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A Mechanism for the Formation of Shells on Freight Car Wheels

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Summary

This digest reports on an investigation relating measured surface tractions on wheel tread to surface cracking, proposes a hypothesis as to how this cracking can progress to high impact wheels (HIW), and proposes a way forward to an improved truck design.

The formation of two crack bands on HIWs is related to measured lateral forces acting on the wheels, resulting in the conclusion that lateral forces may be a root cause for crack band formation.

Transportation Technology Center, Inc. (TTCI) presents a hypothesis for the progression of these crack bands to the break-out of material from the wheel tread to form HIWs, suggesting that lateral forces are, in turn, a root cause of HIWs. A way forward to the verification of this hypothesis and a solution to HIWs is proposed.*

TTCI was tasked to develop a conceptual freight car truck design to address current problems with the performance of current truck designs identified through the Association of American Railroads' Strategic Research Initiatives Program.

A major problem identified is that of HIWs. HIWs are a major cost factor in car operation as well as a contributor to increased track costs and derailments. Car repair billing data shows that more than 400,000 wheels were removed in 2008 for HIWs in the North American industry, resulting in an estimated cost of more than \$500 million in 2008.

* Further investigations into the root cause for these tractions is the subject of future *Technology Digests*.



INTRODUCTION

TTCI was tasked to develop a conceptual freight car truck design to address current problems with the performance of current truck designs identified through the Association of American Railroads’ Strategic Research Initiatives Program.

A major problem identified is that of HIWs. HIWs are a major cost factor in car operation as well as a contributor to increased track costs and derailments. Car repair billing data shows that more than 400,000 wheels were removed in 2008 for HIWs in the North American industry resulting in an estimated cost of more than \$500 million in 2008.

Wheel shells account for approximately 50 percent of all removals for HIWs. Wheel spalls account for the remainder through skidded wheels, caused mainly by unreleased hand brakes.

The problem of unreleased hand brakes will probably be resolved through one or a combination of improved operations or improved hand brakes or hand-brake status indication (TTCI video: “Please Release Me...Let me Roll,” rev. 2007).

The incidence of wheel shells has been attributed to thermal mechanical shelling (TMS), considered a consequence of both overheated wheels and rolling contact fatigue (RCF). It is possible that both of these factors can be addressed through improved truck brake rigging and suspension design; this requires an improved understanding of the mechanism for the formation of shells on wheels.

This digest reports on an investigation relating measured surface tractions on wheel tread to surface cracking, proposes a hypothesis as to how this cracking can progress to HIWs, and also proposes a way forward to an improved truck design.

LITERATURE REVIEW

An inspection of HIWs has suggested that of these wheels:¹

- Approximately 50 percent was damaged by spalling, which is related to unreleased hand brakes.
- The other 50 percent was attributed to TMS, a consequence of overheated wheels and RCF.

This inspection also quantified the surface damage on these wheels, revealing (Figure 1):

- The presence of two bands of cracks on either side of the tape line on the wheel tread; the band on the field side of the tape line is the most dominant.
- Pieces of the wheel tread break-out between the two crack bands to form HIWs.

A survey of wheel impact load detector (WILD) data suggests that HIWs are more prevalent on the lead wheelsets of trucks and occur on routes with long and steep grades where wheels can become overheated.²

It should be noted that routes with long and steep grades generally also have a high degree of curvature. This, together with the indication that lead wheelsets are most affected, suggests that truck steering plays a major role in the formation of HIWs.

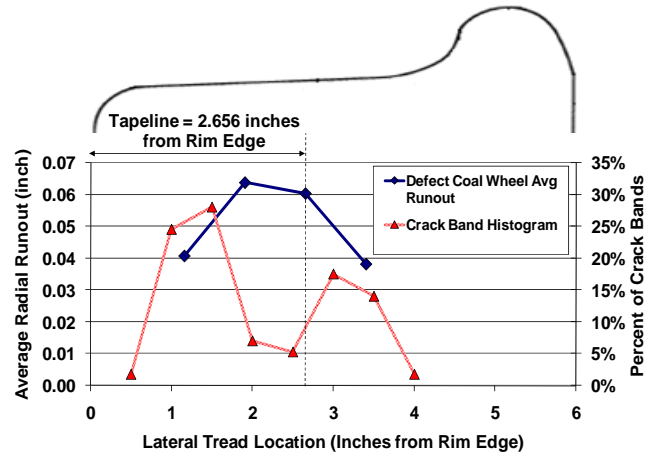


Figure 1. Location of fatigue Damage on Inspected Wheelsets

An analysis of instrumented wheelset (IWS) data, relating wheel traction forces to the shakedown diagram predicting RCF, suggests that RCF will predominate.³

- On the lead wheels of loaded cars when contacting the low rail
- On a small percentage of the distance traveled by a car, and particularly in curves of 4 degrees or sharper
- On a limited number of unique curves, accounting for much of the damage

In summary, the literature suggests that poor truck curving plays a role in the formation of fatigue damage but that the relationship between traction forces and tread damage requires further investigation.

THE RELATION BETWEEN SURFACE TRACTION AND CRACK BANDS ON THE WHEEL

A more detailed analysis of the IWS data was made for a section of 8-degree curve and tangent track identified as possibly being instrumental in the formation of RCF.³ The magnitude of the net traction forces on the lead wheel of the lead truck of a 286,000-pound coal car contacting the low rail was plotted against the lateral position of the center of the contact patch on the wheel tread of the IWS. Figure 2 shows this relationship superimposed on the incidence of the crack bands derived from Figure 1.

Reference was then made to the shakedown diagram developed by Johnson (Figure 3).⁴ For a 286,000-pound car, given assumed wheel and rail profiles, the value for P_0/K is approximately 3. The shakedown diagram suggests that any surface tractions (tangential force/normal force) greater than 0.39 (or when the tangential force is approximately 13,250 pounds for a 286,000-pound car) may have a propensity for developing RCF in both the wheel and the rail.

Measured tractions on the IWS (Figure 2), suggest that tangential forces that exceed 13,250 pounds on the wheel tread are coincident with the lateral positions of the crack bands on the wheel tread. Care must be taken with interpreting the forces for the second force peak close to the wheel flange.

These forces may be due to flange contact or to lateral components of the vertical load as a result of the angle of the contact patch to the horizontal in the vicinity of the flange fillet; consequently, the net traction forces may not be a large as indicated with less of a propensity for shakedown.

The tractions on the field side of the tape line are certainly a result of traction forces. These forces are larger and more prevalent than those to the flange side of the tape line; coincident with the observed greater intensity of the cracks on the field side of the wheel tread. This crack band is almost certainly related to the measured traction forces.

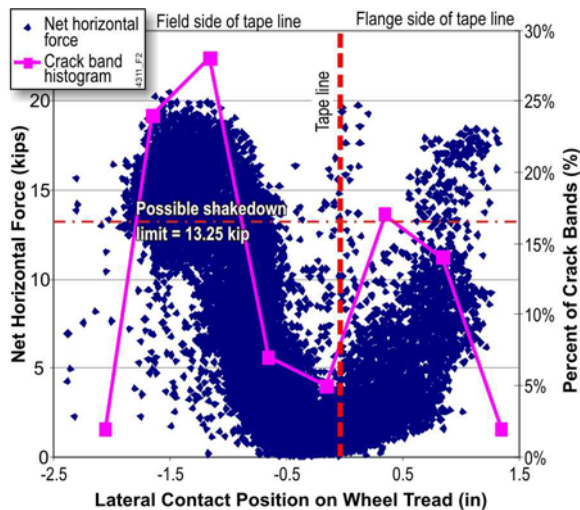


Figure 2. Relation between Measured Surface Traction and Observed Crack Bands on the Wheel

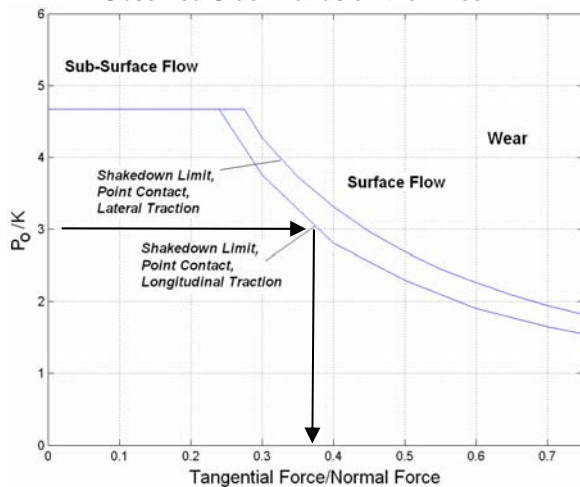


Figure 3. Shakedown Diagram

Much work still needs to be done to:

- Relate the shakedown diagram to wheel and rail materials used in North America as well as relating load cycles, wheel temperatures and traction amplitudes to crack formation
- Account for wear

Nevertheless, there is a sufficiently strong association between the formation of surface cracks and traction forces to suggest that tractions are a root cause for surface cracking.

This does not, however, sufficiently explain the relationship between the crack bands that are formed and the break-out of tread material to form HIWs, particularly as the crack bands are not coincident with the band on which material break-out occurs. This is the subject of a hypothesis presented next.

HYPOTHESIS FOR THE PROGRESSION TO BREAK-OUT OF MATERIAL ON THE WHEEL TREAD BETWEEN THE CRACK BANDS

Consider that cracks have formed in two bands on the wheel tread as a result of high tractions as discussed earlier. Now answer the following three questions:

1. Why should the cracks progress further into the wheel tread?
2. Why should the cracks move laterally toward the tape line to join-up and cause the tread to break-out to form a HIW?
3. Would tread shelling occur without the formation of surface cracks?

There seems to be two mechanisms associated with contact mechanics that may assist in answering these questions:

The locus of the maximum shear stress in the wheel:

Hertz contact without surface tractions ($\mu=0$) results in a maximum shear stress beneath the surface of the contacting bodies (Figure 4).

Increasing traction forces drive the position of the maximum shear stress to the surface (Figure 5); this occurs at ratios of tangential / normal force greater than 0.3.

Consequently, there is a relationship between the depth beneath the contact patch at which the highest stresses occur and the traction forces shown in Figure 2. This relationship can be used to produce a locus of the regions of highest stress for a particular history of loading (Figure 6).

This locus then suggests:

- Surface crack initiation in the bands observed can be driven deeper into the wheel because of load cycles of lower traction and similar contact patch position indicated in Figure 2, resulting in maximum shear at greater depth.
- At a depth approaching that of the maximum shear for zero traction (0.14 inch or 3.5 mm) the deeper cracks can progress towards the taping line from either crack band.
- Resulting cracks can cause break-out of the tread surface to a depth of approximately 0.14 inch or 3.5 mm.

Alteration of the Hertzian stress field through crack formation:

The Hertz stress field assumes contact between two, semi-infinite half-spaces (SIHS).⁵ The material of these SIHS supports the highly-stressed material under the contact patch and enables the wheel and rail material to support high wheel loads. Obviously, both wheel and rail only approximate the model described. TTCI suggests that once extensive cracking occurs, the wheel does not react as a SIHS, but, in terms of the theory of elasticity, exhibits a shape similar to that shown in Figure 7.

This shape has an effective convex curvature in the vicinity of the taping line and thus a higher effective maximum shear stress under the taping line. Consequently, subsurface crack formation and propagation is more likely than in a wheel that does not have crack bands.

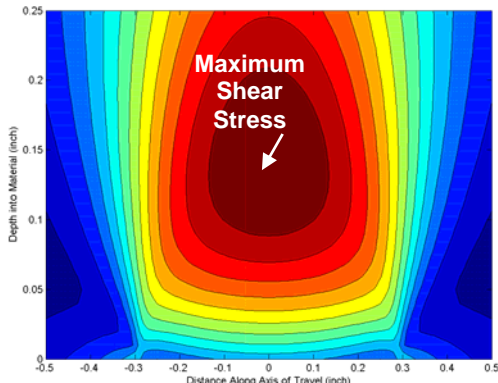


Figure 4. Position of the Maximum Shear Stress for Zero Traction

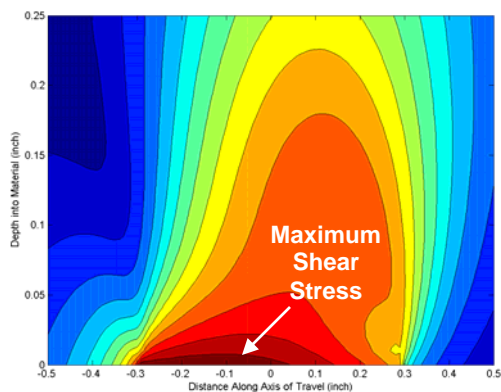


Figure 5. Position of the Maximum Shear Stress for a Traction >0.3

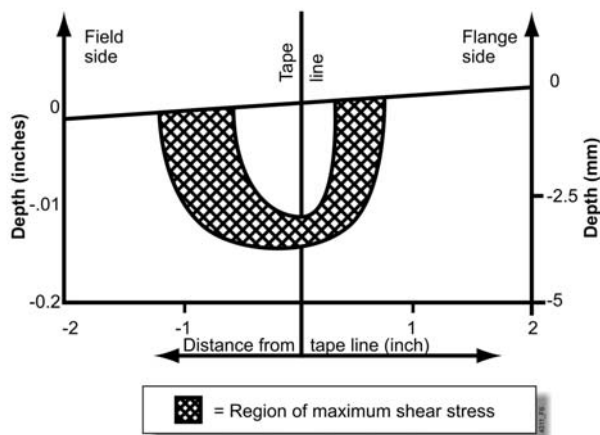


Figure 6. Presumed region of Maximum Shear Force beneath the Wheel Tread

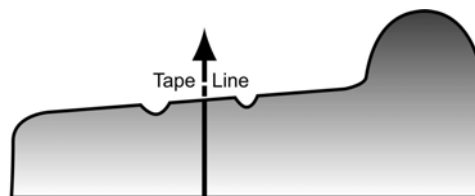


Figure 7. Equivalent Shape of the Wheel as a Result of Tread Cracks

CONCLUSIONS

- The observed bands of cracks on wheel treads of HIWs on either side of the taping line are probably formed by the action of high traction forces; the tractions shown in the band closest to the flange may not be as large as indicated because of flange or flange fillet contact.
- The root cause for high traction forces is the subject of future *Technology Digests*.
- A hypothesis is presented that suggests the progression from the formation of crack bands to the break-out of material from the tread surface; it is concluded that the formation of these crack bands facilitates material break-out.
- High tractions on the wheel tread are considered a root cause for 50 percent of HIWs.
- An understanding of the root cause of the formation of HIWs will assist in developing an improved truck design.

RECOMMENDATIONS

- Produce a shakedown diagram for North American wheel steels.
- Define the relationship between tractions, RCF and wear for North American freight conditions.
- Establish the relationship between tractions and crack formation for North American wheel steels.
- Use a finite element model of the wheel based on fracture mechanics to verify the hypothesis that surface tractions are a root cause for HIWs.
- Establish the root cause of the observed tractions using the IWS and relate it to (1) truck suspension design and (2) wheel/rail friction control capabilities

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