FAILURE OF A TRACTOR WHEEL -

ANALYSIS BY

ROBERT H. WAGONER AND GERALD S. FRANKEL

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INTRODUCTION

On November 8, 2007, at approximately 6:42pm, Dr. Krishna Chintamaneni was killed when his vehicle was struck by a wheel that detached from a passing semi tractor trailer being operated by Carl DeSantis on Interstate 43 in Glendale, Wisconsin. This report outlines the opinions, and the basis for those opinions, regarding the condition of that wheel and the cause of the wheel separation.

A smaller, roughly ring-shaped piece of the detached wheel assembly, herein called the *spider*, remained on the tractor attached by lug nuts. A large piece of the original wheel/tire, comprising nearly all of it and readily identifiable as such, detached from the tractor. This is what struck Dr. Chintamaneni's vehicle. One or more small parts of the original wheel were apparently not recovered and are not part of the evidence reviewed.

It is useful to define or repeat a few terms as used in the previous paragraph and elsewhere in this report:

Wheel – Refers to either the remaining major part of the detached wheel/tire assembly, or to the metallic part of the wheel, distinct from the attached tire. Also refers to complete wheels (i.e. without missing parts separated by fracture), with or without tires mounted on them. The wheels referred to in this report are stud-piloted wheels.

Rim – Refers to the outer part of the metallic wheel, originally welded at manufacture onto the center or hub portion to form the metallic wheel.

Hub – The central portion of the metallic wheel, originally welded at manufacture into the rim to form the wheel.

Spider – A ring-shaped piece that was originally integral to the wheel hub at the center of the metallic wheel. The circumferential fracture passing through the lug holes separated this piece from the remainder of the hub. The spider remained attached to the tractor after separation of the remainder of the wheel took place.

Spider Area – The central, substantially flat, area of a wheel hub that contains the lug nut holes.

Lug nuts – Also called outer cap nuts, these screw onto what are here called studs (or inner cap nuts) to hold the outer wheel of a pair of dual wheels onto the tractor.

Studs – Also called inner cap nuts, these screw onto inboard fasteners and hold the inner dual wheel on. The lug nuts or outer cap nuts screw onto the studs or inner cap nuts.

The sequence of events and time scale were reconstructed by analyzing the wheel portions that remain and examining deposition transcripts and other evidence that was available. Long-term corrosion combined with high-cycle fatigue cracking to weaken the wheel over a period of years. The weakened wheel became misaligned, most likely because of improperly installed lug nuts (e.g. low tightening torque, uneven tightening torque, damaged and corroded nuts) combined with corroded mating surfaces of inner and outer wheels. The misalignment caused high cyclic stresses in the previously weakened wheel, causing new cracks to form and to propagate by fatigue and ultimately overload. The appearance and growth of new cracks initiated the final stages of detachment, which was completed when a circumferential crack propagated around a complete circular path that included lug holes, existing old cracks emanating from the lug holes, and corrosion perforations between the lug holes.

The wheel was first observed in person by the authors at the Milwaukee County Sheriff's Department impound room on April 7, 2008. The overall condition of the wheel was judged poor, unfit for service. That inspection revealed the following observations pertinent to this judgment:

- The wheel was heavily corroded in critical areas, including the wheel-to-wheel mating surface, the spider area on the reverse side of the mating area, and at the hub/rim attachment weld area.

- Rust streaks were apparent on the wheel surface, at least some of them corresponding to cracks near the spider area and radiating outward.

- Many cracks were present. Some of these were labeled and photographs were taken. The appearance of the crack surfaces ranged from shiny and unabraded (new crack surface) to heavily corroded (old crack surface). The cracks had a range of appearances spanning these two extremes.

- Some of the cracks were heavily abraded and deformed, with a smeared, shiny aspect.

- The lug nuts and studs were heavily corroded and at least some of the lug nuts were grossly deformed while others had deformed/eroded mating surfaces where the wheel would make contact with the lug nut.

- One lug nut / stud assembly remained on the spider. It was loose to the touch; it could be turned on the spider.

The tractor continued to be used for an extended trip after the detachment, and then the lug spider, lug nuts, and studs were removed, were mixed with each other, then discarded and later retrieved. Thus there is little direct evidence (beyond the loose remaining lug/stud assembly on the spider) regarding attachment torques and the lug nut and stud positions on the spider and wheel.

The intention of this report is to the summarize the main opinions of the authors and the basis for those opinions. While the intention is to be complete, the evidence cited explicitly in this report is not comprehensive. The files considered at the time of this writing consume more than 7 Gb of data. While all of that evidence has been reviewed and used in reaching the conclusions here, it is impractical to refer to every photograph or document. Instead, representative evidence has been selected as a guide to the full range of evidence available. In order to make the report file size manageable, the photos embedded in this file have been reduced in quality. Original, full-quality photographic files are available digitally. Original file names are used to facilitate their location, with the text "Figure #-#" added at the beginning of the file name to locate the figure in the report, and "LowRes" added at the end of the file name to indicate that the quality has been reduced from the original.

All opinions expressed in this report represent a reasonable degree of engineering certainty.

CHRONOLOGY

1988 – Freightliner tractor was manufactured (approx.)
S/N: 1FUPYSYB5JP320764 (Sheriff Incident Report)

Choose a single font.

1988 – Firestone Wheel was manufactured (detached one), 2/4/86. Markings on wheel (Opinion 1 photos):
Firestone
24.5 x 8.25 x
DOT-T
Canada
02 04 86

1989 – Exemplar wheel from the left-hand side, rear inner dual position was manufactured. Markings on wheel (Opinion 1 photos):
USA T DOT
MOTOR WHEEL
24.5 x8.25
02 24 89
022489A
MAX LOAD 7250 LBS..®..120MAX PSI COLD..M..87897

1999-2000 – Robert Danhausen purchased 1988 Freightliner for $5000 (Danhausen Deposition June 33, 2008)

1999-2003 – 4 used steel wheels were traded for, sandblasted, x-rayed and painted at NFL Tires (“Neal Funk”), and were mounted on “outer positions.” New wheels were put on the steering axle. Replaced 10 aluminum wheels with steel wheels. (Danhausen Deposition June 33, 2008)

2004 – 1988 Freightliner was put into service by Robert Danhausen. (Danhausen Deposition June 33, 2008) Driven 150,000-200,000 miles.

2007 – Robert Danhausen sold 1988 Freightliner to CKC Trucking for $3000, 9/22/2007. (Danhausen Deposition June 33, 2008)

2007 – Annual Inspection of 1988 Freightliner was performed by Thomas McHaney, October 4, 2007, at B. N. Gilbert, LLC. The following components of “Wheels and Rims” were deemed “OK” at this inspection: “Wheels and Rims,” “Fasteners,” and “Welds.” (Attachment to McHaney Deposition, June 24, 2008.)

2007 – Firestone Wheel detached from 1988 Freightliner, kills Krishna S. Chintamaneni, November 8, 2007. Glendale – 62, City, Milwaukee – 40, Highway 43, 0.3 mile S of Silver Spring Dr. W. 6:42pm Central Time. (Wisconsin Motor Vehicle Accident Report.) Photos taken by Deputy Christine Baker, SQD # 26A.

2007 – 1988 Freightliner was taken to B. N. Gilberts for repair of studs and nuts, November 9, 2007. (McHaney Deposition, June 24, 2008.)

2007 – 1988 Freightliner was impounded, November 10, 2007. (Port Huron police department incident report, November 10, 2007.)

2007 – Photos were taken of wheel parts, nuts, studs. 10:31-10:40am, November 26, 2007 (Photo file Properties – "Date Picture Taken" date). Folder: *Photos 3-13-09 CD \ Photo's 11-26-07*.

2007 – Photos were taken after cutting, mounting. 11:36am, November 28, 2007 to 12:06am November 30, 2007 (Photo file Properties – "Date Picture Taken" date) Folder: *Photos 3-13-09 CD \ Photo's 11-28-07 to 11-29-07*

2007 – Photos were taken of spider, stud holes, spider crack surfaces. 4:01pm – 11:40pm, December 6, 2007. (Photo file Properties – "Date Picture Taken" date.)

2008 – Photos were taken of 1988 Freightliner. Provided by B. N. Gilbert to Cannon and Dunphy. Folder: *Photos 3-13-09 CD \ Color Photos of Tractor Trailer*.

2008 – Wagoner was retained by Cannon and Dunphy, March 11, 2008 (letter). Frankel retained at approximately the same time.

2008 – Inspection of Firestone Wheel and parts took place, Milwaukee County Sheriff's office, April 7, 2008. Present: Woodrooffe, Wagoner, Frankel, Baareman, Robinson, Woo (Detective). Photos taken. Folder: Photos 4-7-08 Inspection 5-21-08 CD. (Various notes, calendar.)

2009- X-raying of Firestone Wheel and parts took place at Alloyweld, Bensenville, IL, July 12, 2009. Photos were taken. Present: Wagoner, Robinson, Theus, Grady (Grady, Hayes, and Neary), Rosenberg (Whyte Hirschboeck Dudek), Norfleet (ESI), Danko (ESI), Kleven (Alloyweld). (Various notes, calendar.)

2009 – Inspection of Firestone Wheel and parts took place at Engineering Systems Inc., July 12-13, 2009, Aurora, IL. Photos taken. Present: Present: Wagoner, Robinson, Theus, Grady (Grady, Hayes, and Neary), Rosenberg (Whyte Hirschboeck Dudek), Norfleet (ESI), Danko (ESI). (Various notes, calendar.)

2009 - Inspection of Firestone Wheel and parts took place at Engineering Systems Inc., September 24, 2009, Aurora, IL. Photos taken. Present: Wagoner, Frankel, Theus, Norfleet (ESI), Danko (ESI). (Various notes, calendar.)

OPINIONS

Opinion 1

The wheel detached because a roughly circular crack advanced through corrosion perforations formed throughout the spider area of the wheel, and through the wheel mounting holes.

Opinion 2

At least one large crack, the hub-rim portion of Crack 12, was present prior to the detachment by at least 17 months, and more probably was present for at least 6 years prior to the detachment. The crack is located between the hub and rim, and is approximately 5 inches long. The hub-rim portion of crack 12 was large enough one month prior to the attachment, at the time of the annual inspection, to have been visible to the naked eye. See Opinion 5.

Opinion 3

General corrosion in the spider area perforated the wheel, thus weakening it in a critical area. The Spider B hole is likely older than Crack 12. The Spider hole B was large enough one month prior to the attachment, at the time of the annual inspection, to have been visible to the naked eye. See Opinion 5.

Opinion 4

The cracks present on the Firestone wheel represent a spectrum of ages, with the oldest ones as determined by selected analyses being Crack 12 and the spider hole "B" (Opinions 2 and 3). Crack 9-2, which originated at either the circumferential crack that separated the wheel from the tractor or from a bolt hole, has an intermediate age of at least 3 months prior to the detachment. Other cracks that were analyzed are younger, with a shiny appearance even in regions with no rubbing/abrasion marks. The hub part of Crack 6-4 represents the other extreme; it occurred at or very near the time of the wheel detachment, with the hub-rim part of Crack 6-4 being older. Crack 6-4 is similar in appearance and form to Crack 12, and is located diametrically opposite it.

Opinion 5

The older cracks and perforation(s) were large enough at the time of the annual inspection on October 4, 2007, one month prior to the detachment, to have been visible to the naked eye.

Opinion 6

The wheel and its fasteners were seriously and obviously corroded at the time of the detachment. The general corrosion would have been substantially the same at the time of the annual inspection, October 4, 2007, approximately one month earlier. Visible rust streaks associated with long-standing cracks were obvious. The lug nuts and studs were corroded, as was the mating surfaces between the inner and outer wheels. The presence of any of the following features: wheel cracks, corroded wheel mating surfaces, or corroded fasteners, mandates scrapping of the wheel or fasteners, respectively. Had the wheel and its fasteners been replaced at the time of the annual inspection, the detachment of this wheel would not have occurred.

Opinion 7

The lug nuts were likely not properly torqued at the time of the last annual inspection, thus allowing operational misalignment of the wheel. Evidence of other, related sources of mis-mounting and misalignment leading to failure was found in the forms of the following:

1) The lug nut mating surfaces were damaged, deformed, and worn sufficiently that they should have been scrapped and replaced.
2) The lug nuts were of two kinds of material, the softer ones showing the greatest erosion damage. 3) The inner/outer wheel mating surfaces and lug nuts were heavily corroded, (see Opinion 6).
4) The wheel mating surfaces were heavily corroded (see Opinion 6).

There is no evidence of stud stretching, as would be expected from over-tightening of the lug nuts.

BASIS OF OPINIONS

OPINION 1

Opinion 1

The wheel detached because a roughly circular crack advanced through corrosion perforations formed throughout the spider area of the wheel, and through the wheel mounting holes.

Basis of Opinion 1

There is no question of the detachment of the wheel from the tractor at a circumferential crack. See Figures 1-1 and 1-2 for the major portion of the wheel that was detached, and Figures 1-3 and 1-4 for the spider section that remained attached to the tractor. The detachment crack is visible; running through the wheel mounting holes. See Figures 1-3 and 1-4.

Figures 1-5 and 1-6 show the wheel and spider in approximately the orientation before detachment, along with other cracks and the numbering system (clockwise numbers, starting from the fill valve at 12 o'clock when viewed from the outside of the wheel as mounted on the tractor).

Figures 1-7 and 1-8 show enlarged spider portion of the wheel along with markings used to designate certain areas between the lug nut holes. The marked areas were cut to remove the portions with circumferential crack surfaces for further analysis. Figure 1-7 illustrates the reconstructed relative orientation of the spider relative to the remainder of the wheel based on matching fracture features during the inspection on April 7, 2008.

Some areas of the final detachment crack surface are shiny, indicating either freshly-formed cracks or rubbing and deformation of previously corroded surfaces during the final fracture events. This appearance can be seen in low magnification of spider areas B, C, and D in Figure 1-9, and closer in Figures 1-10, 1-11, and 1-12, Other adjacent areas (either proceeding through the thickness or along the circumference of the crack) have a dark, corroded appearance, and are recessed relative to the shiny fracture surface (and thus partially protected from rubbing). These areas preceded the final detachment by sufficient time to establish corrosion of the crack surface.

Spider section D (Figure 1-9) shows shiny and dull aspects on a single crack surface, indicating existence of the crack surface prior to the detachment, with some portions rubbed shiny at the time of detachment.

Spider section B (Figures 1-9, 1-10, 1-11) shows the presence of a corrosion perforation, or hole, through which the final circumferential crack passed. Portions of the circumferential crack appear shiny, other parts dull, consistent with spider section D.

Spider section C (Figures 1-9 and 1-12) shows two crack surfaces with differing appearance. In Figure 1-12, the left surface is heavily corroded and dull, while the right surface (with propagation at a different angle) has the typical shiny/dull appearance of Spider sections B and D. This appearance corresponds to an older crack originating at the lug hole, and either a younger circumferential crack or one that has been partially rubbed during the final detachment cycles.

Wheel Identification (from photos of wheel surfaces):

Detached, Broken Wheel, from LHS rear outer:

Firestone
24.5 x 8.25 x
DOT-T
Canada
02 04 86

Exemplar Wheel from LHS rear inner (mating wheel to detached wheel):

USA T DOT
MOTOR WHEEL
24.5 x8.25
02 24 89
022489A
MAX LOAD 7250 LBS..®..120MAX PSI COLD..M..87897

Figure 1-1. Wheel OP IV 1 LowRes.jpg

Figure 1-2. Wheel OP IV 1 LowRes.jpg

Figure 1-3. Wheel IP IV 1 Low-Res.jpg

Figure 1-4. Wheel IP OV 1 LowRes.jpg

Figure 1-5. DSC01053 LowRes.jpg

Figure 1-6. DSC01051 LowRes.jpg

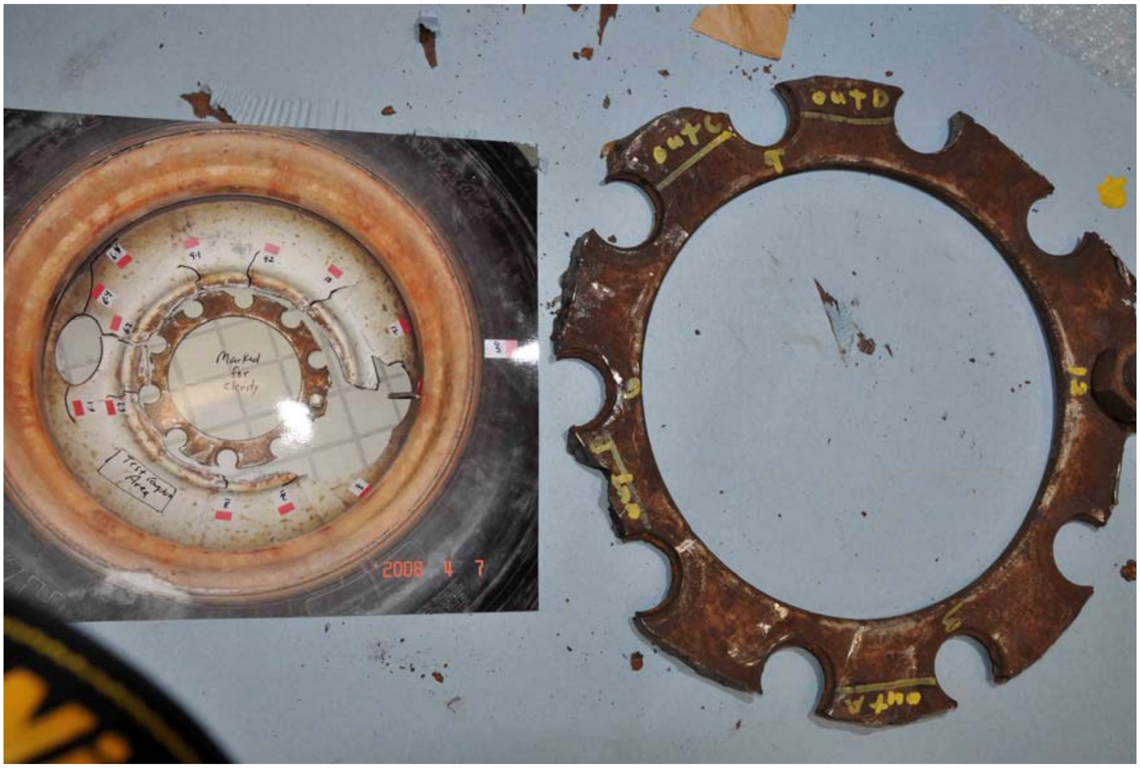


Figure 1-7. DSC_0062 LowRes.jpg

Figure 1-8. DSC00938 LowRes.jpg

Figure 1-9. DSC00974 LowRes.jpg

Figure 1-10. DSC00349 LowRes.jpg

Figure 1-11. Fracture 5-6 LowRes.jpg

Figure 1-12. DSC00947 LowRes.jpg

OPINION 2

Opinion 2

At least one large crack, the hub-rim portion of Crack 12, was present prior to the detachment by at least 17 months, and more probably was present for at least 6 years prior to the detachment. The crack is located between the hub and rim, and is approximately 5 inches long. The hub-rim portion of crack 12 was large enough one month prior to the attachment, at the time of the annual inspection, to have been visible to the naked eye. See Opinion 5.

Basis of Opinion 2

Figures 2-1 and 2-2 show the overall crack pattern on the subject wheel, and the numbering system used to identify them. (Figure 2-1 is the same as Figure 1-5, but the crack paths and original labels have been darkened using a felt marker and the figure was then scanned. This figure was used at the inspections to identify locations.

Crack 12 was selected for further analysis because it was identified by visual inspection as appearing to be the oldest, most corroded fracture surface remaining. As can be seen in the sketch of Figure 2-2 and the photograph Figure 2-3, it has three distinct crack sections. One is gently curved and runs between the hub and rim portions of the wheel through the weld. One is substantially straight, orthogonal to the hub/rim portion and emanating from it. The remaining crack section is a curved portion emanating from the orthogonal portion that joins the hand hole in the hub area of the wheel. The visual appearance of the hub/rim part of Crack 12 is similar to the highly corroded area on the wheel surface near the crack region, Figure 2-3. The other two sections were also corroded, but without the apparent roughness, heavy oxide thickness and age of the hub/rim portion. The remaining photos in this section and many others available confirm this appearance (see, for example, Figure 2-5).

The wheel was sectioned as shown in Figure 2-4 to allow microscopic inspection of Crack 12. Figure 2-4 also shows that the hub/rim portion of Crack 12 is approximately 5” long.

Figure 2-5 shows the smoother fracture surfaces in the hub portion of Crack 12 as compared with the hub-rim portion.

Figures 2-6 and 2-7 are stereomicrographs of the hub/rim surface of Crack 12. Note that some of the central recessed region of the crack surface has a much darker appearance that the edge regions, which show a partially shiny aspect. This is consistent with rubbing and removal of the oxide at the outer areas and less removal at the recessed, inner area.

Figure 2-8 shows the sectioning that was performed to enable finer-scale analysis of Crack 12. Section 12-4 is shown in Figures 2-9 and 2-10 at two magnifications, and Figure 2-11 shows energy dispersive spectroscopy (EDS) results verifying the nature of the oxide. These figures show the following:

- The thickest oxide remaining of the fracture surface is at the center, in a protected, recessed area. Almost no oxide remains on other portions of that section.

- The maximum remaining oxide thickness on this section is 202 μm.

- Other recessed, protected areas show remnant oxide, in this case with thickness of 58 μm.

- Figure 2-9 shows that the oxide thickness on the fracture surface is approximately the same as on the wheel side surface (at the right-hand edge shown in the figure).

The remaining oxide thickness of 202 μm allows the calculation of the minimum time that the hub/rim portion of Crack 12 was open and exposed to the atmosphere. The time calculated will be a minimum because some oxide was likely removed by abrasion; only the remaining part can be viewed today. Furthermore, there may have been sections where the remaining oxide was thicker. Therefore, the oxide thickness before the final fractures causing separation of the wheel was at least 202 μm because this thickness remains today and was observed among the few selected sections that were prepared and examined. On all crack surfaces except for the final overload cracks, rubbing and spalling of the opposing fracture surfaces likely removed all or part of the oxide.

The measured oxide thickness of 202 μm corresponds to a thickness of steel converted to corrosion product (oxide) of ~110 μm using a Pilling-Bedworth ratio of 1.8 [M.G. Fontana and N.D. Greene, Corrosion Engineering, McGraw Hill, 1978] The Pilling-Bedworth ratio expresses the ratio of the oxide thickness converted from an initial metal thickness. Using corrosion rates for plain carbon steel in service, here expressed in micrometers per year (μm/y) of metal converted, the time that the crack surface was exposed to the atmosphere can be calculated.

The steel of the wheel hub portion has a chemistry that corresponds to an AISI Type 1010 plain-carbon steel (or 1012 or 1015, the grades overlapping without importance for this purpose), see Figure 2-12.

The corrosion literature contains many presentations of corrosion rates for plain-carbon steels in atmospheric and similar conditions. These vary widely depending on the particular exposure, i.e. the temperature, relative humidity, time of wetness, chloride content (i.e. from the sea or road salt), industrial pollution, and so on. The corrosion rate tends to decrease slightly with time and then reach a constant value. The following values are reported for the average corrosion rate of structural carbon steel over the first 3.5 years exposure to various environments [ASM Handbook, Vol. 13B Corrosion: Materials, 2005]:

Rural: 15 μm/y
Industrial: 21-26 μm/y
Moderate Marine: 35 μm/y
Severe Marine: 413 μm/y

Clearly, a large range of corrosion rates can be observed depending on particular conditions. For a truck operating in the upper Midwest at ambient temperatures, rates of 10-30 μm/y would be expected. For frequent heated and moist conditions (as described in the Robert Danhausen Deposition) (during hard braking), a faster overall rate might be possible, in the range of 20-60 μm/y.

The average corrosion rate experienced by the 1986 Firestone wheel under its actual operating conditions can be estimated by noting that the oxide layer thickness in the spider area is approximately 0.020″ (500 μm), see Figures 2-13 and 2-14 of a rust chip that fell off the spider during handling. An oxide of this thickness corresponds to a thickness of iron converted of 280 μm.

The service age of the wheel can be estimated from the Robert Danhausen Deposition using two alternate calculations:

1. Mr. Danhausen stated that he traded to obtain used steel wheels for the 1988 Freightliner 4 (which formerly had aluminum wheels) some time in the 1999-2003 period. Of the 8 drive wheels, he stated that 4 wheels were "sandblasted, x-rayed, and painted" sometime in the period 1999-2003, when the truck was out of service. These four wheels were mounted on the outer positions for appearance sake. It is unknown whether Mr. Danhausen's memory is correct, or whether the four wheels remained in the outer positions over the subsequent years.

However, assuming that the Firestone wheel in question was reconditioned in the period 1999-2003 and put into service in early 2004, the wheel would have been in service approximately 3.5 years at the time of the detachment. Thus, the average corrosion rate can be calculated as follows:

280 μm of Fe converted / 3.5 years = 80 μm/y (μm per year Fe removed)

A rate of 80 μm/y is considerably higher than expected based on published rates under atmospheric conditions. While such a rate is improbable, it cannot be entirely ruled out as unrealistic because of the unknown conditions of service, particularly the frequency of high-speed breaking, with associated unknown temperatures and humidity.

2. If the subject Firestone wheel were not one of the four wheels reconditioned, or if Mr. Danhausen's memory about having some wheels reconditioned is faulty, then the wheels may have been developing corrosion over their service lives. Because they were obtained by trading, nothing is known precisely about their service life, although the implication is that they had not been reconditioned previously because their condition caused Mr. Danhausen to take some action to improve their appearance. We can estimate that the wheels were out of service for approximately five years (1999-2004) and we know that they were manufactured on February 4, 1986, so a reasonable estimate of service life is 16 years. The corrosion rate for this scenario can be calculated as follows:

280 μm of Fe converted / 16 years = 18 μm/y

This corrosion rate is consistent with published values; it is on the high end of pure rural service and the low end of industrial locations. The consistency of this value with independently reported values makes it unlikely that the detached wheel was reconditioned 3.5 years prior to the detachment. The two computed corrosion rates for the detached wheel (18 μm/y and 80 μm/y) can nonetheless be taken as bracketing the range of actual corrosion rates in service.

The time in service that Crack 12 existed may be computed using the two calculated extreme corrosion rates and the known minimum oxide thickness of 200 μm, corresponding to the thickness of steel converted of 110 μm:

110 μm / 18 μm/y = 6.1 years

110 μm / 80 μm/y = 1.4 years (17 months)

Lifetime average corrosion rates were used to determine these crack ages.

Thus, we may conclude with confidence that the 5″-long crack, Crack 12, was present for at least 17 months prior to the detachment of the Firestone wheel, and more probably for at least 6 years.

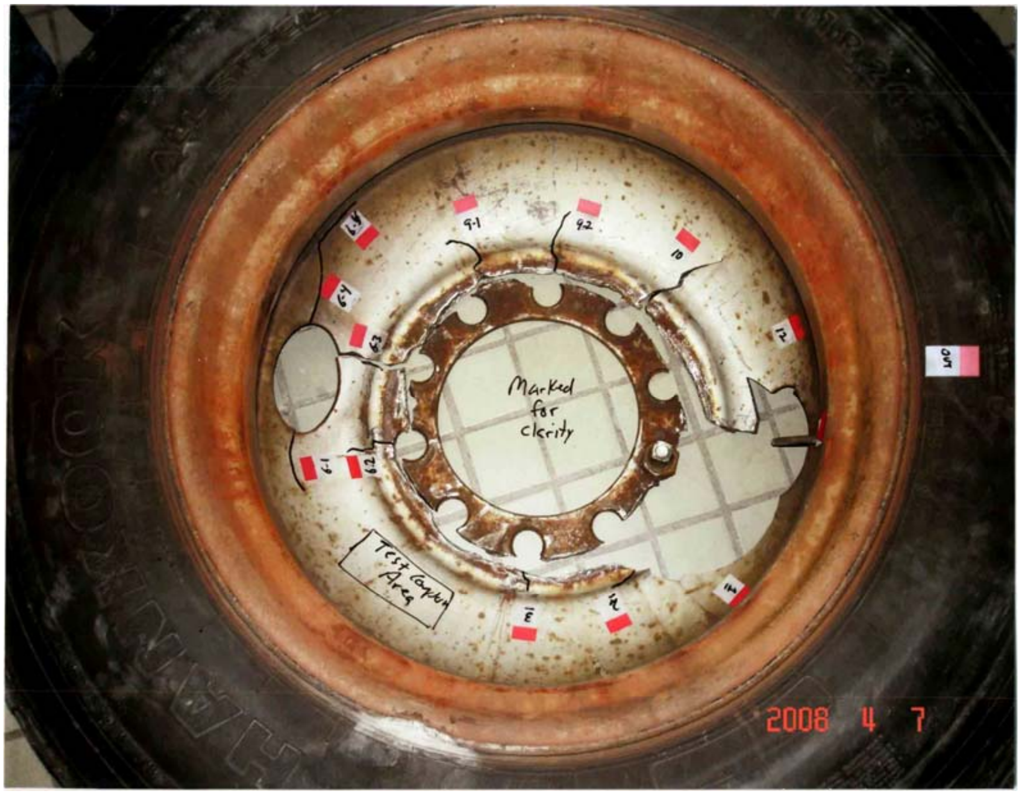


Figure 2-1. Wagoner 6 DSC01053 Scanned Marked

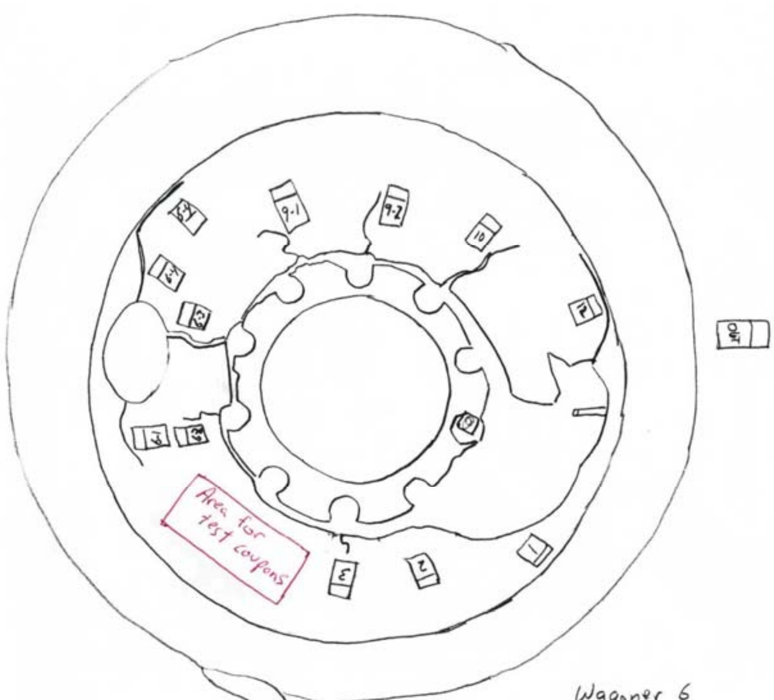


Figure 2-2. Protocol Figure 1 - sketch LowRes.jpg

Figure 2-3. DSC01054 LowRes.jpg

Figure 2-4. DSC_0035 LowRes.jpg

Figure 2-5. DSC00341 LowRes.jpg

Figure 2-6. 12_005 Low-Res.jpg

Figure 2-7. 12_001 LowRes.jpg

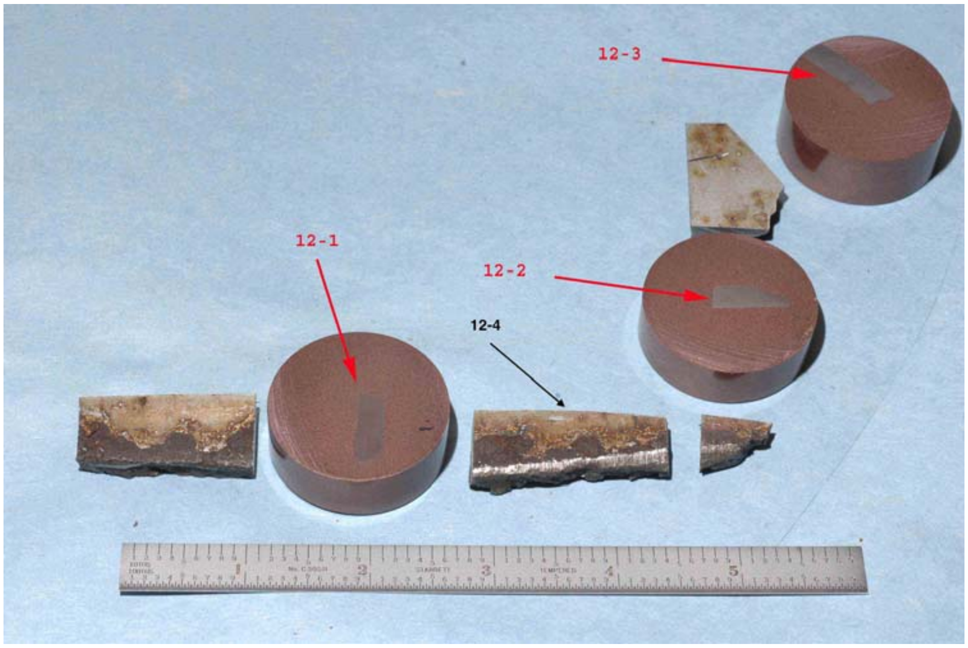


Figure 2-8. Specimen_Locations_1 LowRes.jpg

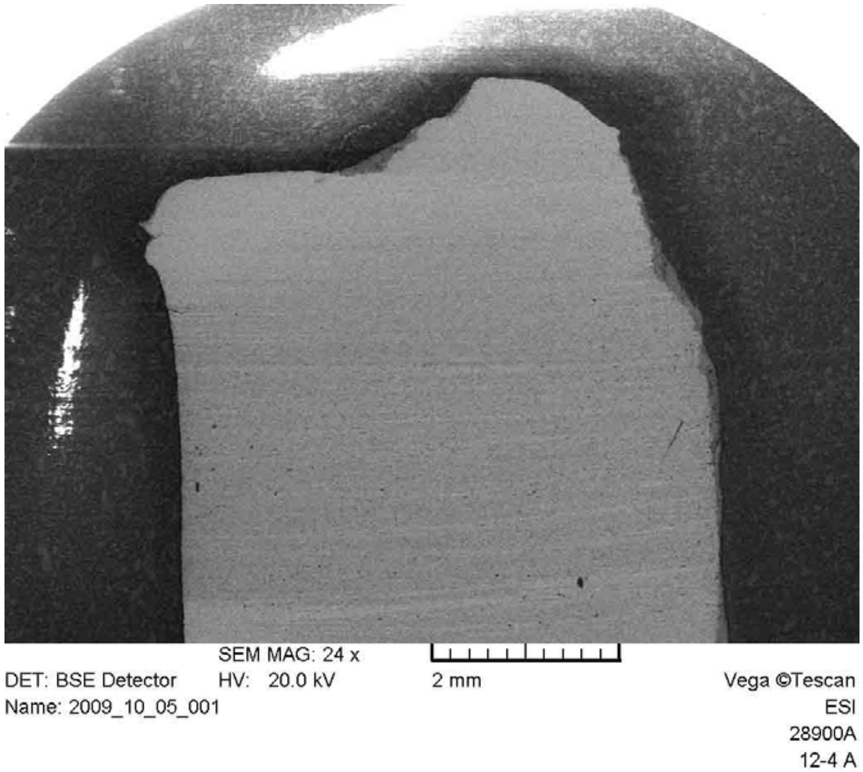


Figure 2-9. 2009_10_05_001 LowRes.jpg

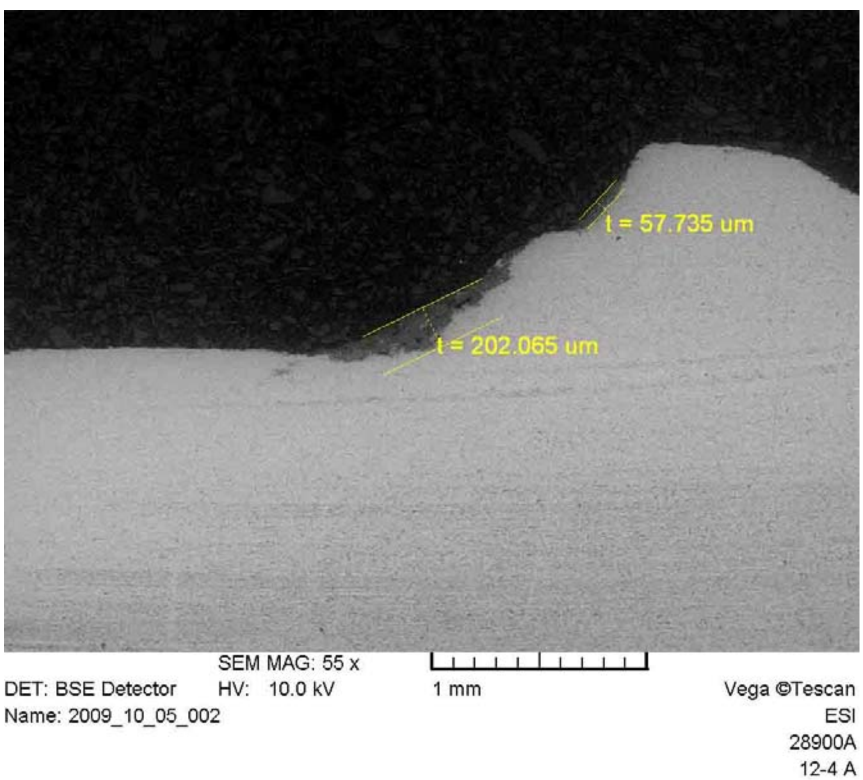
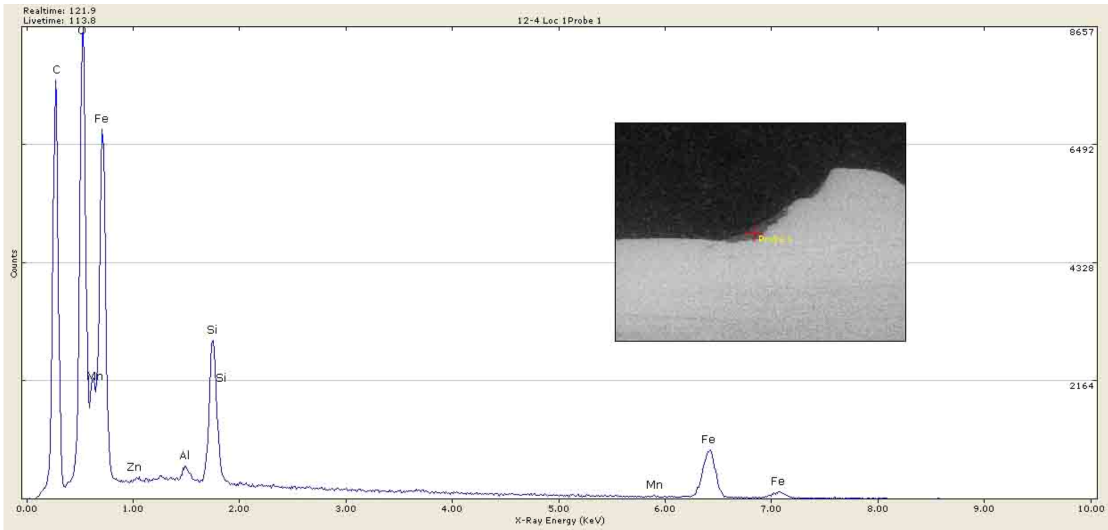


Figure 2-10. 2009_10_05_002_meas LowRes.jpg



Quantitative Results for 12-4 Loc 1Probe 1
Analysis: Bulk Method: Standardless
Acquired 05-Oct-2009, 10.0 KeV @10 eV/channel

Element	Weight %	Atomic %	FWHM (eV)
Zn	0.18	0.07	78.0
Mn	0.23	0.10	132.7
Al	0.27	0.25	84.5
Cu	0.36	0.14	76.2
Si	6.18	5.47	88.0
O	16.89	26.24	69.5
C	20.91	43.26	65.0
Fe	54.98	24.47	137.2
Total	100.00		

Figure 2-11. 12-4 Loc 1 Probe 1 LowRes.jpg

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Melrose Park, IL 60160
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ACCREDITED
TESTING CERT #0510-01

Engineering Systems Inc.
3851 Exchange Avenue
Aurora, IL 60504

Attn: Mr. Michael Danko

Report No.:	149785
Date:	9-4-09
Order No.:	27152
Page:	1 of 1

SAMPLE IDENTIFICATION

Quantity	Sample ID
4	See Below

TEST RESULTS *

Chemical Testing

Element	6-3	6-4	9-2	12
Carbon	.13 %	.13 %	.13 %	.13 %
Manganese	.38	.38	.37	.38
Phosphorus	.008	.008	.008	.008
Sulfur	.006	.006	.007	.007
Silicon	.01	.01	.01	.01
Nickel	.03	.02	.02	.02
Chromium	.01	.01	.01	.01
Molybdenum	<.01	<.01	<.01	<.01
Copper	.02	.02	.02	.02
Aluminum	.05	.06	.05	.05

Hardness Testing

Core Hardness, HRB	82	83	83	82	82	83	84	84	83	85	86	86

* Testing performed in accordance with ASTM E415 and E18 (tungsten ball indenter).

Respectfully Submitted,
MSi Testing & Engineering, Inc.

Bart Bobek

Bart Bobek
Associate Metallurgical Engineer

BB/oa/E-Document

Figure 2-12. 149785 LowRes.jpg from 149785.pdf

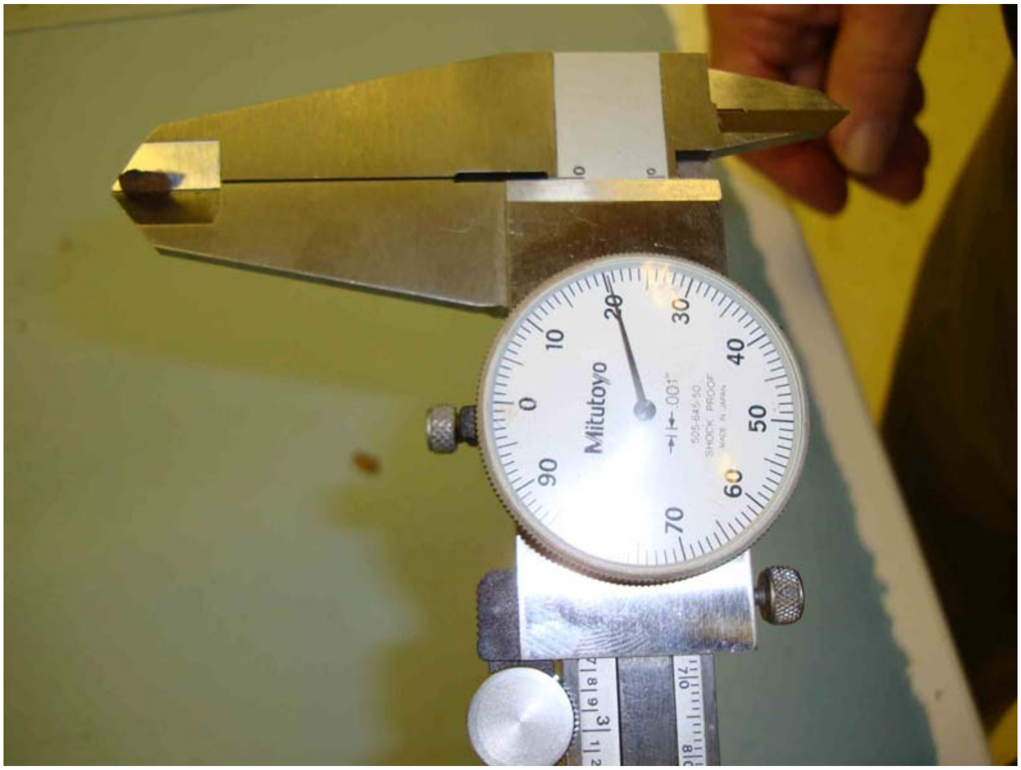


Figure 2-13. DSC00972 LowRes.jpg

Figure 2-14. DSC00991 LowRes.jpg

OPINION 3

Opinion 3

General corrosion in the spider area perforated the wheel, thus weakening it in a critical area. The Spider B hole is likely older than Crack 12. The Spider hole B was large enough one month prior to the attachment, at the time of the annual inspection, to have been visible to the naked eye. See Opinion 5.

Basis of Opinion 3

The orientation of the spider relative to the wheel is shown in Figure 3-1, along with the labeling of areas B, C, and D of the spider. The sectioning of these areas and the scale is shown in Figure 3-2.

The Spider B hole is shown in progressively higher magnification and detail in Figures 3-3 to 3-8, and other, similar holes at earlier stages (non-perforating) can be seen on other parts of the circumferential crack, Figure 3-9. The Spider B hole is today represented by a cone-shaped region not consistent with a fracture surface through which the circumferential crack propagated. The current configuration thus represents approximately half of the hole before fracture. The conical region is about 10 mm in diameter at the inner surface of the wheel and about 4 mm in diameter at the outer surface of the wheel.

Through-thickness perforation of the thick wheel entails more metal removal and thus requires longer corrosion exposure than Crack 12, although it was not possible to find and retain the oxide layer during preparation of the hole surface in order to quantify the age more precisely. It probably developed through preferential corrosion in the vicinity of an inclusion in the steel. The appearance of the surface of the hole is similar to Crack 12 except that corrosion pits are visible on the surface of the hole, Figures 3-7 and 3-8.

One deep pit had a diameter of 0.2mm (200 μm), Figure 3-10, thus indicating metal removal during its formation of 100 μm in thickness. Thus, the age of the pit, which formed after most of the hole had already developed, can be estimated using methods similar to those for Crack 12:

$$100\ \mu m / 18\ \mu m/y = 5.5 \text{ years}$$

$$100\ \mu m / 80\ \mu m/y = 1.3 \text{ years (15 months)}$$

Note that these ages are only for the pit, which formed after the major part of the hole. Thus, it can be concluded that the hole is likely considerably older than these estimates, and thus older than Crack 12.

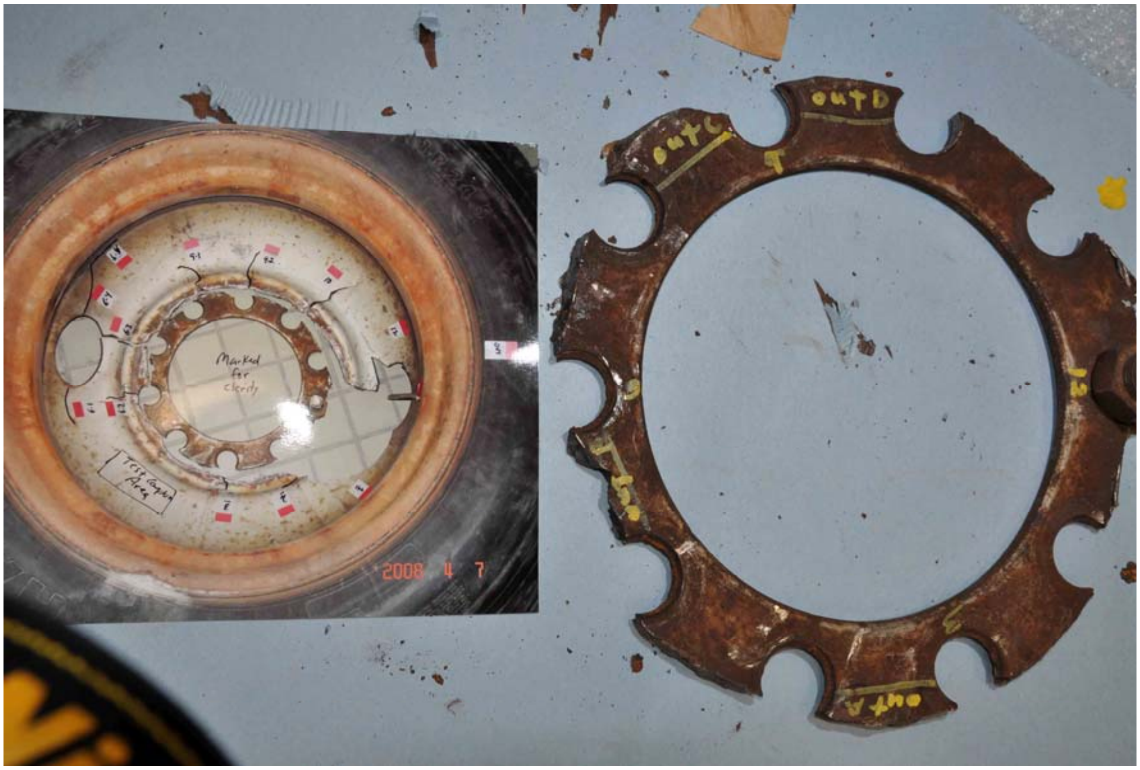


Figure 3-1. DSC_0062 LowRes.jpg

Figure 3-2. DSC00949 LowRes.jpg

Figure 3-3. DSC_0002 LowRes.jpg

Figure 3-4. DSC00944 LowRes.jpg

Figure 3-5. DSC00948 LowRes.jpg

Figure 3-6. DSC00353 LowRes.jpg

Figure 3-7. spider_B_009 LowRes.jpg

Figure 3-8. spider_B_010 LowRes.jpg

Figure 3-9. DSC07782 LowRes.jpg

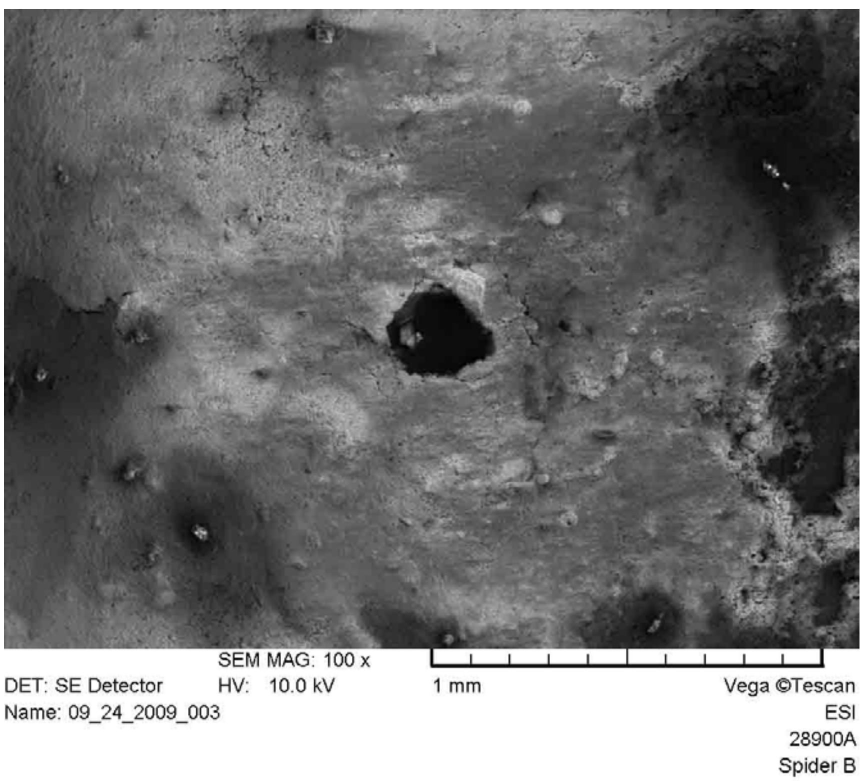


Figure 3-10. 09_24_2009_003 LowRes.jpg

OPINION 4

Opinion 4

The cracks present on the Firestone wheel represent a spectrum of ages, with the oldest ones as determined by selected analyses being Crack 12 and the spider hole "B" (Opinions 2 and 3). Crack 9-2, which originated at either the circumferential crack that separated the wheel from the tractor or from a bolt hole, has an intermediate age of at least 3 months prior to the detachment. Other cracks that were analyzed are younger, with a shiny appearance even in regions with no rubbing/abrasion marks. The hub part of Crack 6-4 represents the other extreme; it occurred at or very near the time of the wheel detachment, with the hub-rim part of Crack 6-4 being older. Crack 6-4 is similar in appearance and form to Crack 12, and is located diametrically opposite it.

Basis of Opinion 4

Distinct differences can be seen in the ages of the cracks in the Firestone wheel by the color, shininess, and overall appearance of corrosion. Whenever an oxide layer of appreciable thickness was found and was able to be retained by sectioning and metallographic preparation, the minimum age of the crack was able to be determined quantitatively. The age of other cracks can be judged approximately by appearance. For undisturbed fresh cracks (i.e. those without significant abrasion), energy dispersive spectroscopy, EDS, can assist in estimating relative crack ages.

The ages of Crack 12 and spider hole B were determined as outlined in Opinions 2 and 3. Crack 9-2, shown in Figures 4-1 to 4-4, has a dark, corroded appearance. It was sectioned as shown in Figure 4-5, with lower and higher magnification SEM images shown in Figures 4-6 and 4-7. Figure 4-8 shows a manual measurement of the oxide thickness, 34 μm. As with other, similar crack surfaces, the oxide appears in recessed, concave regions, indicating that oxide has been removed by rubbing in adjacent areas and probably even in the recessed area.

The identification of the oxide layer was confirmed using EDS, Figure 4-9 and Table 4-1. The ratio of atomic oxygen to oxygen plus iron is 35%. This layer has an appearance distinct from the metal surface which appears white, from the mounting material which is white and black, and the polishing debris layer which looks like a bundle of needles.

The remaining oxide layer thickness was measured at approximately 38 μm, corresponding to a removed Fe layer thickness of 19μm, and age of at least 3 months (and more likely at least 13 months) using the same methods as for Crack 12:

19 μm / 18 μm/y = 13 months

19 μm / 80 μm/y = 3 months

Cracks with little or no oxide on the surface, i.e. those with a shiny appearance, represent either: 1) cracks formed shortly before or at the time of detachment, or 2) older cracks that have been rubbed so as to remove much of the oxide. The appearance of shiny crack surfaces can be used to distinguish between the two cases, with older, rubbed cracks lacking surface detail of a clean fracture surface and having varied regions of shininess and darkness. Compare the two crack surfaces of Crack 6-4 in Figures 4-10 to 4-12 (4-11 is the hub surface, 4-12 is the hub-rim surface): the hub surface is shiny and uniform, with fine detail while the hub-rim surface is darker with regions of shininess and has a coarse surface with little detail.

On some cracks, abraded regions offer clear lines of demarcation between older, oxidized regions. See, for example Figure 1-9, 1-12, or 2-7.

The "young" cracks can be identified visually by their shiny appearance and finely textured surface, i.e. without smearing or rub marks. The hub surface of Crack 6-4 is an example of a fresh crack surface. It is nearly uniformly shiny, in spite of a clearly rubbed surface in a narrow band at its edge (seen at the top of Figure 4-11) that occurred during or just preceding the violent wheel detachment. Figures 4-13 and 4-14 illustrate the shininess of the hub surface of Crack 6-4, relative to other nearby cracks and the hub-rim surface of Crack 6-4. Figure 4-15 confirms the nearly equal shininess of the rubbed and unrubbed parts of the hub surface of Crack 6-4.

Crack 6-4 was sectioned as shown in Figure 4-16 for further examination. A mounted section is shown in Figure 17. No oxide can be seen.

EDS was performed on the hub and hub-crack surfaces for comparison, Table 1 and Figures 4-18 to 4-21. The atomic fraction of atomic oxygen to oxygen plus iron is as follows:

Hub surface, Crack 6-4 (rubbed area), Figure 4-18: 5%

Hub surface, Crack 6-4, (unrubbed area), Figure 4-19:	8%
Hub surface, Crack 6-4 (overall), Figure 4-20:	9%
Hub-rim surface, Crack 6-4 (overall), Figure 4-21:	18%
Fresh saw cut (Table 1):	0%
Rust chip (Table 1, Figures 2-12, 2-13):	48%

The results confirm the conclusions from the appearance, i.e. 1) that the hub surface of Crack 6-4 was formed at nearly the same time of the detachment (the oxide content being indistinguishable from a region rubbed clean at the time of detachment), 2) that the hub-rim surface of Crack 6-4 is older than the hub surface, and 3) that little oxidation has occurred in storage and handling from the time of detachment to the time of the inspection (the oxide percentage increasing from 0 to 5%).

Table 4-1. Energy Dispersive Spectroscopy Results

Crack EDS

Note	Crack	Mount	Probe	Location	O	C	Fe	Other	O/(Fe+O)
*Rim crack	12		1	1	31.3	7.2	58.3	Mg 0.1, Cl 0.2, Na 1.0, Si 0.9, Ca 0.8	35%
Dark area	12		1	2	45	6.1	48.4	Si 0.5	48%
On particle	12		1	3	45.4	6.4	45.9	Al 3.4 Si 1.1 Cl 1.2	50%
Off particle	12		3	3	12.6	2.1	85.3		13%
* Near hole	12		1	4	13.4	8	78.3	Si 0.3	15%
*Near hub surf.	12		1	5	25.5	10.2	63.1	Mg 0.1, Si 0.4, Na 0.6	29%
Further from surface	6-3		1	1	6.1	0	93.1	Ca 0.3	6%
Nearer surface	6-3		2	1	11.5	21	61.9	S 0.4, P 0.4, Ca 0.4, Al 0.7, Si 2.2	16%
Fissure / color	6-3		1	2	6.8	3.4	89.8		7%
Fissure / color	6-3		2	2	12.9	4.1	81.4	Al 0.3, S 0.3, Si 0.5, Mn 0.5	14%
Fissure / color	6-3		3	2	29.8	5.2	64	S 0.1, Si 0.5, Cl 0.5	32%
* Near hole end	6-3		1	3	20.5	5.5	73.8	Si 0.2	22%
* Rim crack	6-4		1	1	16.4	4.8	77.3	NA 0.2, Si 0.4, Ca 0.8	18%
* Dark/Light	6-4		1	3	8.7	6	83.3	Al 1.5, Na 0.2, Si 0.2	9%
Light / rub area	6-4		2	3	4.9	5.6	89.2	Si 0.3	5%

Dark half	6-4		3	3	7.3	5.8	82.1	Al 4.3, Na 0.1, Si 0.4	8%
Dark area (non-rub)	9-2		1	1	30.5	6	62.8	S 0.1, Si 0.5	33%
Light / rub area	9-2		1	2	12.1	2.1	85.2	Al 0.1, Si 0.4	12%
*Crack area	9-2		1	3	28.6	5.7	65.3	Si 0.4	30%
In fissure	5		1	9	8.5	2	89.5		9%
Adjacent fissure	5		1	11	31	15.7	39.5	Al 0.2, Mg 0.4, P 0.5, Cl 0.9, S 1.0, Na 3.1, Ca 2.7, Si 5.1	44%
In fissure (same?)	5		1	10	28.7	9.8	61.6		32%

Mounts EDS

Note	Crack	Mount	Probe	Location	O	C	Fe	Other	O/(Fe+O)
Entrainment t=40 (side)	12	12-2	1	5	25.7	8.7	60.1	Al 3.3	30%
In crack/fissure	12	12-3	1	7	18.5	17.3	58.6	Al 2.6 Si 2.4	24%
Intrude island	12	12-3	1	6	28.2	13.5	53.8	Al 3.3	34%
Oxide island t=100 (side)	12	12-1	1	4	47.9	7.2	39.8	Al 3.9	55%
Intrude island t=80 (side)	12	12-1	1	3	41.4	13.8	38.7	Al 3.4 Si 1.1 Cl 1.2	52%
Layer t=200 (side)	12	12-1	1	2	26.2	35.4	13.1	Al 4.3 Cu 1.3 Si 19.1	67%
Intrusion	12	12-1	2	1	27.9	26.2	32	Al 9.3 Si 2.9	47%
Outward bundle	12	12-1	1	1	12.1	18.2	53.2	Al 10.7 Si 4.7	19%
Debris	9-2	9-2-1	2	9	0	8.2	90.4	Cu 1.1	0%
Layer t=30-40	9-2	9-2-1	1	9	22	28.9	41.1	Al 5.8 Si 1.3	35%
Oxide layer t=200	12	12-4	1	1	26.2	43.3	24.5	Zn 0.1, Mn 0.1, Al 0.3, Cu 0.1, Si 5.5	52%
Oxide layer	12	12-4	1	2	28.1	38.3	27.9	Al 0.1, Zn 0.1, Cu 0.1, Si 5.8	50%

Spider EDS

Note	Crack	Mount	Probe	Location	O	C	Fe	Other	O/(Fe+O)
Spider B - Hole			1	1	29.4	10.3	60.3		33%
Spider B - Hole 20kV			1b	1	18	5	76.2	Si 0.7	19%
Spider B - Inside pit			1	2	24.9	6.7	68.4		27%
Spider B - Adjacent pit			2	2	34.1	8.4	56.6	Si 0.1, Na 0.7	38%

Spider C - Hole			1	3	42.8	11.2	44.2	Na 1.1	49%
Spider C - Not hole			1	4? (says 3)	42	20.2	29.1	P 0.2, Al 0.5, Mg 1.1, Na 2.1, Si 2.3, Ca 2.5	59%
Spider C - outer surf.			1	5	39.2	19.7	30.4	Al 0.3, P 0.5, S 0.6, Mg 1.0, Si 1.7, Cl 1.4, Ca 1.3, Na 4.2	56%
Spider D - Hole	*		1	8	33.4	5.9	53.1	Cl 2.2, Na 5.5	39%
Spider D - Hole			2	8	34.3	10.8	50.1	Si 0.2, Cl 0.5, Na 2.1, Ca 2.0	41%

<u>Other EDS</u>

Note	Crack	Mount	Probe	Location	O	C	Fe	Other	O/(Fe+O)
Sawcut	0				0.2	2.1	97.7		0%
Inside surface	Chip		1	6	43.7	5.4	48.2	Na 1.0, Cl 1.2	48%
Outside surface	Chip		1	7	43.5	3	46.6	Na 0.9, Cl 5.7	48%
Paint	6-4		1	2	37.1	42.1	10.7	Al 0.6, Ca 5.0, Cl 0.1, S 0.2, Mg 0.5, Na 1.6, Si 2.1	78%
Paint / normal	12		1	6	24.2	71.3	0	Cl 0.1, P 0.2, Mg 0.6, Na 1.1, Al 1.1, Si 1.4	100%

Figure 4-1. Wagoner10 LowRes.jpg

Figure 4-2. DSC07814 LowRes.jpg

Figure 4-3. DSC_0047 LowRes.jpg


Figure 4-4. DSC_0048 LowRes.jpg

Figure 4-5. DSC_0003 LowRes.jpg

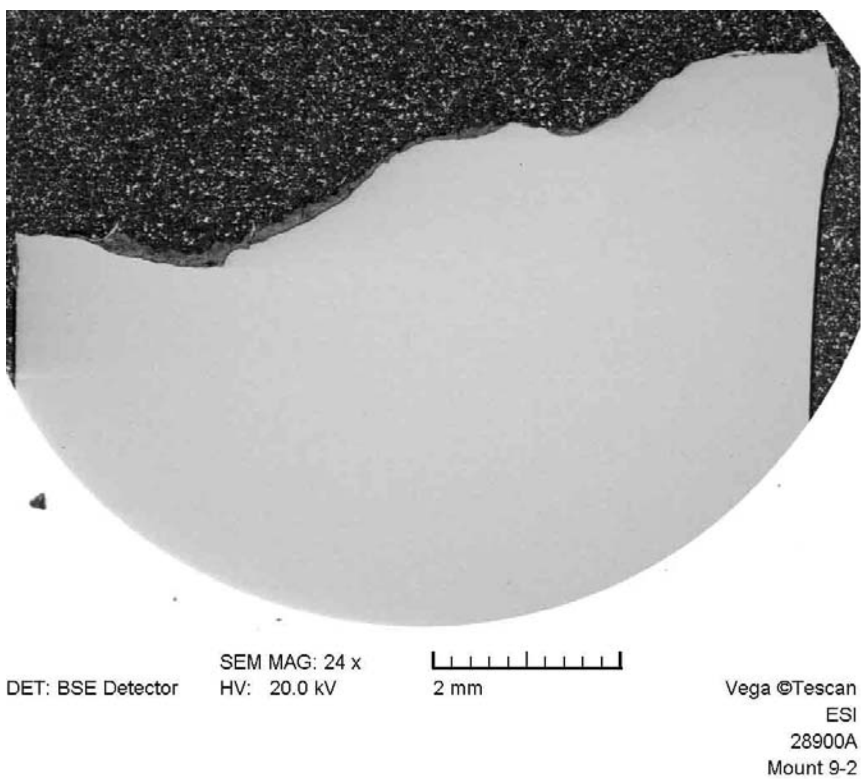


Figure 4-6. 2009_08_30_042_ann LowRes.jpg

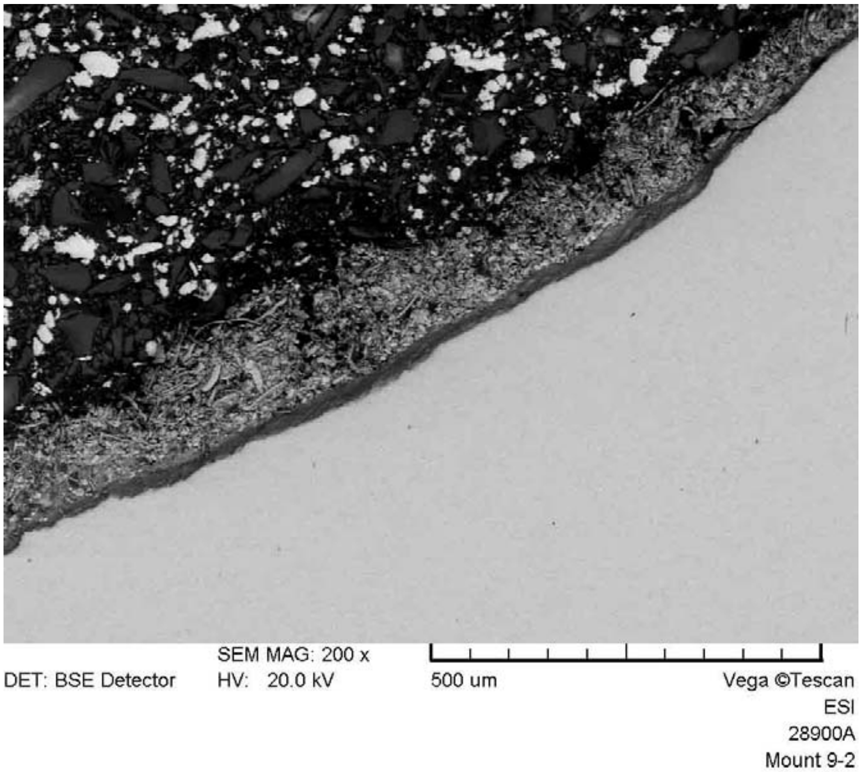


Figure 4-7. 2009_08_30_046 LowRes.jpg

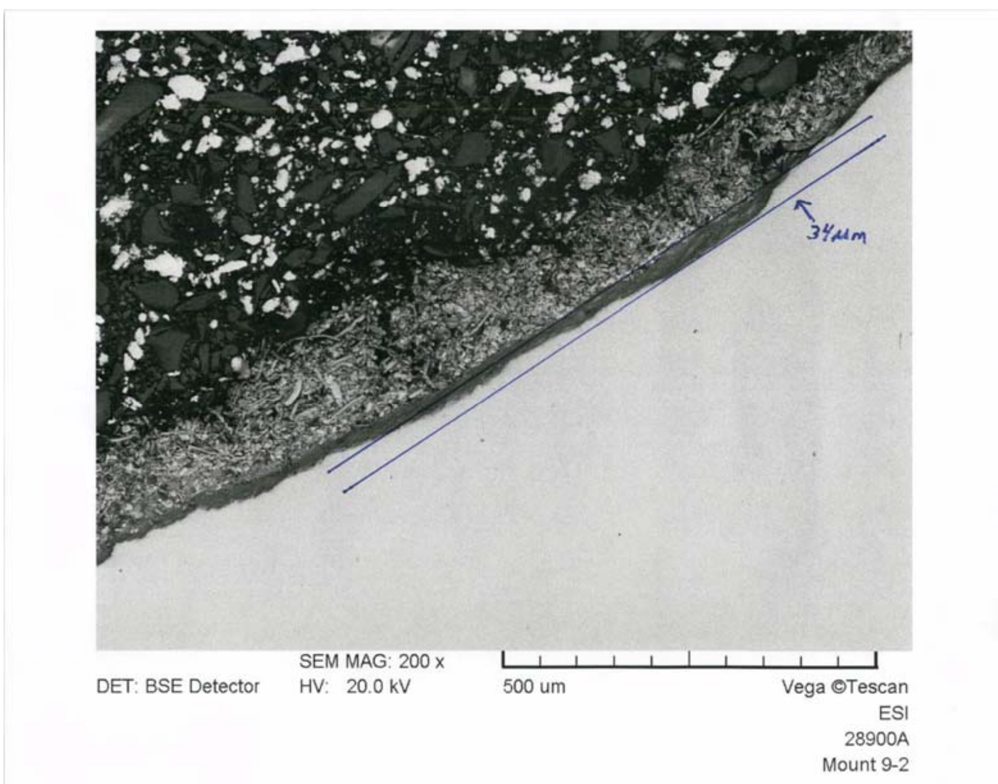
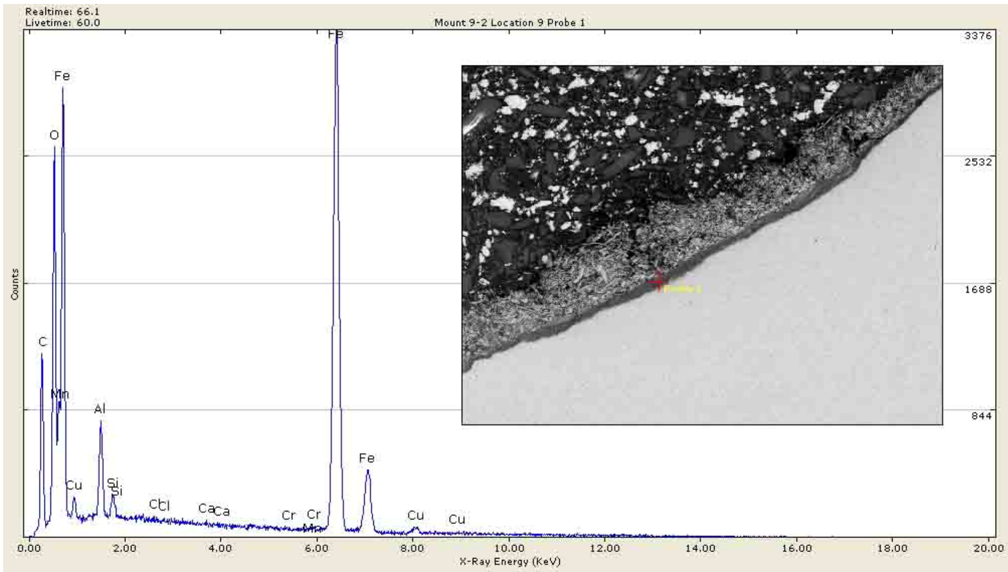


Figure 4-8. 20009_08-30-04 Scanned and Marked LowRes.jpg



Quantitative Results for Mount 9-2 Location 9 Probe 1
Analysis: Bulk Method: Standardless
Acquired 30-Aug-2009, 20.0 KeV @10 eV/channel

Element	Weight %	Atomic %	FWHM (eV)
Cl	0.00	0.00	99.2
Cr	0.00	0.00	128.3
Ca	0.01	0.01	111.1
Mn	0.06	0.03	132.7
Si	1.10	1.28	88.0
Cu	1.70	0.87	150.8
Al	4.83	5.81	84.5
C	10.68	28.86	65.0
O	10.87	22.04	69.5
Fe	70.75	41.10	137.2
Total	100.00		

Figure 4-9. Mount 9-2 Location 9 Probe 1 LowRes.jpg

Figure 4-10. DSC00363 LowRes.jpg

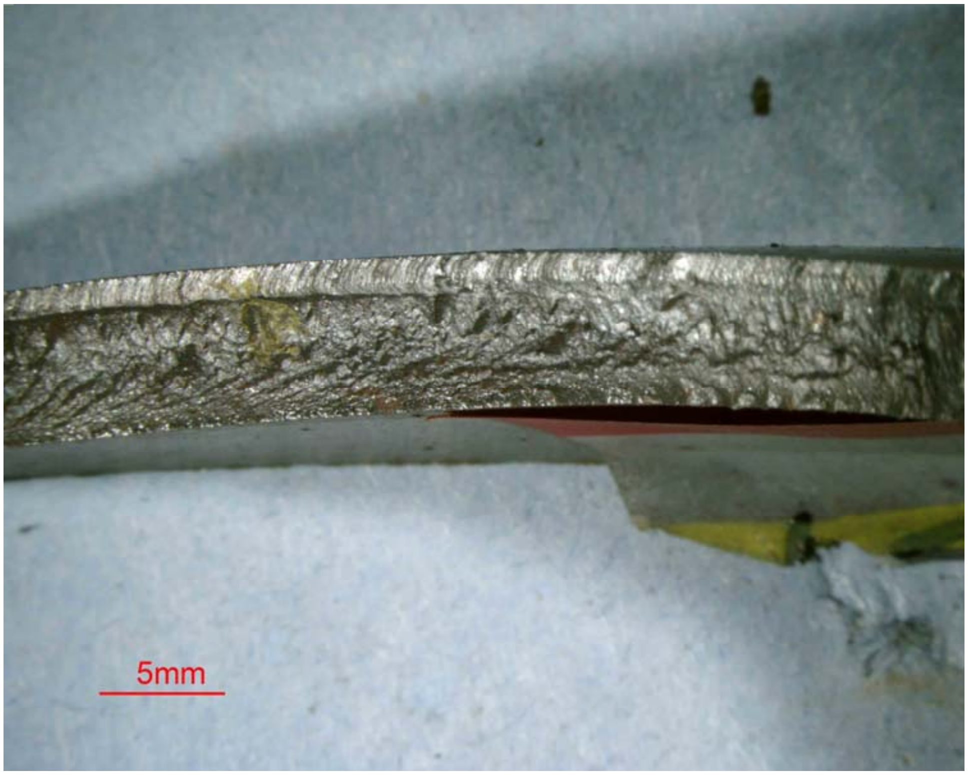


Figure 4-11. 6-4_002 LowRes.jpg

Figure 4-12. 6-4_006 LowRes.jpg

Figure 4-13. DSC07815 Low Res.jpg

Figure 4-14. JW- April 7, 2008- 018 LowRes.jpg

Figure 4-15. DSC00344 LowRes.jpg

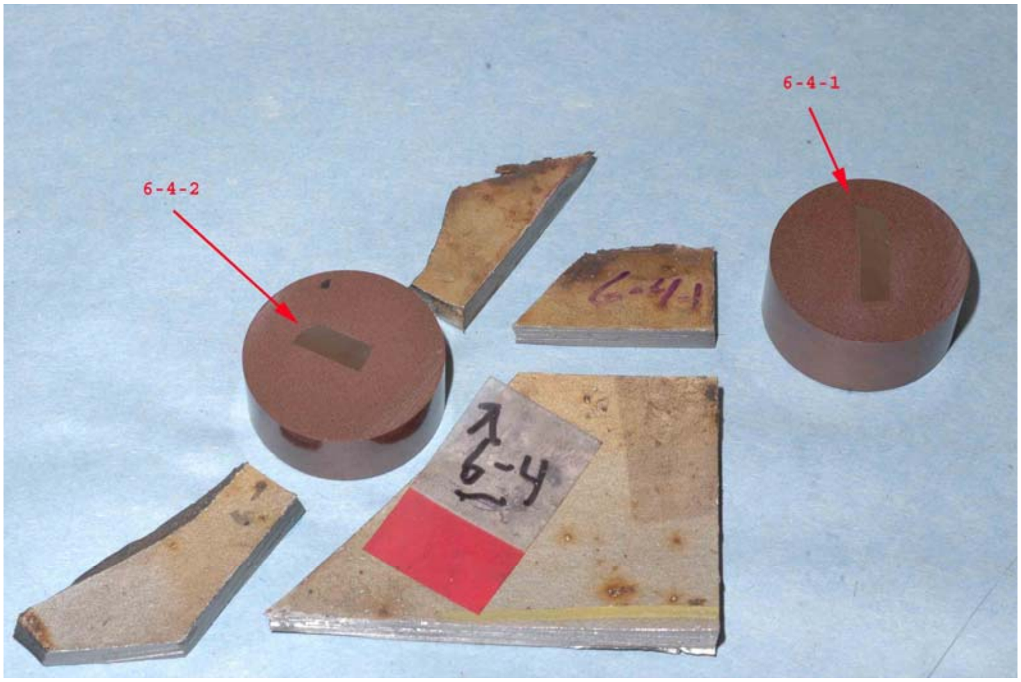


Figure 4-16. Specimen_Locations LowRes.jpg

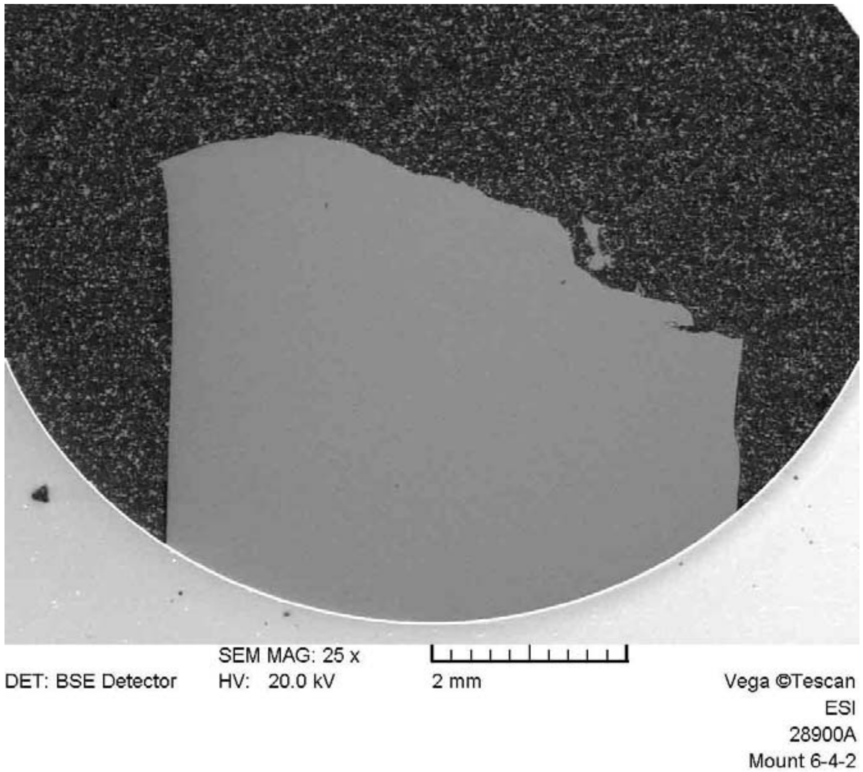


Figure 4-17. 2009_08_30_033_ann LowRes.jpg

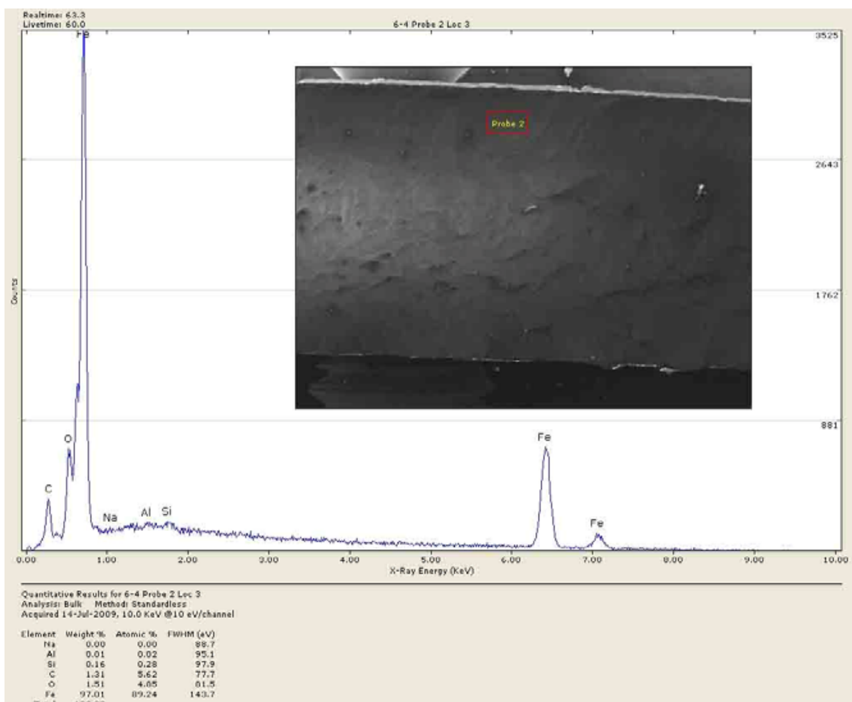


Figure 4-18. 6-4 Probe 2 Loc 3

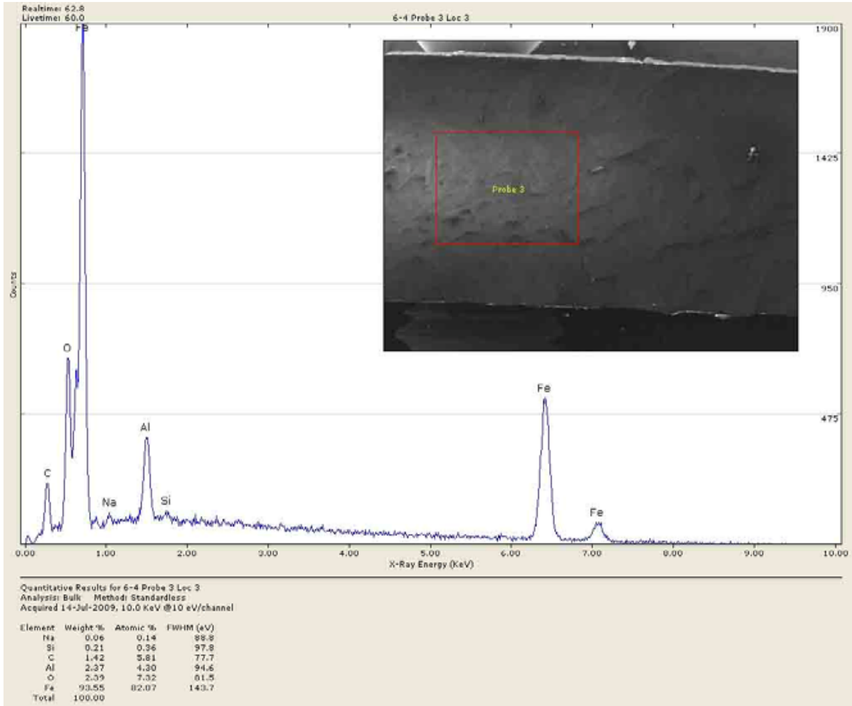


Figure 4-19. 6-4 Probe 3 Loc 3 LowRes.jpg

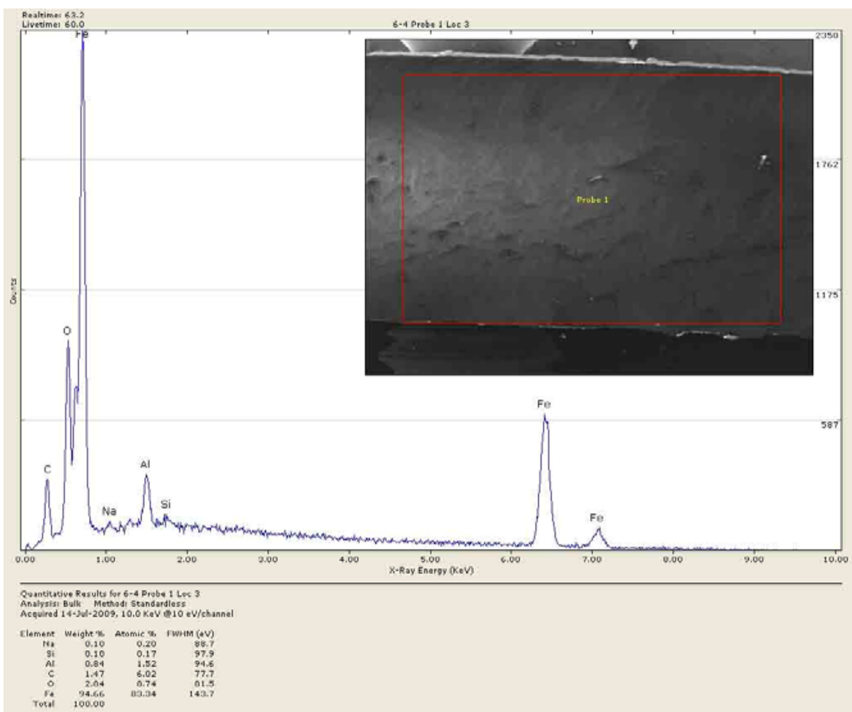


Figure 4-20. 6-4 Probe 1 Loc 3 LowRes.jpg

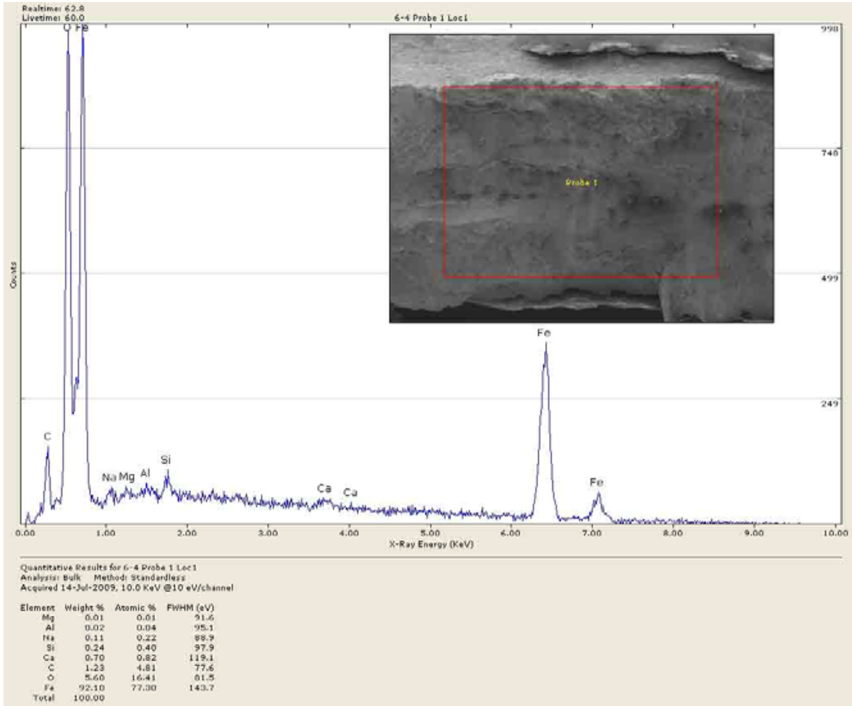


Figure 4-21. 6-4 Probe 1 Loc1 LowRes.jpg

OPINION 5

Opinion 5

The older cracks and perforation(s) were large enough at the time of the annual inspection on October 4, 2007, one month prior to the detachment, to have been visible to the naked eye.

Basis of Opinion 5

Certain cracks are known to have existed months before the detachment: the hub-rim surface of Crack 12, Crack 9-2, spider hole B, and portions of the circumferential crack. All are large enough to be clearly visible, with lengths ranging from 4mm to almost 5 inches. The length of these cracks, which have minimum ages of several months, would have been nearly what is seen today. For example, there is no noticeable difference in the appearance of the hub-rim surface of Crack 12 from one end to the other.

The cracks exhibited visible width as well, as indicated by the remnant thick oxide surfaces in some areas. Rust stains would have been visible in the crack openings, magnifying the visible widths as well. (Rust streaks on the painted wheel surface, indirect visual evidence of cracks, would also have been present emanating from many of the cracks, as shown clearly by photographs of the detached wheel taken at the time of the detachment: see Opinion 6).

Other cracks, ones that were not analyzed for quantitative ages, were most likely visible, including the hub/rim surface of Crack 6-4 and at least portions of the circumferential crack that caused the final wheel separation.

The evidence for Opinion 5 has already been presented in previous opinions, but reference is made to a few photographs for clarity.

Figures 5-1 and 5-2 illustrate the accessibility and the scale of the hub-rim section of Crack 12, which is the top, gently curved section shown in the Figure 5-1 (or at the bottom of Figure 5-2). Note that the hub-rim section of the crack is rougher and with a heavier oxide layer than the two sections of the crack that propagated in the hub. This is consistent with the hub-rim section of Crack 12 being older than the hub sections of Crack 12.

Figures 5-3 and 5-4 illustrate the accessibility and the scale of Crack 9-2. Note that Crack 9-2 originates from either a bolt hole or from a section of the circumferential crack. In the first case, Crack 9-2 was longer than shown today because it extended to the bolt hole. In the second case, the portion of the circumferential crack must have preceded Crack 9-2 and thus would also have been visible. The circumferential crack was generally too abraded too determine its age directly.

Figures 5-5 and 5-6 provide an overview of the spider and one surface of the circumferential crack. Figure 5-5 is a view from the inside direction, before subsequent handling and sectioning. Note the spider hole area near the bottom of the spider in Figure 5-5 (Spider B), and slightly to the left. Also note the area two lug holes counter-clockwise (Spider C). Figure 5-6, a view from the outside of the wheel, shows the marking of these same areas for sectioning. Note that the spider hole B (Figure 5-7) is clearly visible from the inside and outside of the wheel, and also that the portion of Spider C that can be clearly seen as an old crack (the left-hand rusty surface, as shown in Figure 5-8) is much larger than any visible limit.

Figure 5-1. Wagoner7 LowRes.jpg

Figure 5-2. DSC00368 LowRes.jpg

Figure 5-3. Wagoner10 LowRes.jpg

Figure 5-4 DSC_0031 LowRes.jpg

Figure 5-5. Wheel IP IV 1 LowRes.jpg

Figure 5-6. DSC00938 LowRes.jpg

Figure 5-7. DSC00349 LowRes.jpg

Figure 5-8. DSC00943 LowRes.jpg

OPINION 6

Opinion 6

The wheel and its fasteners were seriously and obviously corroded at the time of the detachment. The general corrosion would have been substantially the same at the time of the annual inspection, October 4, 2007, approximately one month earlier. Visible rust streaks associated with long-standing cracks were obvious. The lug nuts and studs were corroded, as was the mating surfaces between the inner and outer wheels. The presence of any of the following features: wheel cracks, corroded wheel mating surfaces, or corroded fasteners, mandates scrapping of the wheel or fasteners, respectively. Had the wheel and its fasteners been replaced at the time of the annual inspection, the detachment of this wheel would not have occurred.

Basis of Opinion 6

Figures 6-1 to 6-4, taken at the scene of the detachment on the day of the detachment, show cracks and associated rust streaks.

Figures 6-5 to 6-9 are photos of lug nuts and studs that were removed and recovered from the wheel. They show the extent of corrosion discernible by inspection.

Figures 6-10 to 6-11 show the inner wheel ("exemplar" wheel) and the apparent scale and corrosion on the mating surface.

Figures 6-12 to 6-15 show various views of the detached wheel and spider taken in the laboratory, for orientation. Figure 6-12 shows the condition of the mating surface on the detached wheel, with heavy corrosion and scale.

Figures 6-16 to 6-20 are photos taken from the Users' Guide to Wheels and Rims (Technology & Maintenance Council of American Trucking Associations, Inc., 1994, 2003, Second Edition, 2003) for comparison with photos of the detached wheel and exemplar wheel.

Figure 6-21 represents pages from the User's Guide corresponding to the photos in Figures 6-16 t to 6-20. They state that for each of the conditions pictured in those photos, the damaged wheel or fasteners should be removed from service and scrapped.

A few pertinent passages from the User's Guide (page 16 referring to periodic vehicle inspections of disc wheels) are reproduced below:

4. Rust streaks extending from bolt holes. (This indicates either worn, poor quality or loose wheel nuts.) Make sure the correct nuts for the wheel system are being used, inspect wheel bolt holes for wear or damage, then tighten fasteners to the correct torque. Then remove rust streaks.

8. Cracks or damage on any wheel component. Check all metal surfaces thoroughly including both sides of the wheels and between duals. Replace any wheel that is cracked or has damaged components.

9. Pitting or corrosion that has reduced the metal thickness. Replace any wheel that has extensive corrosion.

NOTE: Before replacing components, determine and correct the cause of the damage to avoid further problems.

Figure 6-1. 64 LowRes.jpg

Figure 6-2. 65 LowRes.jpg

Figure 6-3. 66 LowRes.jpg

Figure 6-4. 72 LowRes.jpg

Figure 6-5. Cap Nuts and Lug Nuts LowRes.jpg

Figure 6-6. DSC_0049 LowRes.jpg

Figure 6-7. DSC_0050 LowRes.jpg

Figure 6-8. DSC_0068 LowRes.jpg

Figure 6-9. DSC_0069 LowRes.jpg

Figure 6-10. 036 LowRes.jpg

Figure 6-11. DSC_0011 LowRes.jpg

Figure 6-12. Wheel IP IV 1 LowRes.jpg

Figure 6-13. Wheel OP IV 1 LowRes.jpg

Figure 6-14. Wheel OP OV 1 LowRes.jpg

Figure 6-15. DSC01048 LowRes.jpg

Figure 6-16. Users Guide p45 - Bolt Hole Cracks LowRes.jpg

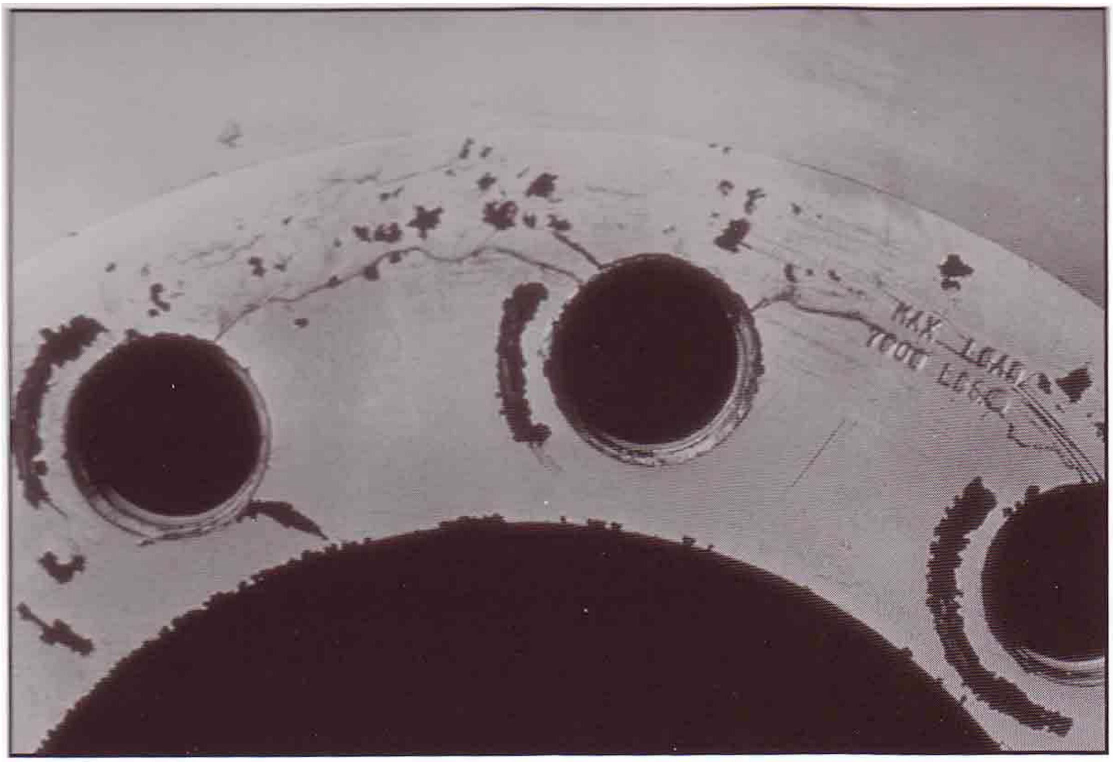


Figure 6-17. Users Guide p46 - Bolt to Bolt Cracks LowRes.jpg

Figure 6-18. Users Guide p60 - Attachment Weld Cracks LowRes.jpg

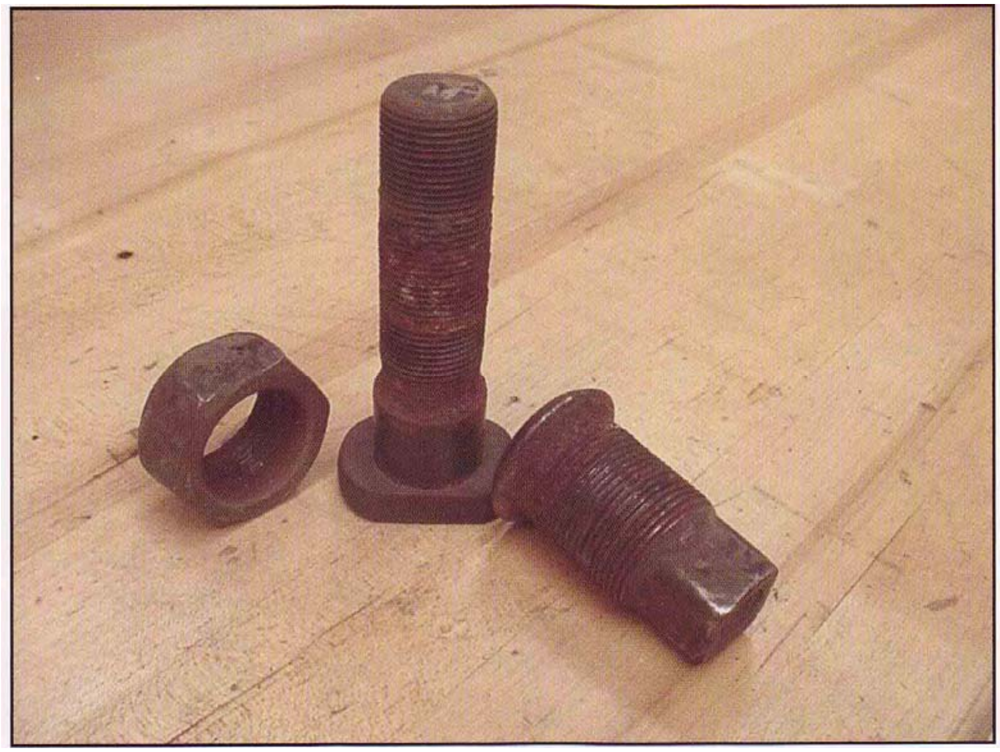


Figure 6-19. Users Guide p97 - Corrosion Nut and Stud LowRes.jpg

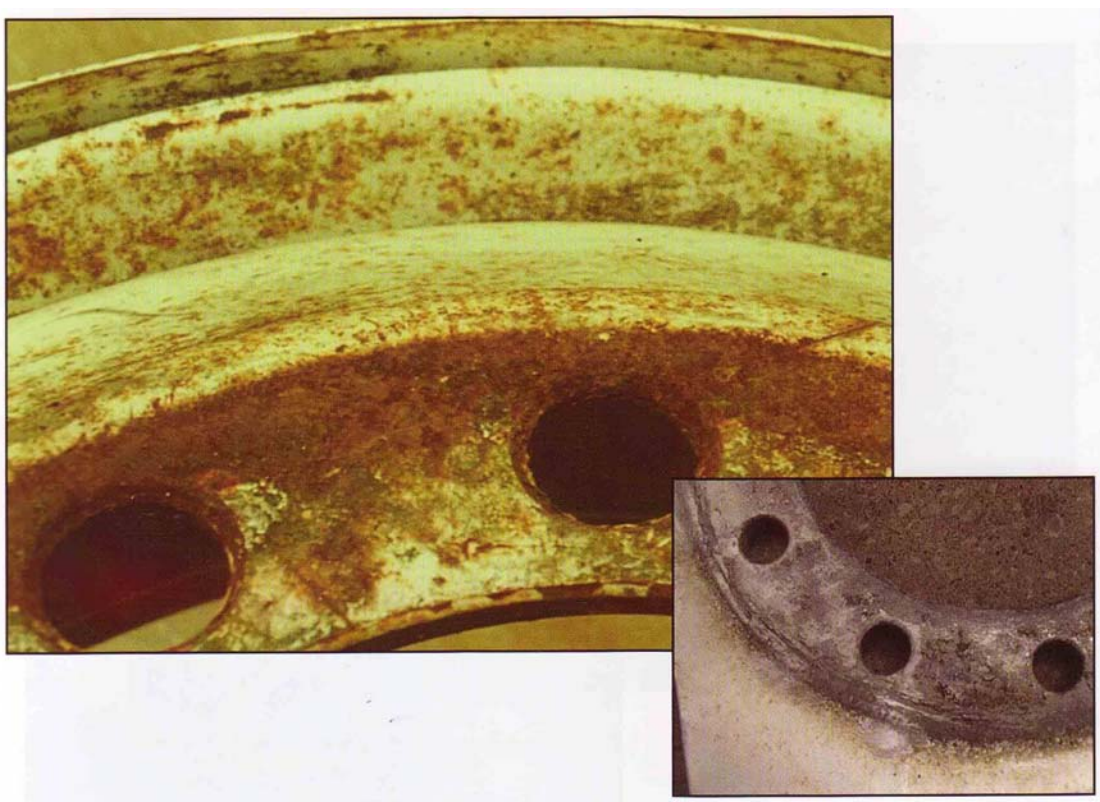
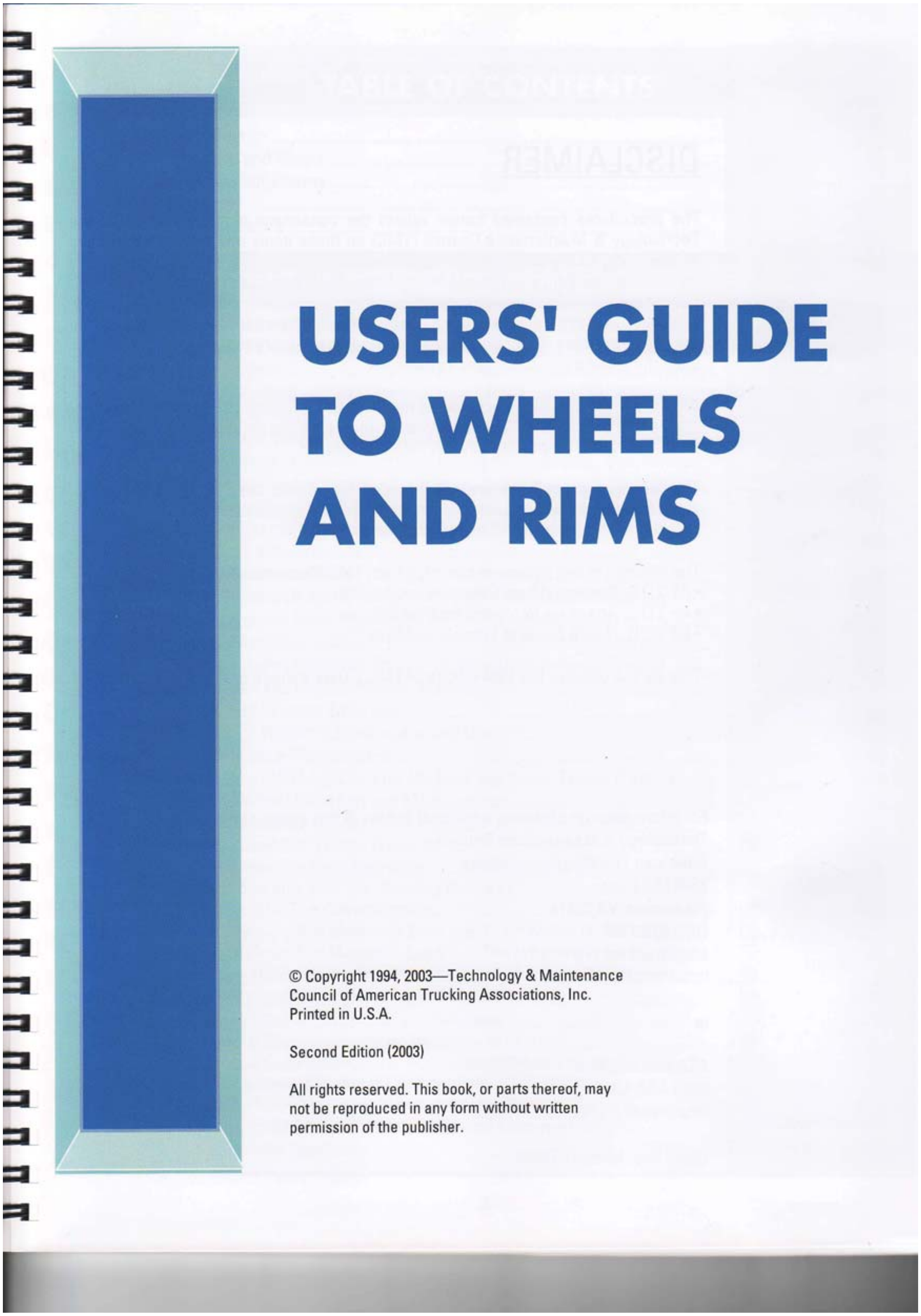


Figure 6-20. Users Guide p57 - Corrosion Disc Face LowRes.jpg



USERS' GUIDE TO WHEELS AND RIMS

Printed in U.S.A.

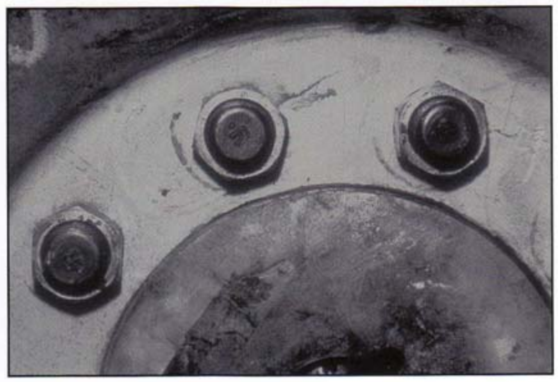
Second Edition (2003)

Figure 6-21. UsersGuide Cover p 24 46 57 60 97_Page_1.jpg

BOLT HOLE CRACKS

DISC—OUT-OF-SERVICE CONDITIONS

APPEARANCE	Cracks that start at the bolt hole and radiate outward, typically in a 30 degree direction.
PROBABLE CAUSE	Loose wheel nuts, improper installation procedure, use of improper or worn studs or nuts, mounting area of wheel, hub or drum not flat.



VMRS SYSTEM CODE (CODE KEY 31): 018

VMRS TECHNICIAN FAILURE CODE (CODE KEY 18): 14

ACTION

WHEEL	Remove from service and scrap.
OPERATIONS	Review installation procedure, retorquing program, proper torque level.
VEHICLE	Inspect attachment parts for proper size, type and wear. Check flatness of mating surfaces and replace if necessary.

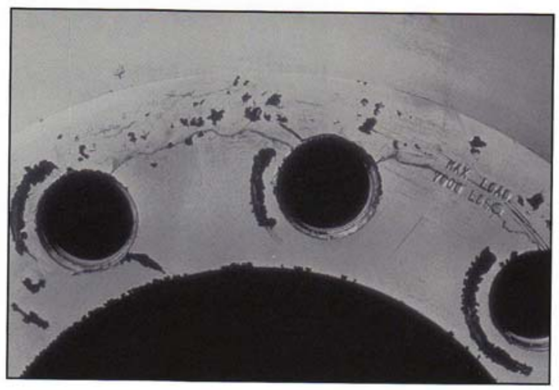
45

Figure 6-21. UsersGuide Cover p 24 46 57 60 97_Page_2.jpg

BOLT HOLE TO BOLT HOLE CRACKS

DISC—OUT-OF-SERVICE CONDITIONS

APPEARANCE	Cracks which run from one bolt hole circumferen-tially to an adjacent bolt hole or crack(s) which begin between bolt holes and progress toward them.
PROBABLE CAUSE	Loose wheel nuts, insufficient wheel support, improper installation procedure, mounting area of wheel, hub or drum not flat, use of worn studs or nuts. Corrosive or abrasive environments exaggerate this condition.



VMRS SYSTEM CODE (CODE KEY 31) :

018

VMRS TECHNICIAN FAILURE CODE (CODE KEY 18) :

14

ACTION

WHEEL	Remove from service and scrap.
OPERATIONS	Review retorquing program, proper torque level and installation procedure.
VEHICLE	Inspect hub and drum, studs and nuts for proper size, type and wear. Check flatness of hub backup diameter, and mating surfaces.

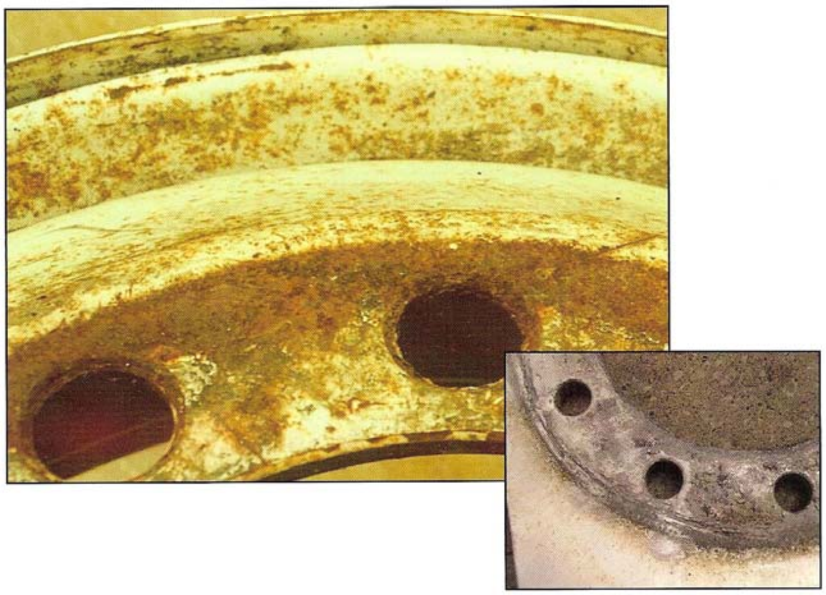
46

Figure 6-21. UsersGuide Cover p 24 46 57 60 97_Page_3.jpg

EXCESSIVE WEAR/CORROSION OF DISC FACE

DISC—OUT-OF-SERVICE CONDITIONS

APPEARANCE	Abrasive wear, pitting and corrosion on disc mounting surface.
PROBABLE CAUSE	Insufficient reconditioning of mating surfaces prior to installation, insufficient hub or drum backup, or worn mating surfaces. Corrosive or abrasive environments aggravate this condition.



VMRS SYSTEM CODE (CODE KEY 31): 018

VMRS TECHNICIAN FAILURE CODE (CODE KEY 18): 35

ACTION

WHEEL	Remove from service and scrap.
OPERATIONS	Recondition mating surfaces prior to installation. Review service application of the wheel.
VEHICLE	Check mating surfaces of hub or drum backup for wear or corrosion. Consider using wheel separators designed to control corrosion and wear.

57

Figure 6-21. UsersGuide Cover p 24 46 57 60 97_Page_4.jpg

ATTACHMENT WELD CRACKS

DISC—OUT-OF-SERVICE CONDITIONS

APPEARANCE	Cracks at disc-to-rim weld.
PROBABLE CAUSE	Exceeding load/inflation capacity, faulty weld, use of radial tires on non-radial approved rims.

VMRS SYSTEM CODE (CODE KEY 31): 018

VMRS TECHNICIAN FAILURE CODE (CODE KEY 18): 14

ACTION

WHEEL	Remove from service and scrap. Request evaluation by supplier before scrapping.
OPERATIONS	Check wheel load capacity against actual service conditions. Ensure proper tire/rim combination is being used.
VEHICLE	None.

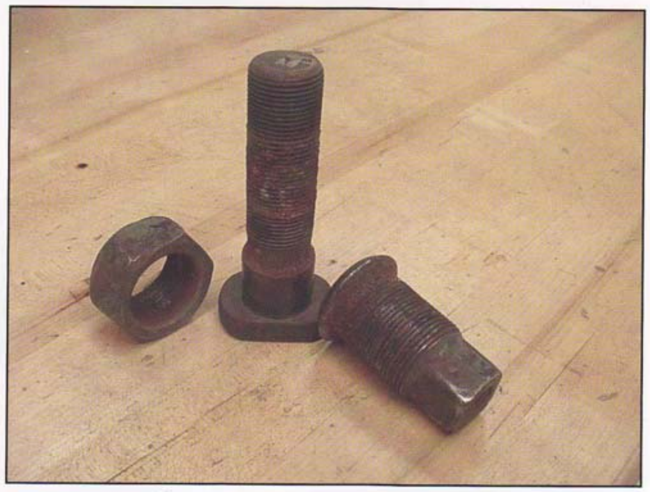
60

Figure 6-21. UsersGuide Cover p 24 46 57 60 97_Page_5.jpg

CORROSION - NUT AND STUD

FASTENERS—OUT-OF-SERVICE CONDITIONS

APPEARANCE	Evidence of rust and scale on fastener.
PROBABLE CAUSE	Operating in corrosive environments, prolonged use, lack of proper maintenance, inadequate coating during manufacturing, and corrosive washes used to clean vehicles.



VMRS SYSTEM CODE (CODE KEY 31): 018

VMRS TECHNICIAN FAILURE CODE (CODE KEY 18): 35

ACTION

FASTENERS	Scrap the fastener.
OPERATIONS	Wire brush studs at every installation. Inspect fasteners and replace as necessary. Use recommended installation procedures.
VEHICLE	None

97

Figure 6-21. UsersGuide Cover p 24 46 57 60 97_Page_6.jpg

OPINION 7

Opinion 7

The lug nuts were likely not properly torqued at the time of the last annual inspection, thus allowing operational misalignment of the wheel. Evidence of other, related sources of mis-mounting and misalignment leading to failure was found in the forms of the following:

1) The lug nut mating surfaces were damaged, deformed, and worn sufficiently that they should have been scrapped and replaced.
2) The lug nuts were of two kinds of material, the softer ones showing the greatest erosion damage. 3) The inner/outer wheel mating surfaces and lug nuts were heavily corroded, (see Opinion 6).
4) The wheel mating surfaces were heavily corroded (see Opinion 6).

There is no evidence of stud stretching, as would be expected from over-tightening of the lug nuts.

Basis of Opinion 7

The principal cause of cracks around bolt holes is known to be loose lug nuts. See Figures 6-21 and Figure 7-1. Other related causes include improper installation procedures, problems with mounting surfaces (including corrosion), and problems with studs and nuts (including corrosion). One lug nut and stud assembly remain on the spider. That assembly can be rotated by hand, indicating very low tightening torque.

Visual inspection of the lug nuts shows corrosion but little or no gross mechanical damage on some of them (A, H) – see Figure 7-2, moderate deformation possibly caused by the wheel wobbling on others (B, D, E, F, H) – Figure 7-3, and severe damage with a significant part of the mating surface to the wheel missing (C, G, I) – Figure 7-4. The three lug nuts with the most severe damage, C, G, and I, correspond to the three softer ones with lower carbon content among the 9 lug nuts tested. (The 10th lug nut, J, remains attached to the spider. It was not analyzed.)

The following summarizes that hardness, carbon content, and visual condition of the 10 lug nuts:

Lug Nut	Rc or Rb	UTS(MPa)	C content(%)	Condition (visual inspection)
A	Rc 34	1050	0.37	minor deformation
B	Rc 37	1140	0.37	moderate deformation
C	Rb 78	470	0.05	severe corrosion/deformation
D	Rc 33	1020	0.42	moderate deformation
E	Rc 31	970	0.42	moderate corrosion/deformation
F	Rc 36	1110	0.37	moderate deformation

G	Rb 94	640	0.04	severe deformation/corrosion
H	Rc 33	1020	0.46	minor deformation
I (with stud)	Rb 82	490	0.07	severe corrosion/deformation
J (on spider)				

Conversion chart: http://mdmetric.com/tech/hardnessconversion.html

The original data appears in Tables 7-1 and 7-2. Photographs of lug nuts A-I appear as Figures 7-2 to 7-10. Figure 7-10 shows a side view of a lug and stud assembly that has not been separated.

The studs, Figure 7-11, show no significant evidence of stretching. The hole depth measurements, as shown below, are all within =/- 0.004", i.e. within 0.3% of the average length:

Stud	Max. Length	Internal Length
3	2.260"	1.469"
4	2.271"	1.471"
5	2.282"	1.467"
6	2.273"	1.474"
7	2.298"	1.466"
8	2.273"	1.471"
9	2.279"	1.470"

The original data appears in Table 7-3.

A 16/inch thread gage engaged with the threads shows no significant disgregistry, as would be expected for a significantly stretched stud, Figure 7-12.

In addition to the gross deformation, corrosion, and erosion of some of the lug nuts, there is deformation of the mating surface of the lug nuts to the wheels, shown in detail in Figure 7-13. Comparison of Figure 7-13 with Figure 7-14 reveals the flattening of the mating surfaces from their normal aspect having a geometry of sections of a sphere. Such flattening and distortion of lug mating surfaces mandates removal and replacement of lug nuts, Figure 7-15.

Table 7-1. 149653.jpg

MSi Testing & Engineering, Inc.

Your Source for Metallurgical Testing and Failure Analysis

1390 N. 25th Avenue
Melrose Park, IL 60160
708-343-3444
F A X-3033

TESTING CERT #0510-01

Engineering Systems Inc.
3851 Exchange Avenue
Aurora, IL 60504

Attn: Mr. Michael Danko

Report No.:	149653
Date:	8-31-09
Order No.:	27152
Page:	1 of 1

SAMPLE IDENTIFICATION

Project No.	Grade	Description
28900	N/A	See Below

TEST RESULTS *

Chemical Testing

	"Split" Cap Nut	"Intact" Cap Nut	"A" Lug Nut	"B" Lug Nut	"C" Lug Nut
Carbon	.36 %	.36 %	.37 %	.37 %	.05 %
Manganese	.73	.72	.71	.71	.30
Phosphorus	.015	.014	.017	.017	.014
Sulfur	.012	.011	.010	.010	.027
Silicon	.21	.21	.20	.20	<.01
Nickel	.01	.01	.01	.01	.01
Chromium	.02	.02	.02	.02	<.01
Molybdenum	<.01	<.01	<.01	<.01	<.01
Copper	.02	.01	.03	.03	.01
Aluminum	.03	.03	.02	.02	<.01

Hardness Testing

Core Hardness, HRC	36 36 36	38 37 37	34 34 34	32 33 34	77[1] 78[1] 78[1]

* Testing performed in accordance with ASTM E415 and E18 (tungsten ball indenter).
Note 1: Results in Rockwell B Scale.

Respectfully Submitted,

MSi Testing & Engineering Inc.

Bart Bobek

Bart Bobek
Associate Metallurgical Engineer

BB/jc/E-Document

Table 7-2. MSi_151230_Page_1.jpg

MSi Testing & Engineering, Inc.
Your Source for Metallurgical Testing and Failure Analysis
1390 N. 25th Avenue
Melrose Park, IL 60160
708-343-3444
F A X-3033

TESTING CERT #0510-01

Engineering Systems Inc.
3851 Exchange Avenue
Aurora, IL 60504

Attn: Mr. Michael Danko

Report No.: 151230
Date: 10-14-09
Order No.: 27250
Page: 1 of 2

SAMPLE IDENTIFICATION

Project No.	Sample I.D.
28900	See Below

TEST RESULTS *

Chemical Testing

Element	D	E	F	G	H
Carbon	.42 %	.42 %	.37 %	.04 %	.46 %
Manganese	.79	.80	.74	.42	.79
Phosphorus	.009	.009	.017	.013	.012
Sulfur	.011	.012	.011	.014	.010
Silicon	.23	.23	.21	<.01	.19
Nickel	.02	.02	.02	.02	.02
Chromium	<.01	<.01	.02	<.01	.01
Molybdenum	<.01	<.01	<.01	<.01	<.01
Copper	<.01	.01	.03	.01	.01
Aluminum	.04	.04	.02	<.01	.01

Element	3	4	5	6	7
Carbon	.40 %	.39 %	.40 %	.39 %	.40 %
Manganese	.76	.75	.76	.76	.76
Phosphorus	.016	.015	.015	.015	.016
Sulfur	.013	.013	.013	.013	.013
Silicon	.21	.21	.21	.21	.21
Nickel	.02	.02	.02	.02	.20
Chromium	.01	.02	.02	.02	.02
Molybdenum	<.01	<.01	<.01	<.01	<.01
Copper	.02	.02	.02	.02	.02
Aluminum	.03	.03	.03	.03	.03

* Testing performed in accordance with ASTM E415.

CONTINUED ON NEXT PAGE

Engineering Systems Inc.
MSi Report No. 151230

TEST RESULTS (Continued) *

Chemical Testing

Element	8	9	I-5	Weld Metal
Carbon	.39 %	.38 %	.07 %	.11 %
Manganese	.75	.75	.31	1.15
Phosphorus	.015	.015	.016	.009
Sulfur	.012	.012	.017	.016
Silicon	.21	.21	<.01	.39
Nickel	.02	.02	.02	.01
Chromium	.02	.02	<.01	.03
Molybdenum	<.01	<.01	<.01	<.01
Copper	.02	.02	.01	.02
Aluminum	.03	.03	.01	<.01
Titanium	- -	- -	- -	.03

Hardness Testing

	D			E			F			**G			H		
Core Hardness, HRC	33	32	33	30	31	32	36	36	36	93	94	94	33	33	33

	3			4			5			6			7		
Core Hardness, HRC	36	35	35	34	34	36	34	36	34	34	35	34	36	35	35

	8			9			**I-5		
Core Hardness, HRC	35	35	35	36	35	35	81	83	82

* Testing performed in accordance with ASTM E415 and E18.
** Core Hardness, HRB performed in accordance with ASTM E18 (tungsten ball indenter).

Respectfully Submitted,

MSi Testing & Engineering, Inc.

James Kobrinetz

James Kobrinetz
Staff Metallurgical Engineer

JK/sr/E-Document

MSi

Table 7-3. Lug_and_Post_Measurements_Page_1.jpg

Engineering Systems Inc.
3851 Exchange Ave.
Aurora, IL 60504 630-851-4566

Chintamaneni v C. K. C. Trucking, et al
ESI File #28900
Lug Nut and Stud Post Dimension Measurements

Dimensional measurements were performed on 5 lug nuts and 7 stud posts. All dimensions are reported in inches and all measurements were conducted at locations away from obvious deformation. Lug nut measurements are reported in Table 1 and stud post measurements are reported in Table 2.

Measurements performed on the lug nuts consisted of distance across the wrench flats (measurements 1, 2, and 3), internal minor diameter (measurement 4), maximum length (measurement 5), and thread pitch. Photographs 1- 3 illustrate the measured dimensions.

Table 1: Lug Nut Dimensions (in)

Lug Nut "D"				
Across Wrench Flats			Internal Minor Dia.	Maximum Length
1	2	3	4	5
1.490	1.494	1.480	1.063 ± .002	.886
Thread pitch – 16 threads per inch (tpi)				
Lug Nut "E"				
Across Wrench Flats			Internal Minor Dia.	Maximum Length
1	2	3	4	5
1.486	1.498	1.492	1.058 ± .002	.878
Thread pitch – 16 threads per inch (tpi)				
Lug Nut "F"				
Across Wrench Flats			Internal Minor Dia.	Maximum Length
1	2	3	4	5
1.501	1.495	1.498	1.060 ± .003	.872
Thread pitch – 16 threads per inch (tpi)				
Lug Nut "G"				
Across Wrench Flats			Internal Minor Dia.	Maximum Length
1	2	3	4	5
1.490	1.496	1.495	1.060 ±.005	.861
Thread pitch – 16 threads per inch (tpi)				
Lug Nut "H"				
Across Wrench Flats			Internal Minor Dia.	Maximum Length
1	2	3	1	2
1.480	1.490	1.485	1.060 ±.005	.895
Thread pitch – 16 threads per inch (tpi)				

Measurements conducted on the stud posts include total length (1), major external threaded diameter (2), seat outside diameter (3), minor internal threaded diameter (4), distance across wrench flats, top to bottom (5), left to right (6), internal depth (7), internal and external thread pitch. Measurements are presented in Table 2. Photographs 4 - illustrate the measured dimensions.

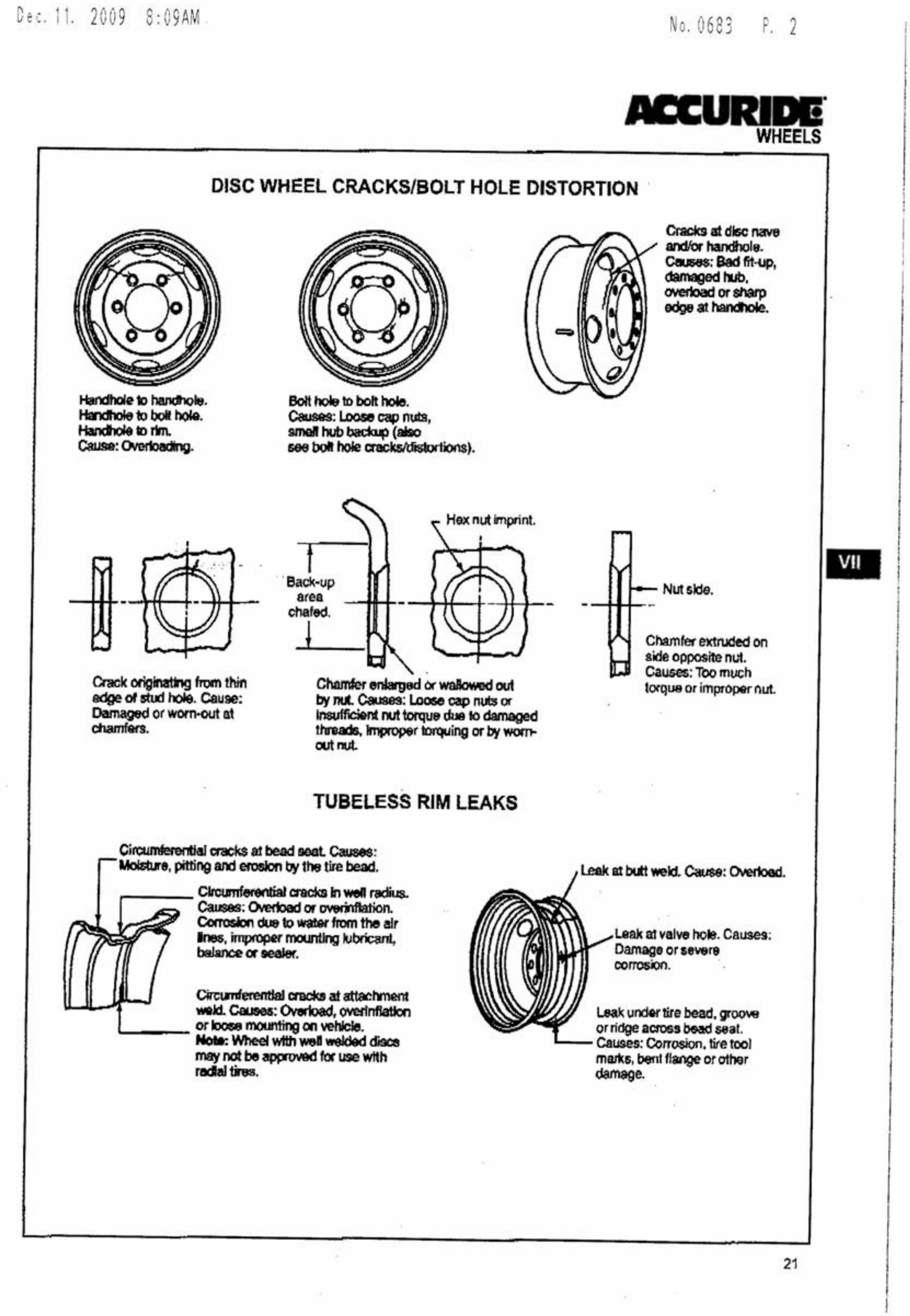
Table 2: Stud Post Measurements (in)

Stud #3						
Length (1)	Major External Dia. (2)	Seat Diameter (3)	Minor Internal Dia. (4)	Wrench Flat top – bottom (5)	Wrench Flat left – right (6)	Internal Depth (7)
2.260 max	1.109 max	1.404 max	.689 ± .003	.811 max	.807 max	1.469 max
Internal and external thread pitch, 16 tpi						
Stud #4						
Length (1)	Major External Dia. (2)	Seat Diameter (3)	Minor Internal Dia. (4)	Wrench Flat top – bottom (5)	Wrench Flat left – right (6)	Internal Depth (7)
2.271 max	1.112 max	1.405 max	.691 ± .002	.810 max	.813 max	1.471 max
Internal and external thread pitch, 16 tpi						
Stud #5						
Length (1)	Major External Dia. (2)	Seat Diameter (3)	Minor Internal Dia. (4)	Wrench Flat top – bottom (5)	Wrench Flat left – right (6)	Internal Depth (7)
2.282 max	1.113 max	1.386 max	.689 ± .002	.817 max	.814 max	1.467 max
Internal and external thread pitch, 16 tpi						
Stud #6						
Length (1)	Major External Dia. (2)	Seat Diameter (3)	Minor Internal Dia. (4)	Wrench Flat top – bottom (5)	Wrench Flat left – right (6)	Internal Depth (7)
2.273 max	1.110 max	1.400 max	.694 ± .003	.818 max	.812 max	1.474 max
Internal and external thread pitch, 16 tpi						
Stud # 7						
Length (1)	Major External Dia. (2)	Seat Diameter (3)	Minor Internal Dia. (4)	Wrench Flat top – bottom (5)	Wrench Flat left – right (6)	Internal Depth (7)
2.298 max	1.110 max	1.400 max	.690 ± .002	.818 max	.816 max	1.466 max
Internal and external thread pitch, 16 tpi						

Table 2, continued

Stud # 8						
Length (1)	Major External Dia. (2)	Seat Diameter (3)	Minor Internal Dia. (4)	Wrench Flat top – bottom (5)	Wrench Flat left – right (6)	Internal Depth (7)
2.273 max	1.111 max	1.396 max	.694 ± .002	.812 max	.816 max	1.471 max
Internal and external thread pitch, 16 tpi						
Stud # 9						
Length (1)	Major External Dia. (2)	Seat Diameter (3)	Minor Internal Dia. (4)	Wrench Flat top – bottom (5)	Wrench Flat left – right (6)	Internal Depth (7)
2.279 max	1.108 max	1.394 max	.693 ± .002	.819 max	.812 max	1.470 max
Internal and external thread pitch, 16 tpi						

Photograph 1
Measurements 1 -3, across wrench flats, and measurement 4, minor internal diameter, performed on the lug nut specimens



Dec. 11. 2009 8:09AM No. 0683 P. 2

ACCURIDE WHEELS

VII

DISC WHEEL CRACKS/BOLT HOLE DISTORTION

Handhole to handhole.
Handhole to bolt hole.
Handhole to rim.
Cause: Overloading.

Bolt hole to bolt hole.
Causes: Loose cap nuts, small hub backup (also see bolt hole cracks/distortions).

Cracks at disc nave and/or handhole.
Causes: Bad fit-up, damaged hub, overload or sharp edge at handhole.

Hex nut imprint.

Back-up area chafed.

Nut side.

Crack originating from thin edge of stud hole. Cause: Damaged or worn-out at chamfers.

Chamfer enlarged or wallowed out by nut. Causes: Loose cap nuts or insufficient nut torque due to damaged threads, improper torquing or by worn-out nut.

Chamfer extruded on side opposite nut. Causes: Too much torque or improper nut.

TUBELESS RIM LEAKS

Circumferential cracks at bead seat. Causes: Moisture, pitting and erosion by the tire bead.

Circumferential cracks in well radius. Causes: Overload or overinflation. Corrosion due to water from the air lines, improper mounting lubricant, balance or sealer.

Circumferential cracks at attachment weld. Causes: Overload, overinflation or loose mounting on vehicle.
Note: Wheel with well welded discs may not be approved for use with radial tires.

Leak at butt weld. Cause: Overload.

Leak at valve hole. Causes: Damage or severe corrosion.

Leak under tire bead, groove or ridge across bead seat. Causes: Corrosion, tire tool marks, bent flange or other damage.

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Figure 7-1. Baareman fax pages_Page_1.jpg

Figure 7-2. DSC_0050 LowRes.jpg

Figure 7-3. DSC_0053 LowRes.jpg

Figure 7-4. DSC_0056 LowRes.jpg

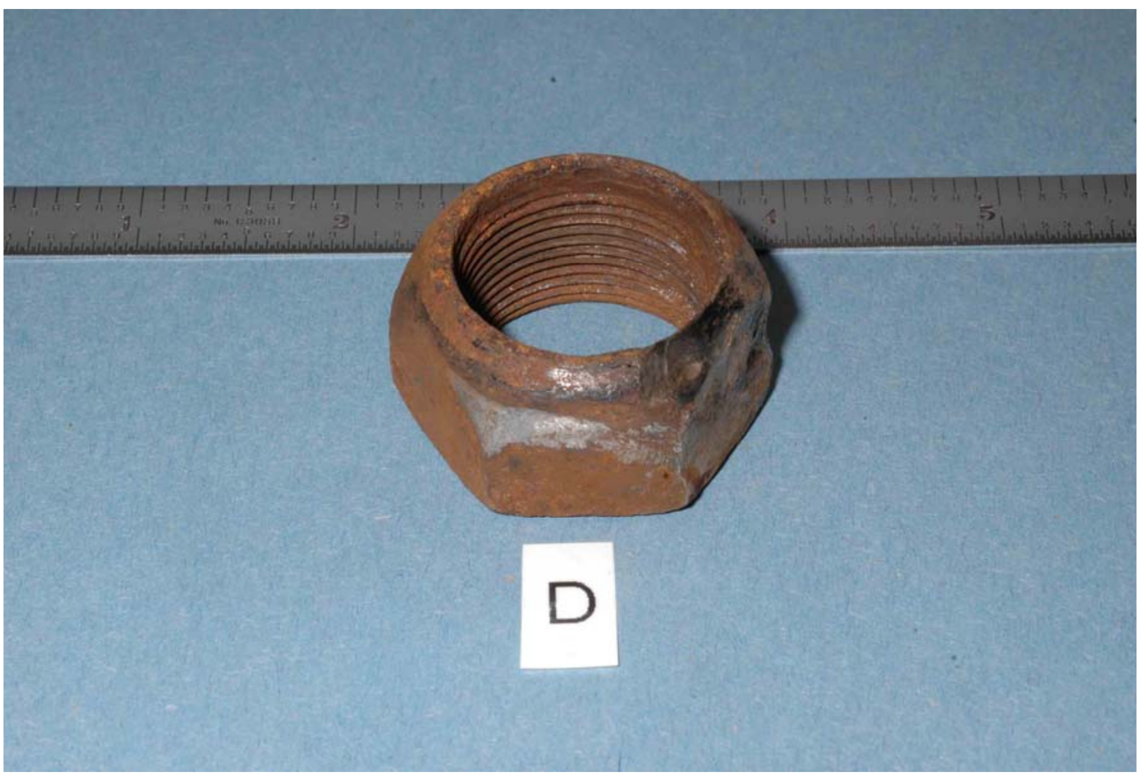


Figure 7-5. DSC_0002 LowRes.jpg

Figure 7-6. DSC_0005 LowRes.jpg

Figure 7-7. DSC_0008(2) LowRes.jpg

Figure 7-8. DSC_0010 LowRes.jpg

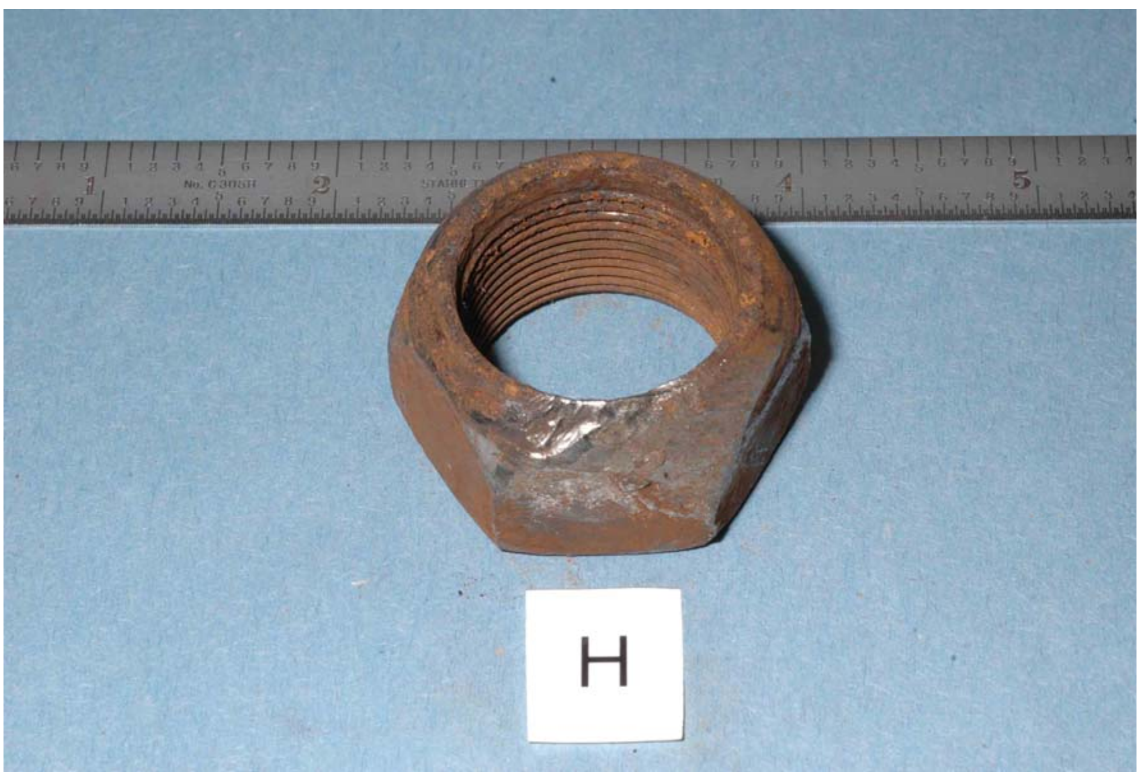


Figure 7-9. DSC_0012 LowRes.jpg

Figure 7-10. DSC_0023 LowRes.jpg

Figure 7-11. DSC_0068 LowRes.jpg

Figure 7-12. DSC_0051 LowRes.jpg

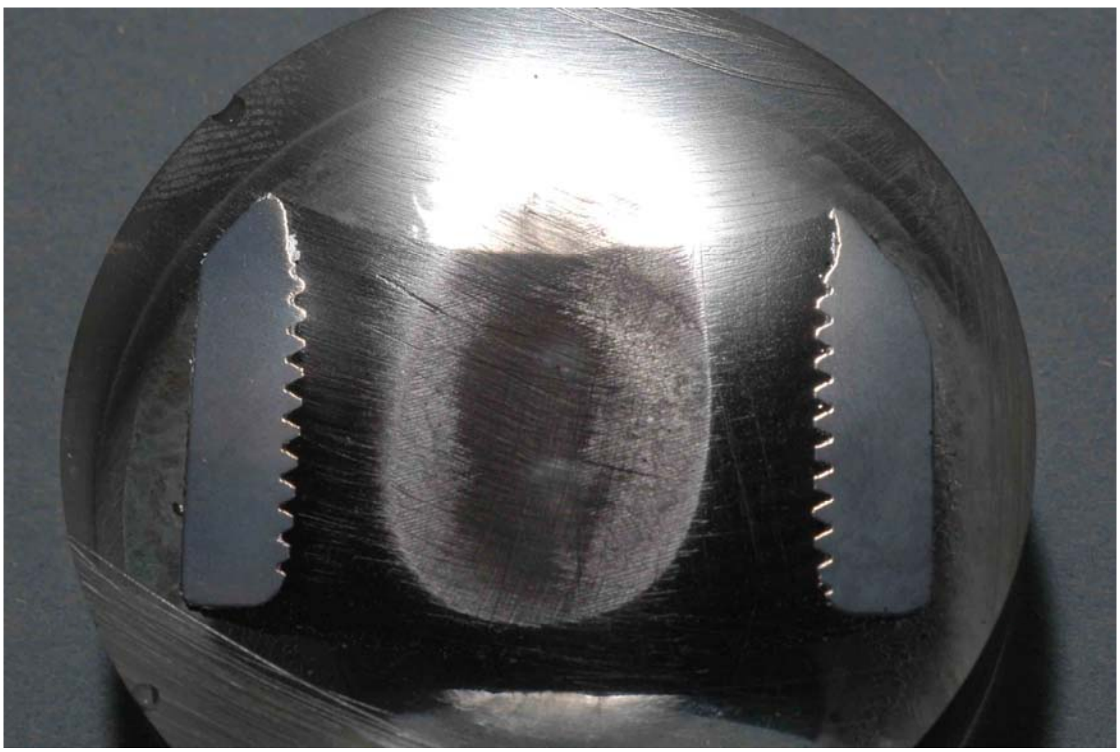


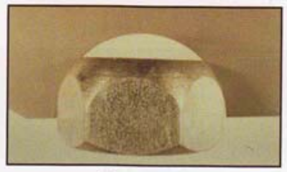
Figure 7-13. DSC_0001 LowRes.jpg

Figure 7-14. Users Guide p98 - Ball Seat Radius LowRes.jpg

WORN/DAMAGED BALL SEAT RADIUS

FASTENERS—OUT-OF-SERVICE CONDITIONS

APPEARANCE	The ball seat radius of either the inner or outer nut is worn or distorted and no longer spherical. A gap is apparent when checked with a radius or nut gauge.
PROBABLE CAUSE	Multiple re-use, low torque over prolonged operation, and worn/damaged wheel ball seat.



Acceptable

Unacceptable

Unacceptable

VMRS SYSTEM CODE (CODE KEY 31): 018

VMRS TECHNICIAN FAILURE CODE (CODE KEY 18): 44

ACTION

FASTENERS	Scrap the nut.
OPERATIONS	Ensure correct torque is applied and inspect other components of the assembly for damage and wear. Replace if necessary. Ensure proper installation procedures are followed.
VEHICLE	None

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Figure 7-15. Users Guide - p98 300dpi LowRes.jpg