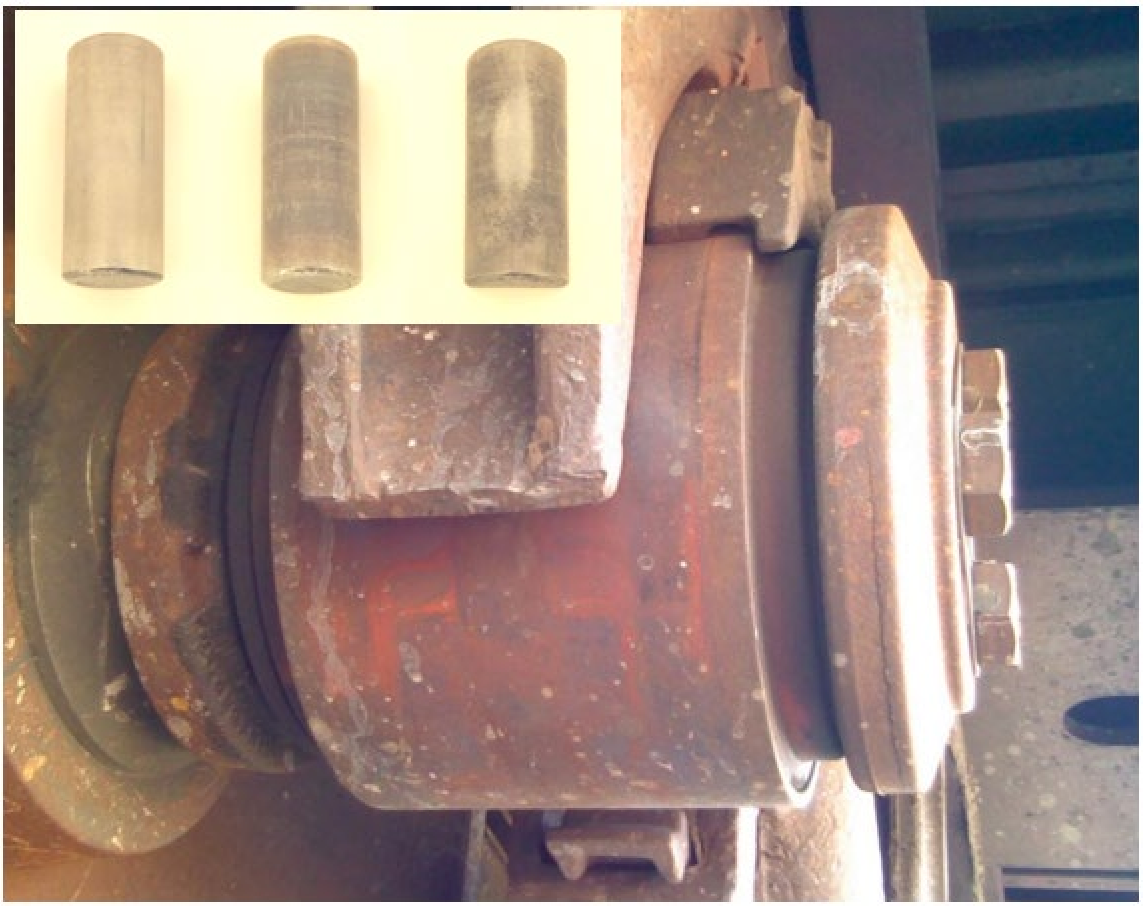
Federal Railroad Administration

Office of Research, Development and Technology
Washington, DC 20590

Bearing Grease Degradation Related to Water and Roller Bluing



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13. ABSTRACT (Maximum 200 words) The Federal Railroad Administration sponsored a team from Transportation Technology Center, Inc. to conduct two investigations to improve the safety of roller bearing operations on railcars. The team conducted the research between September 2018 and April 2022 in collaboration with Burlington Northern Santa Fe Railway, Timken Company, and Amsted Rail Company, Inc. to provide insight into the internal state of bearings that have degraded due to grease degradation from water ingress. The tests conducted in the investigation of water ingress-related bearing grease degradation indicated a difference between bearings with "Water-Etch" and "Non-Verified" failure modes based on ferrous debris levels in the grease. This difference is due to wear of the bearing material deposited in the grease. The tests conducted in the investigation of lube stain in bearings showed lube stain does not affect any tested metallurgical material properties other than surface discoloration. The team recommends that further grease samples should be taken to allow statistical inference of other variables other than ferrous wear, including contamination, consistency, and moisture levels.			
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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0	1	2	3	4	5

Centimeters	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

The Federal Railroad Administration (FRA) sponsored a research team from Transportation Technology Center, Inc. (TTCI) to conduct two investigations to improve the safety of roller bearing operations on railcars. The team conducted the research from September 2018 to April 2022.

Bearing defects can result in a premature termination of service life. Water ingress into the bearing is a factor for premature failure, as water may corrupt internal parts and degrade the bearing grease. TTCI and FRA conducted this research in collaboration with Burlington Northern Santa Fe Railway, Timken Company, and Amsted Rail Company, Inc. to provide insight into the internal state of bearings that have degraded due to grease degradation from water ingress.

The railroad industry also has observed the separate issue of bearing roller "bluing" or "lube stain." This discoloration may be a harmless surface effect, or it may result from effects similar to heat bluing. Determining true metallurgical effects may lead to a better understanding of the differentiation between these two types of bluing.

To study bearings with water-related lubrication degradation, the research team collected grease samples from two populations of bearing lubrication at bearing service locations. One population contained bearings showing water-related damage, and a second population was a control set of bearings. Researchers conducted primary grease analysis per the American Society for Testing and Materials (ASTM) D7918, which provides metrics of wear, contamination, consistency, and oxidative properties. The team performed additional testing where results indicated they would be useful, including measurements of antioxidants remaining in grease and microscopic analysis of wear particles in the grease.

The team examined bluing or lube stain bearing components through analysis of lubrication and metallurgical metrics. Collections of samples from bearing shops included representative small amounts of grease and blued steel parts from bearings exhibiting surface discoloration. A second sample set included steel parts and grease samples from a control set of bearings and a third set of rollers were heat-blued in the laboratory. Researchers tested lube stained rollers and control set rollers for metallurgical changes. Analysis of the bearing steel consisted of hardness and micro-hardness testing of polished samples, examination to compare microstructural features, and residual stress tests.

The tests conducted in the investigation of water ingress-related bearing grease degradation indicated a difference between bearings with "Water-Etch" and "Non-Verified" failure modes based on ferrous debris levels in the grease. This difference is due to wear of the bearing material deposited in the grease. The tests conducted in the investigation of lube stain in bearings showed lube stain does not affect any tested metallurgical material properties other than surface discoloration.

The team recommends that further grease samples should be taken to allow statistical inference of other variables other than ferrous wear, including contamination, consistency, and moisture levels. Additional testing also would determine if the grease samples vary over different locations in individual bearings, and possibly could identify the best location for sampling.

Further grease analysis also could determine better guidelines for industry-specific grease degradation metrics.

1. Introduction

The Federal Railroad Administration (FRA) sponsored a research team from Transportation Technology Center, Inc. (TTCI) to conduct two investigations to improve the safety of roller bearing operations on railcars. The team conducted the research between September 2018 and April 2022 in collaboration with Burlington Northern Santa Fe Railway (BNSF), Timken Company, and Amsted Rail Company, Inc. to provide insight into the internal state of bearings that have degraded due to grease degradation from water ingress.

1.1 Background

Bearing defects can result in a premature termination of bearing service life. Water ingress into the bearing is a factor for premature failure. Among bearings that are inspected by the railroads as part of the Association of American Railroads (AAR) Roller Bearing Inspection Report (i.e., AAR MD-11) [1], those identified as having water damage (indicated as “Water-Etch” in the AAR MD-11 report) comprise the biggest proportion of early failure modes. Water may corrupt internal parts and degrade the bearing grease. It is vital, therefore, to understand grease analysis as a tool for bearing research. Grease analysis provides metrics of wear, contamination, consistency, and oxidative properties. This research provides insight into the internal state of bearings that have failed because of grease degradation due to water ingress. Separately, the railroad industry has observed bearing roller “bluing” or “lube stain.” Lube stain is a surface discoloration identified by the industry as a staining caused by grease on the bearing roller and other bearing components. This discoloration may be a harmless surface effect, or it may result from effects similar to heat bluing. Determining true metallurgical effects may lead to a better understanding of the differentiation between these two types of bluing.

1.2 Objectives

The primary objective of this research was to improve the safety of roller bearing operations on railcars and reduce accidents associated with their failure. The research team met these objectives through two investigations: the first was to explore bearing grease degradation in bearings that experienced water ingress, and the second was to determine the effects of lube stain on bearing performance.

1.3 Overall Approach

To understand grease degradation related to water ingress, the team compared differences in grease from bearings with water-related defects and grease from a control set of bearings. This comparison allowed a direct contrast of the differences in the state of the grease from bearings without condemnable defects and bearings that had water damage.

To determine the effects of lube stain in bearing operation, the team compared specific examples of bearings with lube stain to a control set of bearings. Two approaches were taken to conduct the investigation into lube stain. The first was to compare the grease characteristics of bearings that contain lube stain to bearings that do not to see if there is a difference in the grease that caused the lube stain to a grease that did not. The second approach was to compare the metallurgical differences in rollers that exhibit lube stain and those that do not to see if any changes occurred that might interfere with bearing performance.

1.4 Scope

This research project concentrates on Class F and K railway bearings, the two most prevalent types in revenue service. The samples were taken from one of the largest wheel shops in North America, offering a large possible sample population of bearings with varying operational and geographic histories. Researchers assumed that the bearings sampled for this research project are representative of bearings in revenue service.

1.5 Organization of Report

The following sections detail the work that took place under this project:

Section 2 provides the approach to understanding grease degradation related to water ingress.

Section 3 offers a data analysis of the water-related grease degradation.

Section 4 details the results and key lessons of the water-related data analysis.

Section 5 determines the effects of lube stain in bearing operation.

Section 6 provides a lube stain data analysis based on the investigation in Section 5.

Section 7 summarizes the results from the lube stain data analysis with an informed discussion.

Section 8 briefly outlines the results founded and the recommendations for future work.

2. Water Ingress-Related Grease Degradation

To understand grease degradation related to water ingress the team compared differences in grease from bearings with water-related defects and grease from a control set of bearings. This comparison allowed a direct contrast of the differences in the state of the grease from bearings without condemnable defects and bearings with water damage.

The team first identified bearings with water-related defects by using the industry standard AAR MD-11 process in which the failure mode related to water is called Water-Etch. Water-Etch is defined as condemnable etching on the races (i.e., rollers) of the bearing. This can be identified by rusty bearing parts, water or moisture in the bearing grease, or evidence that the railcar has been flooded [1]. The AAR MD-11 process is performed by a representative from the railroad and a representative from the bearing manufacturer. The bearings that go through this process are indicated as defective by a wayside detection device, either an Acoustic Bearing Detector (ABD) or a Hot Bearing Detector (HBD).

To identify a control set, it is important to understand the lifecycle of a railroad roller bearing. Bearings are greased for life, meaning that they are sealed and never re-greased during their service periods. Bearings are removed from service at the end of life, or earlier if a defect is detected. They can be reconditioned or remanufactured and placed back into service, at which time they are freshly greased and given new seals. Fresh grease is very different from worn grease in its properties. Thus, the most meaningful comparison is not between fresh grease and grease from bearings with defects, but rather between grease from bearings with defects and grease from bearings that have been in service without defects. These bearings are identified as "Non-Verified" in the AAR MD-11 process [1]. These samples do not allow comparison of Water-Etch failure mode to defect-free bearings, or more broadly, to grease from bearings in the general revenue service. It only allows a comparison of bearings identified as defective by a detector later found to have no condemnable defect (Non-Verified) and those later found with water damage (Water-Etch).

2.1 Grease Sample Collection

Researchers collected grease samples prior to the inspection of the bearings for the AAR MD-11 process. Once bearings are identified as defective by wayside detectors, they are removed from the equipment and brought to the wheel shop. The typical process of preparing bearings for the AAR MD-11 begins as the bearing is pulled from the axle. The seal is popped off so the bearing can be disassembled and washed, removing all the grease. The parts are placed together and stored, awaiting review. AAR MD-11 reviews are held multiple times a year.

It is not possible to wait until the defects are known to collect grease from bearings with specific failure modes. The grease is washed away before any investigation into the bearing is conducted. Therefore, to collect adequate grease samples for the specific defect conditions in this research, the team collected grease samples from every bearing at the shop. Researchers then used the later AAR MD-11 report conclusions to determine the samples for the two research groups. Examinations of historical AAR MD-11 records indicated that 200 grease samples would be sufficient to ensure that approximately 30 would be from bearings showing the Water-Etch failure mode.

Of the 200 samples collected, 27 were identified with Water-Etch failure mode and 27 were identified with Non-Verified failure mode. These were used to create the two comparison groups. Each sample had 53 data variables from the AAR MD-11 report and the grease analysis. Four different types of greases were identified among these samples. Researchers used Grease Thief® sample collection kits to obtain the grease samples, as shown in Figure 1.

Figure 1. Collected Grease Thief Samples

The kit allows for complete analysis with a very small sample size of approximately 1 gram. The grease was sampled as the bearings were opened for the first time and the samples were taken from the center of the bearing, near the spacer. As the bearings' failure modes were determined throughout the year, the grease samples were sent to the laboratory for testing.

2.2 Grease Testing

Grease samples were sent to ALS Tribology Services via MRG Labs for testing in accordance with American Society for Testing and Materials (ASTM) D7918 standards [2]. The laboratory conducted up to six tests on each sample, focusing on wear, consistency, contamination, and oxidation. Analytical Ferrography and Remaining Useful Life (RULER) tests were recommended by the laboratory for samples that indicated high wear or water levels. Table 1 provides the tests used for each category.

Table 1. Grease Tests

Wear	Consistency	Contamination	Oxidation
Ferrous Debris Analyzer (fdM+)	Die Extrusion	Fourier-transform Infrared Spectroscopy (FTIR) Spectroscopy	Rotating Disc Emissions (RDE) Spectroscopy
RDE Spectroscopy	--	RDE Spectroscopy	RULER Analysis
Analytical Ferrography	--	Visible Light Spectrum	--

The laboratory used fresh grease obtained from the manufacturer to form baseline measurements. These baselines were used to understand the change in grease throughout its life cycle to the point it was sampled. It was necessary to know initial chemical compositions of the greases to determine amounts of contamination or loss of antioxidants. Specifically for this project, the fresh grease baseline was used to identify grease sampled from each bearing. There are six approved greases in use in the North American rail industry [3]. Overall, grease used in a particular bearing is not tracked in any systematic way. Shops use any available approved grease as supplies last, and the bearings could be in service for decades. The original grease type of each sample was identified through the grease analysis used in this investigation.

3. Water-Related Data Analysis

Data analysis of the water-related grease degradation began with a breakdown of the attributes of the sample sets. Figure 2 shows that most of the bearings sampled from both sets were Car Type A – Equipped Box Cars, Type C – Covered Hopper Cars, Type J – Rotary Gondala Cars, and Type T – Tank Cars. Most of the Water-Etch set and a plurality of the Non-Verified set came from Tank Cars.

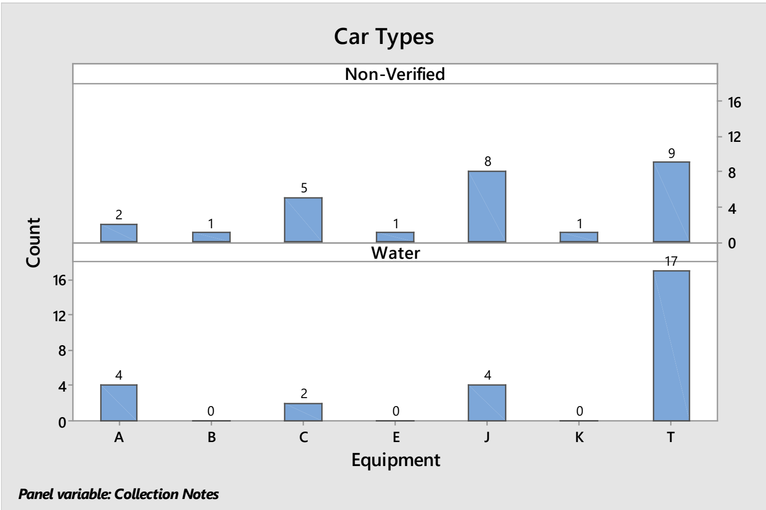

Figure 2. Chart of Car Types

The number of years since installation for each bearing gave an indication of the service life of the bearing. Most of the bearings sampled in each group were from within the last decade, with some bearings installed as long ago as 1991. The chart in Figure 3 shows the dates of manufacture or most recent reconditioning/remanufacture.

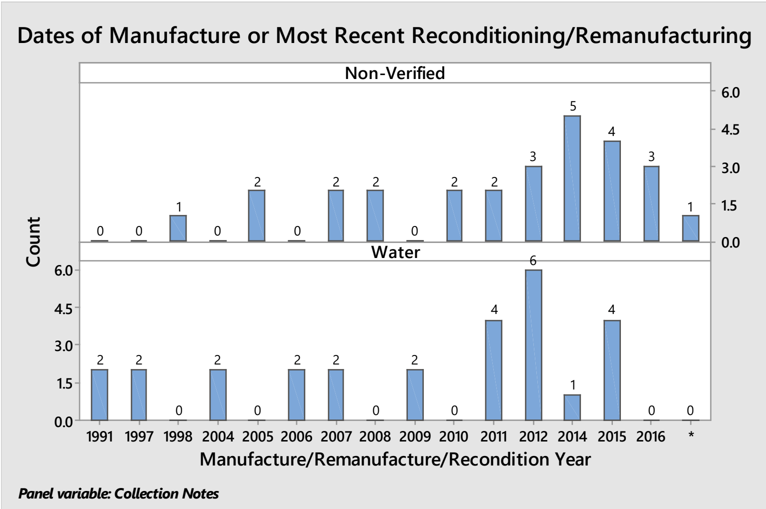

Figure 3. Chart of Dates of Manufacture

Figure 4 shows the number of times each bearing sampled had been reconditioned or remanufactured. The majority of Water-Etch bearings and a plurality of Non-Verified bearings were in use for the first time, and had not been reconditioned or remanufactured.

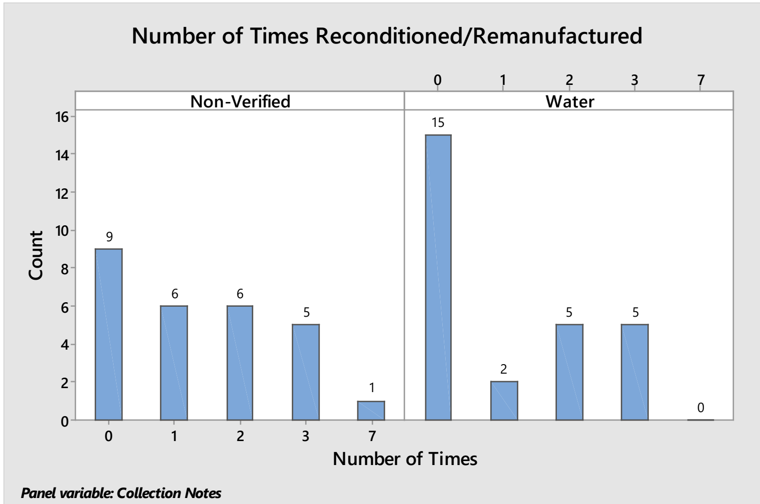

Figure 4. Chart of Number of Times Reconditioned/Remanufactured

Researchers also determined the method of detection by which the bearings were removed from service. Figure 5 shows the most common method of removal for Water-Etch defect bearings was from ABD. The Why Made (WM) codes 51 (WM51) and 52 (WM52) are used when the alerting wayside detection device is an HBD [4].

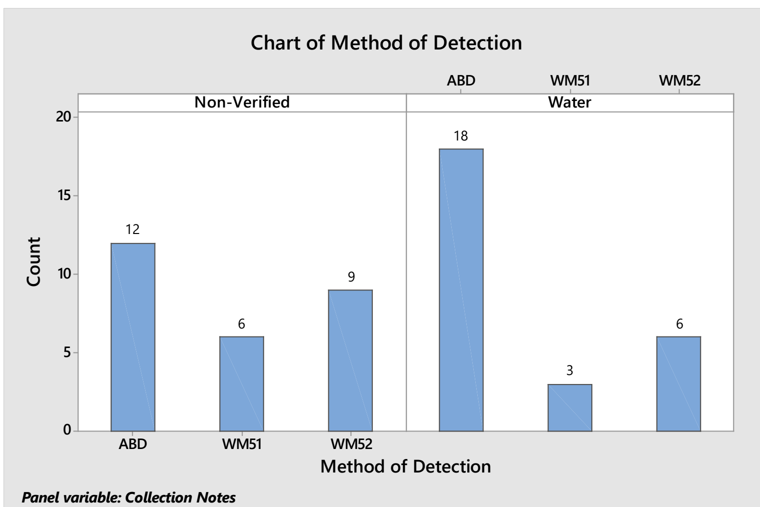

Figure 5. Chart of Method of Detection

Other data available from the AAR MD-11 reports showed that the bearings did not favor a car position. In other words, they were equally likely to come from either car side or any axle position. All samples were from Class F or K bearings, with slightly more F class bearings in each set. More samples would allow analyses of grease degradation by other attributes such as seal types, bearing sizes, or grease types.

Once the samples are evaluated for wear, consistency, contamination, and oxidation, they are then rated in each category on a severity scale. The least severe level is green and the most severe is red, with yellow between. This rating is based on a set threshold for each tested variable. For example, Ferrous Debris Levels over 6,000 parts per million (ppm) create a red severity rating for the wear category. Figure 6 shows an example of the severity ratings given for a particular sample.

Figure 6. Example of Severity Rating

The severity levels counts in the wear category show a significant difference between the Water-Etch set and the Non-Verified set, with the Water-Etch set indicating more red severity level ratings than the Non-Verified set. The other categories of grease testing do not show a significant difference in severity counts. Figure 7 shows the severity rating counts in the wear category for each sample set.

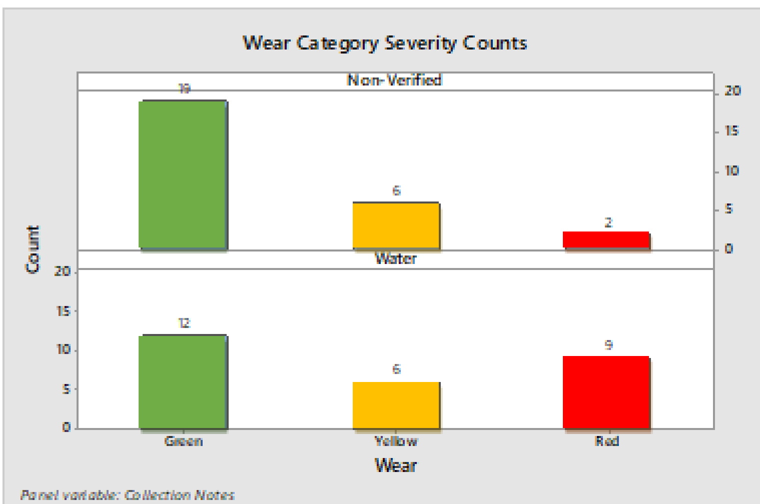

Figure 7. Chart of Severity Ratings for Wear of Water-Etch and Non-Verified Sample Sets of Bearings

The wear category contains measurements of the constituents of steel expected in bearings. The more of the bearing steel deposited into the grease, the higher the measurements would be in the wear category. These measurements are obtained using two tests, the Ferrous Debris Analyzer (fdM+) and Rotating Disc Emissions (RDE) spectroscopy. The fdM+ test uses the magnetic properties of the grease to determine a count of ferrous debris, while RDE spectroscopy measures the concentrations of atomic elements in the grease sample [5]. Comparing this measurement to the fresh grease determines what atomic elements have been accumulating in the grease sample. The wear category measures concentrations for the following variables: ferrous debris, iron, copper, lead, aluminum, silicon, molybdenum, chromium, manganese, nickel, titanium, and vanadium.

All the wear category red severity ratings in the two sample sets were based on ppm counts of ferrous debris and iron levels. Ferrous debris levels over 6,000 ppm and Iron levels over 2,500 ppm create a red severity rating for the wear category. An examination into the concentration counts of the elements included in the wear category shows that iron is significantly correlated with copper, aluminum, chromium, nickel, and ferrous debris levels. This correlation is to be expected, as the wear category measures the amount of bearing material that has been deposited in the grease and these correlated elements could be expected to make up the steel of the bearings sampled. Ferrous debris and iron have the highest concentration of these elements in the grease. Ferrous debris levels are also lognormally distributed for both sample sets. A transform of the ferrous debris levels allows a direct comparison of the Water-Etch set of samples and the Non-Verified set of samples.

A statistical T-test of log-transformed ferrous debris levels was performed in Minitab® 17 [6] and the results are shown in Table 2. Since the p-value is below the threshold of 0.05, the test shows a statistically significant difference between the ferrous debris levels of the Water-Etch set and the Non-Verified set. Since this comparison was done on the transformed data, it is truly a comparison of the geometric means of the two sets.

Table 2. T-Test of Log-Transformed Ferrous Debris Levels

Group	N	Mean	StDev
Non-Verified	27	6.2	1.81
Water-Etch	27	7.32	1.71
Difference = μ (Control) - μ (Water)			
Estimate for difference: -1.124			
95% CI for difference: (-2.086, -0.163)			
T-Test of difference = 0 (vs ≠): T-Value = -2.35 P-Value = 0.023 DF = 51			

4. Water-Related Discussion

This section presents a discussion of the results and key lessons attributed to water-related data.

4.1 Results

These tests indicate the ability to distinguish between bearings with Water-Etch and Non-Verified bearings based on ferrous debris levels in the grease. The difference is due to wear of the bearing material deposited in the grease. The bearings that were identified as containing the Water-Etch defect in the AAR MD-11 process have more wear particle concentration in their grease than those bearings identified as Non-Verified, which contain no condemnable defect.

The grease analysis provides information about the other categories of grease degradation in contaminates, consistency, and oxidation levels. However, the fresh grease samples contain wide differences in composition that do not allow comparison of the sampled sets based on the chemicals that constitute the fresh greases. Further, the grease analysis provides more data variables than there are samples to do meaningful comparison.

4.2 Key Lessons

Bearings set aside for an AAR MD-11 inspection are not representative of all revenue service bearings – they may not include obvious failures such as derailments or burn-offs. In addition, they do not include failed hand roll inspection bearings from ABD sites [7]. The bearings are only those believed to be defective. Further research should include samples from failed hand roll inspection when the focus is on suspect bearings identified by wayside detection. It should also include samples from random revenue service bearings that have not been identified as defective when the focus is on grease degradation in general revenue service.

Further grease samples should be taken to allow statistical inference of other variables including contamination, consistency, and moisture levels.

Additional testing would also determine if the grease samples vary over different locations in individual bearings, and possibly identify the best location for sampling. It would also be useful to verify confidence intervals of the data variables of the fresh grease samples.

Finally, further testing could determine better guidelines for industry-specific grease degradation metrics. The grease laboratory severity ratings are not optimal metrics for use in the railroad industry, as the laboratory did assign severe ratings to some samples from Non-Verified bearings. This would cause false positive identification of defective bearings if these general benchmarks were employed. Instead, custom benchmarks appropriate for the rail industry should be explored.

5. Lube Stain Investigation

To determine the effects of lube stain in bearing operation, researchers compared specific examples of bearings with lube stain to a control set of bearings.

The team first identified bearings with lube stain, which was most noticeable on the rollers. When discolored rollers are discovered and there are no other signs of heat, a rub test can be performed. The rub test, an industry standard process, is passed when a 180-grit or finer abrasive cloth can remove the discolorations from the surface [8]. Once the rub test has been confirmed, the bearing is said to contain lube stain. The rub test is completed by a representative from the railroad or a representative from the bearing manufacturer.

Researchers took two approaches to conduct the investigation into lube stain. The first was to compare the grease characteristics of bearings that contain lube stain to bearings that do not to indicate a difference in the grease that caused lube stain to a grease that did not. The second approach was to compare the metallurgical differences in rollers that exhibit lube stain and those that do not to indicate if any changes have occurred that might interfere with bearing performance. Since lube stain has similar visual indicators to true heat bluing, the lube stain rollers were compared to a defect-free set of rollers of similar life and use and to a heat-blued set of rollers.

5.1 Grease Sample Collection and Testing

Researchers collected grease samples from BNSF's Havelock Yard wheel shop comprising 31 samples from bearings identified to have lube stain and 36 samples from bearings that did not have lube stain. This comparison set is different than the comparison set mentioned previously in the water-related research; it contains bearings that did not exhibit lube stain but did not contain non-condemnable defects.

The grease samples from lube stain bearings were tested in the same manner and at the same location as the samples from the water-related test.

5.2 Metallurgical Sample Collection and Testing

The metallurgical samples were collected by the bearing manufacturer, Timken. Forty defect-free rollers were sampled, as well as 20 lube stain rollers. Figure 8 shows the visual differences between the control set and the lube stain set of rollers. Also shown is an example of the rub test that demonstrates how the discoloration is removable from the surface of the bearing.

Figure 8. Control Set Roller, Lube Stain Roller, Rub Test

Of the 40 control set rollers, 20 were heat blued by placing them in a furnace for 1 hour at 500 °F (it took 30 minutes to reach the desired temperature, and after 1 hour the samples were air cooled). The bluing was done to create a set of rollers with the same surface discoloration as lube stain, but which actually contained the material effects of heat on the roller steel. This allowed a comparison to determine if the lube stain rollers showed any metallurgical changes related to heat.

The three sets – control, heat-blue, and lube stain – were sent to Hill Engineering, LLC for residual stress testing on the material. Due to the geometry of the rollers, it was determined that a slitting method would provide the best measurement. The slit was made in the axial direction of the roller. The test was designed to measure stress on the work surface in the hoop direction.

After residual stress testing was complete the samples were cut, mounted, and polished to allow micro-hardness testing and a microscopic examination of the microstructure, which was conducted at the Metallurgical Laboratory at FRA's Transportation Technology Center.

To determine the micro-hardness of the rollers, 12 readings in each sample were taken from the surface of the roller to the interior. The machine took a reading every 584 microns and used the Rockwell C Hardness Scale.

The samples were etched and examined under the microscope to determine if any microstructure changes had occurred in the material of the lube stain and heat-blue sets of rollers, specifically any changes in grain size and growth.

6. Lube Stain Data Analysis

This section offers an analysis of lube stain data.

6.1 Grease Analysis

Two sets of samples were used in the analysis of the grease in the lube stain: the set from bearings that exhibited lube stain and the set from bearings that showed no sign of lube stain. Each set of grease samples contained varied failure modes, as determined by the AAR MD-11 process. Figure 9 shows the counts of the bearing failure modes for each set (AD2 = Adapter Defect, LO = Loose Bearing Failure, MD = Manufacturer / Remanufacturer/ Reconditioned Defect, ME = Mechanical, MK (ME) = Mate to Mechanical Defect, MK (NV) = Mate to Non-Verified, MK (WD) = Mate to Wheel Defect, MS (SP) = Mate to Fatigue Spalling, NV = Non-Verified, SP = Fatigue Spalling, WD = Wheel Tread Defect).

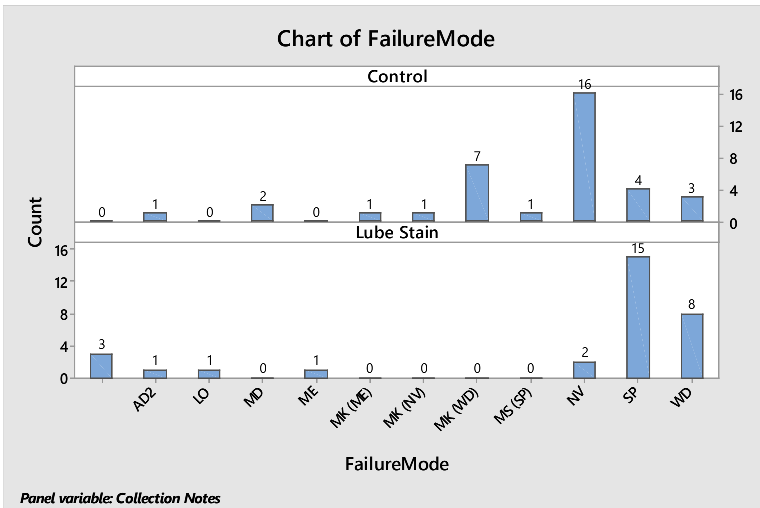

Figure 9. Failure Modes across Grease Sample Sets

The counts in Figure 9 show a disproportionate distribution of failure modes. The set without lube stain has a high number of Non-Verified (labeled NV) failure modes, and the set with lube stain has a high number of Fatigue Spall (SP) failure modes. Any differences in the analysis of the grease may be related to Fatigue Spall versus Non-Verified defect modes, and not the intended comparison of samples with lube stain versus samples with lube stain.

However, lube stain is not necessarily related to the Fatigue Spall failure mode. The failure mode breakdown of these sets may be by chance. Spall and Non-Verified failure modes are large proportions of bearings set aside for AAR MD-11 inspection. To investigate further, it would be necessary to measure the rates of lube stain versus no lube stain in Fatigue Spall failure mode bearings. Any further analysis of the grease-related testing would be speculative and not advisable until more information is gathered.

6.2 Roller Samples

The rollers taken for the samples were from bearings that had been sent back to the facility for reconditioning or remanufacturing and ranged from 4 to 15+ years of service. There is no way to determine the bearing of origin for these rollers, as they were removed from their roller cages before being selected for this test; thus, no specific equipment, placement, or other identifying attributes are known. All the rollers were from F and K type bearings.

6.3 Residual Stress

The residual stress was measured to 2 millimeters in depth across all 60 rollers. Figure 10 shows the average measurements for each set of rollers for the near surface measurements.

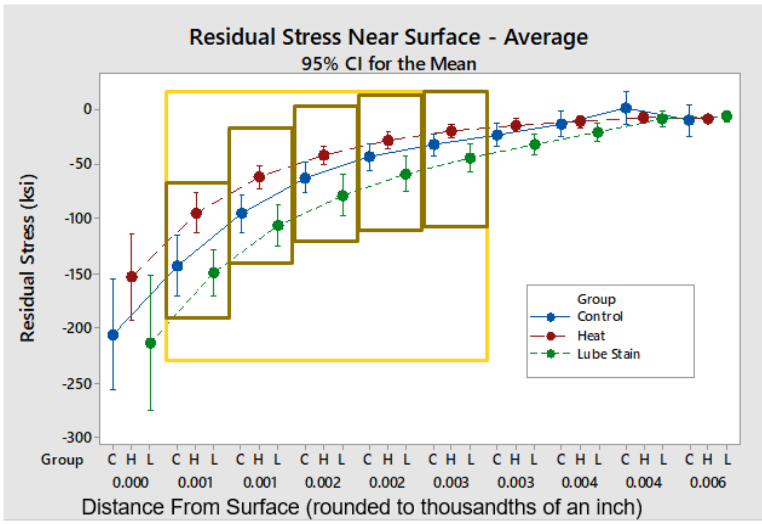

Figure 10. Near Surface Average Residual Stress

The team observed no significant difference between rollers with lube stain and the control set of rollers. There is significantly less compressive stress in the near surface measurements of the heat-blued rollers, probably due to heat relieving stress in the material. Losing compressive residual stress can result in earlier failure of the material in the form of spalling.

6.4 Micro-hardness

Figure 11 shows the average micro-hardness measurements of the three sample sets from the surface of the roller toward the center.

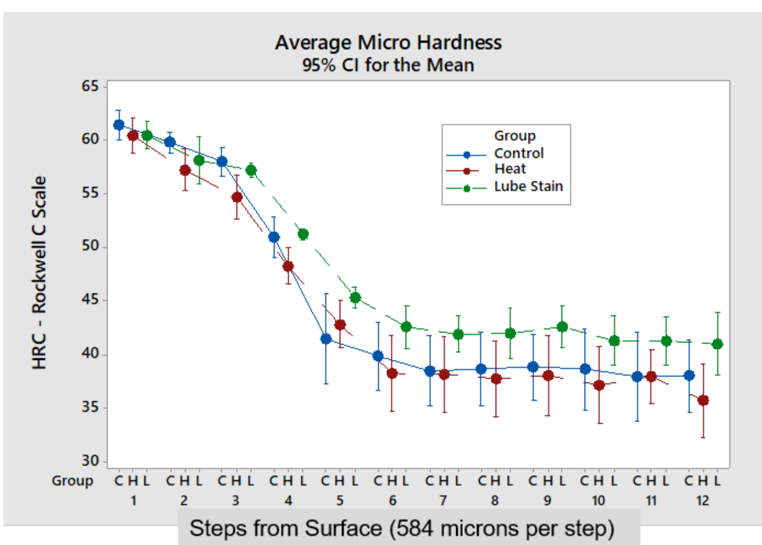

Figure 11. Average Micro-hardness

No practical differences in hardness were found between the sets; any differences in hardness found were less than the variation of the testing machine. The maximum difference between the average near-surface readings was approximately 3 on the Rockwell C Hardness Scale (HRC).

6.5 Microstructure

After study of the microstructure, no observable differences were found between the sets. While the heat-blue method employed in this study was enough to discolor the metal, it was not hot enough, nor of a long enough duration, to change grain structure.

7. Lube Stain Discussion

The research team observed no metallurgical differences between the lube-stained rollers and the defect-free rollers. Lube stain does not appear to have affected any tested material properties other than surface discoloration. The heat-blued set of rollers lost near-surface compressive stress, but this effect did not occur in the rollers with lube stain.

Further grease testing should be done to explore the relationship of lube stain with specific failure modes. Since Non-Verified and Fatigue Spall make up a large proportion of the AAR MD-11 failure modes, the disproportionate sampling observed in this test could be by chance.

Further testing could also include sampling bearings from different periods of the bearing life cycle to determine when lube stain occurs and how long it takes to develop.

8. Conclusion

The research team conducted two investigations designed to improve safety of roller bearing operations on railcars. The following are the key results from the conducted research.

8.1 Water Degradation

Investigation of water-related bearing grease degradation indicates a difference between bearings with Water-Etch and Non-Verified failure modes based on ferrous debris levels in the grease. This difference is due to wear of the bearing material deposited in the grease.

8.2 Lube Stain

Investigation of lube stain in bearings shows lube stain does not affect any tested metallurgical material properties other than surface discoloration. More samples are required across possible failure modes to reach conclusions regarding the lube stain grease analysis.

8.3 Recommended Future Work

Research into grease degradation in bearings should be continued to further industry understanding. Future research should include samples from failed hand roll inspections with the focus on bearings identified by wayside detection. It should also include samples from random revenue service bearings that have not been identified as defective, with the focus on grease degradation in general revenue service bearings.

Further grease samples should be taken to allow statistical inference of other variables including contamination, consistency, and moisture levels.

Additional testing also would determine if the grease samples vary over different locations in individual bearings, and possibly identify the best location for sampling. This testing could determine better guidelines for industry-specific grease degradation metrics.

Future grease testing also should be done to explore the relationship of lube stain with specific failure modes. Since Non-Verified and Fatigue Spall make up a large proportion of the AAR MD-11 failure modes, the disproportionate sampling observed in this project could be by chance.

Finally, testing could also include sampling bearings from different periods of the bearing lifecycle to determine when lube stain occurs and how long it takes to develop.

In addition to understanding the effects of water degradation on bearing performance, research should be expanded to investigate possible solutions to water ingress. This would include examining advancements in bearing seals and water-resistant greases.

9. References

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Abbreviations and Acronyms

ACRONYM	DEFINITION
ABD	Acoustic Bearing Detector
ASTM	American Society for Testing and Materials
AAR	Association of American Railroads
BNSF	Burlington Northern Santa Fe Railway
SP	Fatigue Spall
FRA	Federal Railroad Administration
fdM+	Ferrous Debris Analyzer
FTIR	Fourier-transform Infrared Spectroscopy
HRC	Hardness Scale
HBD	Hot Bearing Detector
NV	Non-Verified
ppm	Parts Per Million
RULER	Remaining Useful Life
RDE	Rotating Disc Emissions
TTC	Transportation Technology Center (the site)
TTCI	Transportation Technology Center, Inc. (the company)
WM	Why Made