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Metallurgical Failure Investigation to Determine the Cause of Recent 'Wheel-Offs' Limited to Great Dane Trailers

For

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1.0 Introduction

A recent 'wheel off' incident occurred on a Yanke Group of Companies trailer which was from a group of 50 Great Dane trailers manufactured in 2001. The 'wheel off' occurred at Kapuskasing .ON on March 2,2006. The incident prompted the Yanke Group to attain our services to provide data which could relate to a "wheel off" situation.

The trailer hubs use a 'Unimount' system, which uses a Conmet aluminum hub (part #150767). The hub contains 10 steel bolts, and 4 hub-piloting cogs which are an integral cast part of the hub.

The trailer which experienced the "wheel off" had been serviced and safetied on February 20, 2006 in Brampton ON. At this time, the wheels in questioned were removed and reinstalled, being torqued to 534 ft-lbs.

The temperature in Brampton on February 20, 2006 , when the wheels were installed, was in the range of -10°C to -6°C . The temperature on March 2 ,2006 in Kampuskasing, ON when the wheel off" occurred was in the range of -17°C to -7°C.

The specified torque for the bolts is 500 ft-lbs. It was found that the torque wrench used on February 22, 2006 was out of calibration by 7%. Consequently, the wheel nuts had been inadvertently torqued to 534 ft-lbs.

1.1 Sample Description and Method of Labeling

All bolts from the various hubs tested were arbitrarily assigned a number between 1 and 10, ascending in a counter-clockwise rotation as viewed from the outside of the wheel assembly.

Assemblies consisted of:

- 2 rims
- 1 brake drum
- 1 Conmet aluminum hub
- 10 flanged cap nuts

2.0 Environmental Torque Audit Testing

Torque auditing was conducted on a complete **new** wheel assembly which included:

- 2 new wheel rims,
- 1 new brake drum
- 1 new Conmet aluminum hub (part #150767)
- 10 new Euclid flanged cap nuts (part #E-6000A)

The assembly was secured to the floor during the application and auditing of the bolt torque using 4 custom-made clamps. An overall view of the wheel assembly secured inside the environmental chamber is shown in Figure 1. A closer view of the assembly is provided in Figure 2.

Two torque auditing methods were used to measure the torque of the cap nuts following the duration of each environmental test. These methods were the:

1. Crack-Off Method – this is the torque value required to loosen the nut when a loosening torque was applied.
2. Marked Fastener Method – the fastener was marked to a reference with respect to the wheel assembly and then loosened by about 30° of rotation. The nut was then re-tightened to its initial position at the mark. The torque required to return the fastener to its initial position was recorded.

2.1 Test #1: All New Components Assembled at 20°C & Then Torque Audited at -35°C

The first torque auditing test was conducted using an initial temperature of approximately 20°C (room temperature) at which the wheel assembly was assembled and tightened. A torque of 535 ft-lbs was applied to each of the 10 cap nuts of the assembly. This torque value was selected and used as this was the torque that had been applied to the cap nuts of the wheel which had experienced a 'wheel-off' on March 2, 2006. The specified torque for this wheel assembly is 500 ft-lbs.

The wheel assembly was left overnight to chill within the cold chamber to approximately -35°C. Each of the 10 cap nuts was then audited to determine the torque of each of the nuts after a temperature drop of approximately 55°C. The data obtained from Torque Audit Test #1 is provided below.

		Torque Audit Test at -35°C	
Bolt #	Initial Assembly Torque Applied at 20°C (ft-lbs)	Crack-Off Method (ft-lbs)	Marked Fastener Method (ft-lbs)
1	535	> 600	> 600
2	535	625	625
3	535	no data	630
4	535	650	650
5	535	660	> 590
6	535	670	680
7	535	650	595
8	535	610	600
9	535	700	700
10	535	662	> 600

Table 1: Torque data from Torque Audit Test #1: All new components. Assembled at 20°C & then the Torque was Audited at -35°C

The torque audits, completed at a temperature of -35°C, found that the torque of **ALL** the cap nuts had ***increased***. The audited torque values were found to range between 595 ft-lbs and 700 ft-lbs. This reflects an **average increase of approximately 19% in torque** with respect to the initial applied torque of 535 ft-lbs.

2.2 Test #2: All New Components Assembled at -35°C & Then Torque Audited at 20°C

Following the results of Test #1 which indicated a definite *increase* in audited torque values following a significant decrease in temperature, Test #2 was conducted to determine the effect of an *increase* in temperature, and the resulting affect on the torque applied to the cap nuts.

Prior to assembly, all components of the wheel assembly were allowed to chill to a temperature of approximately -35°C. The assembly was then put together and each of the ten cap nuts were torqued to a value of 500 ft-lbs, which was the specified torque for the wheel assembly.

The wheel assembly was then removed from the environmental chamber and was allowed to warm up to room temperature over a period of approximately 4 hours. The surface temperature of the outside rim adjacent to the bolts and cap nuts was measured to be 19.1°C. The data obtained from Torque Audit Test #2 is provided below.

		Torque Audit Test at 19°C	
Bolt #	Initial Assembly Torque Applied at -35°C (ft-lbs)	Crack-Off Method (ft-lbs)	Marked Fastener Method (ft-lbs)
1	500	275	340
2	500	295	290
3	500	285	275
4	500	265	290
5	500	290	310
6	500	270	325
7	500	320	305
8	500	260	275
9	500	250	300
10	500	280	280

Table 2: Torque data from Torque Audit Test #2: All New Components. Assembled at -35°C & the then Torque was Audited at 19°C

It was found that the torque of all the cap nuts had ***significantly decreased*** with an increase of the temperature of the wheel of approximately 55°C. The audited torque values were found to range between 250 and 340 ft-lbs. The temperature rise of 55°C caused the nuts to exhibit an **average decrease in torque of 211 ft-lbs, or a 42% decrease** from the original torqued value of 500 ft-lbs.

Comment: Information obtained from the Yanke Group indicated that the 'wheel off' occurred as the truck was slowing down as it was entering a town. Braking during deceleration would generate a significant amount of heat. Heat would also be generated within the bearings of the wheel due to friction. The actual temperatures of the wheel hub and bolts at the time of the 'wheel-off' are unknown, but would be expected to be significantly greater than 20°C. Thus, if the wheels were torqued on the trailer at a sub-zero temperature, and if the hub assembly and cap nuts were subsequently heated by braking during operation, the cap nuts would have experienced a significant reduction in torque.

3.0 Dimensional Analysis

A dimensional analysis of bolts from the hub which experienced the wheel-off, and from a new hub was conducted to determine if the bolts which were involved in the wheel off had indicated a noticeable degree of stretch.

It should be noted that the bolts which were from the NEW hub were **significantly** different than those which were removed from the 'wheel-off' hub.

NEW Bolts

Identification on head of bolt: "N 102190 10.9"
Length: 5.345 – inches
Number of turns: 60

Wheel-Off Bolts

Identification on head of bolt: "N 102188 10.9"
Length: 4.475 – inches
Number of turns: 40

Important Note:

The NEW bolts were 0.870 inches longer.

Making the assumption that the original manufactured thread pitch was equal between the two styles of wheel bolts, the thread pitch of 2 NEW bolts and 2 'wheel-off' bolts was measured.

The results of the dimensional analysis is shown below:

Bolt #	Thread Pitch (Threads per Inch)
NEW #3	16.877 ±0.015
NEW #7	16.880 ±0.015
NEW Average:	16.8785
Wheel Off #3	16.869 ±0.022
Wheel Off #7	16.864 ±0.022
Wheel Off Average:	16.8665

Table 3: Dimensional Measurement of Threads to Determine Stretch of Wheel-Off Bolts

The measurement data indicated that the Wheel-Off bolts had a marginally lower thread pitch. With the assumption that both threads were manufactured equally, a smaller thread pitch would indicate that the bolt had been stretched.
The average difference in thread pitch was:

16.8785-16.8665 = 0.012 TPI, or **0.0711%**

Including the inherent error in the measurements, the greatest possible stretch of the 'wheel-off' bolts was calculated to be:

(16.8785+0.015) – (16.8665-0.022) = 0.049 TPI or 0.290%

Note: The error in the dimensional analysis of the thread pitch between the NEW and 'wheel-off' bolts overlap, and thus could also indicate no change in Thread Pitch, and hence ***no stretch*** of the 'wheel-off' bolts.

The calculations for the worst case scenario for permanent deflection / stretch from the dimensional analysis were then compared to the plots of stress vs. strain from the tensile results of the 'wheel-off' bolts.

To induce a permanent stretch of 0.29%, the bolt would have had to have been subjected to a stress 2000 psi greater than the yield strength of the bolt (approx. 150,000 psi) This would equate to a stress level of 101.3% of the bolt's yield strength, which could be a very marginal excessive force.

4.0 Tensile Testing

4.1 'Wheel-Off' Bolts

Tensile tests were conducted on Bolts #1, 5 & 9 from the hub which had experienced the 'wheel off' on March 2, 2006. The tensile tests were conducted to determine if the bolts used in the 'wheel off' hub exhibited sufficient and specified tensile properties. The results of the tensile test were as follows:

Bolt	Yield Strength (psi)	Ultimate Tensile Strength (psi)	Elongation (%)
#1	151,149	163,294	13.6
#5	154,320	166,504	12.1
#9	145,480	158,827	12.2

Table 3: Tensile Properties for 3 Bolts Extracted from the Wheel Hub Which Experienced a Wheel-Off on March 2, 2006

4.2 Tension Test of *New* Bolts

Bolt	Yield Strength (psi)	Ultimate Tensile Strength (psi)	Elongation (%)
#1 NEW	163,400	175,600	17.6
#5 NEW	162,300	174,600	16.0
# 9 NEW	161,400	173,400	15.9

Table 4: Tensile Properties for 3 NEW Bolts

The samples of the NEW bolts exhibited slightly higher yield and ultimate tensile strength values when compared to the samples of the bolts which had experienced the 'wheel-off'. Comparing the NEW and 'wheel-off' bolts, the 'wheel-off' bolts exhibited on average a 7.4% lower yield strength and 6.7% lower ultimate tensile strength.

4.3 Rockwell Hardness Testing to Verify Variation in Hardness

Rockwell hardness testing was conducted on three samples of the NEW and 'wheel off' wheel bolts to verify the small variation in tensile strengths observed between the NEW and 'wheel off' wheel bolts.

<u>Note:</u> The hardness of a material is proportional to its Tensile Strength

The tests were conducted on a transverse cross section made through the grips of the 6 tensile specimens as listed in Sections 4.1 & 4.2. The results of the hardness testing are tabulated below.

	Rockwell C Hardness Results (HRC)					
	1	2	3	4	5	Average
NEW #1	37.00	35.90	37.70	40.50	35.30	37.28
NEW #5	36.70	36.80	40.10	38.20	38.50	38.06
NEW #9	36.90	41.00	38.80	37.80	40.20	38.94
NEW Average						38.09
WO #1	37.40	39.10	35.70	35.40	34.70	36.46
WO #5	38.90	36.70	36.20	37.80	38.40	37.60
WO #9	40.00	34.90	34.10	35.70	36.00	36.14
WO Average						36.73

Table 5: Rockwell C Hardness Results for the 6 Tensile Specimens From 'NEW' and 'Wheel Off' Bolts

The results showed that the NEW wheel bolts had an average hardness of 38.1 HRC, whereas the wheel bolts involved in the 'wheel off' were found to have a lower average hardness of 36.7 HRC. The 'wheel off' bolts exhibited a 3.7% lower hardness than the NEW bolts, confirming that the ultimate tensile strength of the 'wheel-off' bolts should be lower than the NEW bolts.

5.0 Discussions

5.1 Torque Auditing

Torque auditing testing over decreasing and increasing temperature differentials revealed two complimentary observations:

i) a wheel assembly, initially torqued at room temperature, and subsequently exposed to colder temperatures resulted in an ***increase in torque*** of the fasteners.

ii) a wheel assembly initially torqued at cold temperatures and subsequently exposed to warmer temperatures resulted in a ***decrease in torque*** of the fasteners.

The specific mechanism or phenomenon which is responsible for this effect is not clear in this system, but may be attributed to a few factors.

1. **Material Properties / Coefficients of Thermal Expansion** - *Aluminum and Steel have drastically different coefficients of thermal expansion.* The coefficient of thermal expansion for steel is typically 11-12 μm/m•K whereas the coefficient of thermal expansion for aluminum is nearly twice as large, being approximately 21 μm/m•K.

2. **Friction** – Bolt torque applied is generally predominantly to overcome frictional forces between mating surfaces of the bolt and nut components. Changes in temperature may alter the friction coefficients between the mating surfaces, and thus altering the perceived torque of the wheel bolts.

5.2 Tensile Testing

Tension testing of 3 NEW bolts and 3 'wheel-off' bolts indicated that the 'wheel-off' bolts had an approximate 7% lower yield and ultimate tensile strength. Hardness testing of the same samples indicated an approximate 4% lower hardness for the 'wheel-off' bolts as compared to the NEW bolts.

This is a very small margin of difference between the two sets of wheel bolts. It is unlikely that this minor change in mechanical properties would have contributed to the loosening of the fasteners on the wheels which experienced the 'wheel-off'.

6.0 Conclusions

1. A torque audit testing found that:

   i) a wheel assembly, initially torqued at room temperature, and subsequently exposed to colder temperatures resulted in an ***increase in torque*** of the fasteners.

   ii) a wheel assembly initially torqued at cold temperatures and subsequently exposed to warmer temperatures resulted in a ***decrease in torque*** of the fasteners.

2. Dimensional measurements of NEW and 'wheel-off' bolts indicated a very small margin in thread pitch which was smaller than the inherent measurement error. This would indicate either no stretching of the 'wheel-off' bolts, or a very small (0.29%) stretch of the bolts.

3. Tension testing indicated the 'wheel –off' bolts had an approximate 7% lower yield and tensile strength, and a 4% lower hardness value, as compared to the NEW bolts.

   The small difference in strength and hardness of the 'wheel-off' bolts could be attributed to manufacturing of the different batch and style of wheel bolt.

   The difference in mechanical properties of the steel would have not likely contributed to the loosening of the fasteners of the wheel.

4. In conclusion, the probable cause of the 'wheel-off' can be attributed to inadvertent torquing of the wheel nuts at sub-zero temperatures. The wheels and nuts will warm up during braking, with a positive temperature differential to cause of significant **decrease in applied nut torque in the range of 42%.**

   This unexpected decrease in applied nut torque could be held responsible for the 'wheel-off'.