

RECENT RESEARCH TO BETTER UNDERSTAND WHEEL RIM AXIAL RESIDUAL STRESS AND VERTICAL SPLIT RIM WHEEL FAILURES

November, 2012



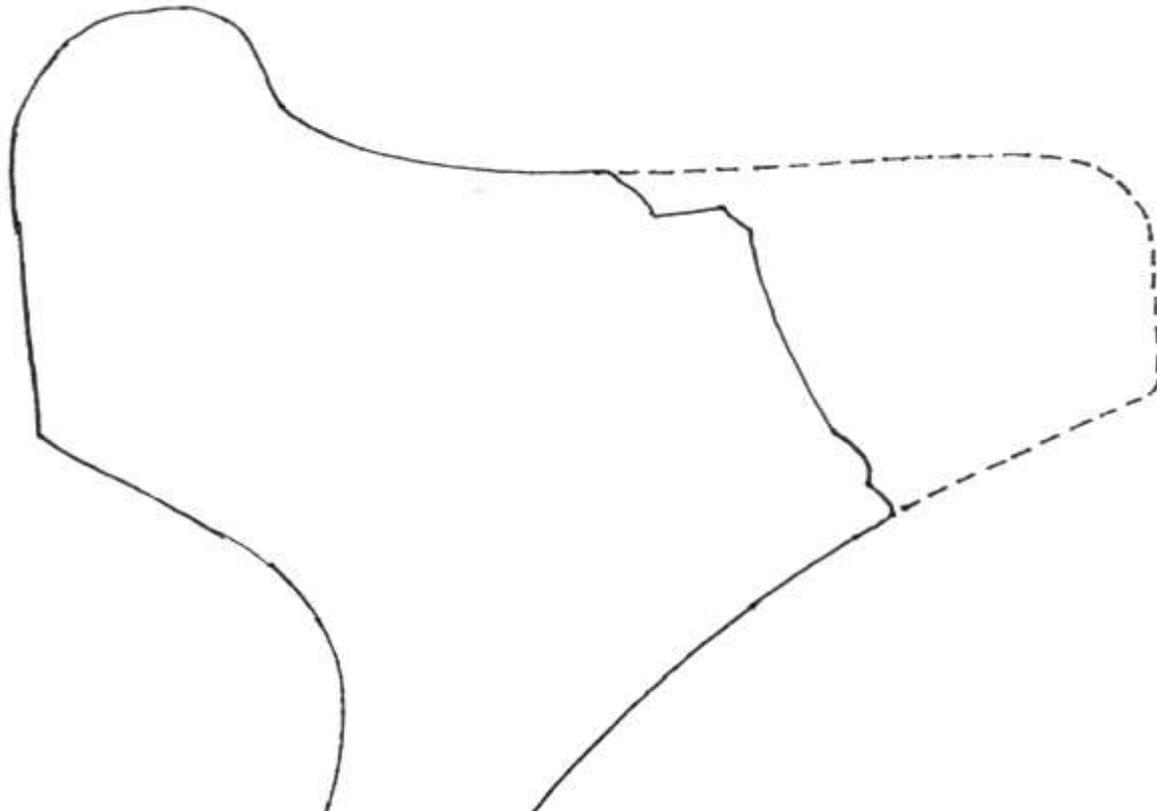
Amsted Rail bringing heavy haul freight rail transportation to the World

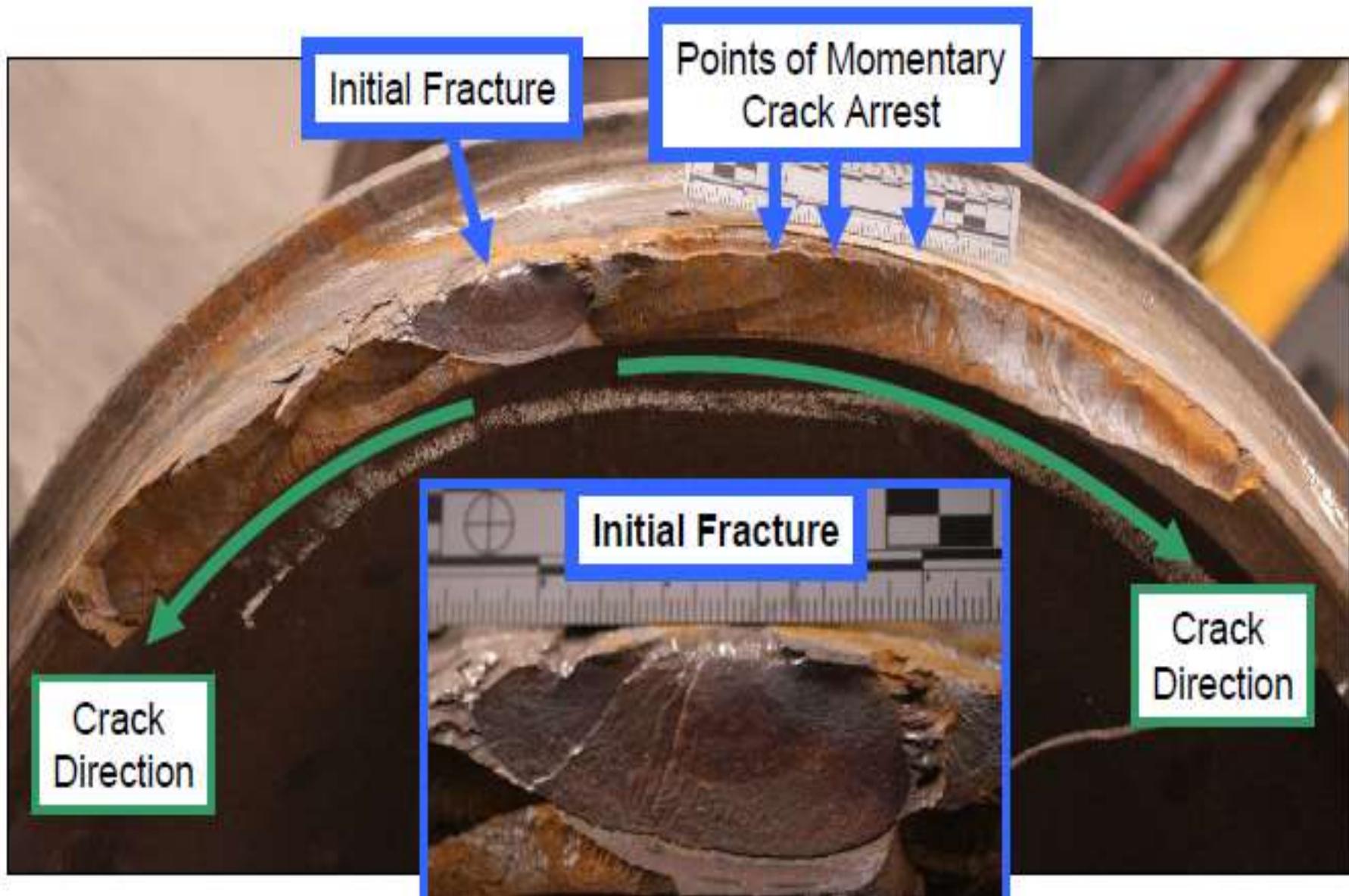
Presentation Outline

- Vertical Split Rim (VSR) Wheel Failures
- Background Information
- The VSR Puzzle
- Drop Hammer Research Efforts
- Residual Stress Measurements From the Tread Surface
- Radial Slices – X-ray Diffraction
- Axial Residual Stress – At & Away From Failure
- Out-of-round and Axial Residual Stress
- Wheel Truing and Axial Residual Stress

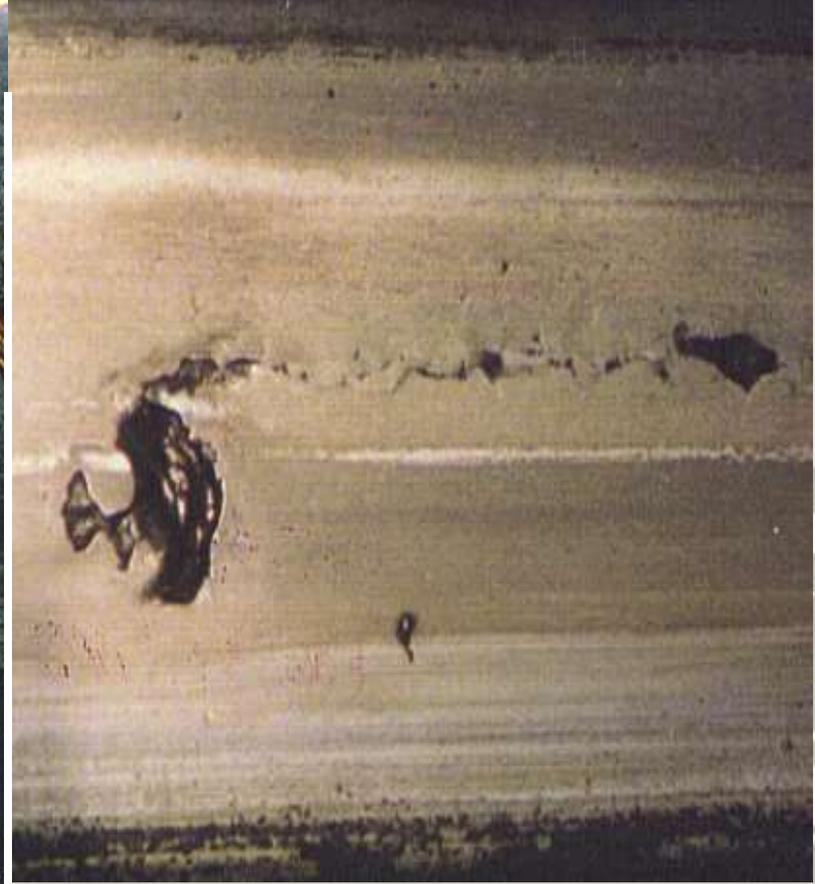
Vertical Split Rims

- VSRs start almost exclusively at tread damage
- Typically, a circumferential section of the front rim face breaks off, and wheel can drop into gage





Tread Damage



Observations on VSRs by Dick, et al. on 68 wheels

- VSRs length is typically 15 cm to entire circumference
- Typically VSR is 25 to 70 mm from wheel's front rim face
- 263K GRL and 286K GRL cars have similar number of VSRs
- Covered hoppers had most VSRs with 15/17 on B end
- 62/68 wheels were 36" or 38", only 6/68 were 33"
- Not all were thin rimmed wheels
- Most VSRs had hollow tread wear
- VSRs more common in winter months
- Most VSRs were impacting before failure
- Both forged and cast wheels have VSRs

The VSR Puzzle

- Historical VSR failure analysis did not identify conclusive root cause(s)
- No material abnormalities
- Hardness OK
- Cleanliness normal
- Microstructure/transformation - normal
- No evidence of thermal overload
- TTCl microcleanliness tests - 28/30 VSRs passed
- Drop hammer, 30,000+ impacts – no failure

VSR Puzzle - UT and Chemistry

- Griffin collects and records ultrasonic signal data for all wheels tested in plants after manufacturing.
- Max UT signal data noted during testing was retrieved for 26 VSR wheels.
- Distribution of signals for VSR wheels was the same as for 24,000 normal production wheels from 2006.
- Also S and P values for a group of VSR wheels was less than the average S and P values for production wheels.
- MnS inclusions directly related to Sulfur content.

Drop Hammer Research Efforts

- Tried to create a VSR in lab setting
- Found tread damaged wheelsets that could be susceptible to impact damage
- Used ASF-Keystone drop hammer, Camp Hill, PA, on wheel tread to simulate service impact load
- Goal – Determine critical impact load and load location
- Tread damaged wheel hit more than 31,000 times in a drop hammer with 250-300 kips impact load
- Did not create VSR but wheel rim was severely deformed

**ASF Keystone
drop hammer can
impart dynamic
loads up to 2,000
kips – well in
excess of 200 kips
occasionally seen
in service.**



ASF-Keystone
Drop Hammer
was modified
to accept a
wheelset for
impact testing



Rim Edge Deformation At 28,500 Drop Hammer Hits



Drop Hammer & FEA Research

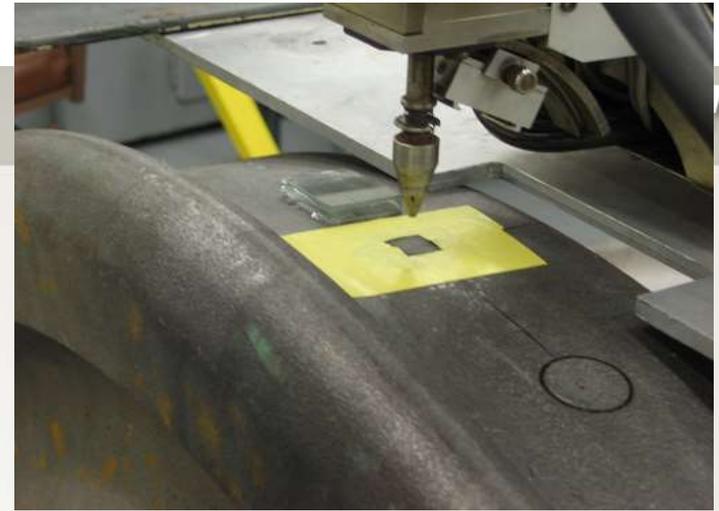
- 54 miles of service given wheel circumference
- Cracks noted below tread damage
- FEA work with condemnable wheel rim thickness 7/8", and 100 kip point load 1" from front rim face showed 28.5 ksi axial stress at tape line
- Also the hoop stress at the front rim face to plate fillet was 28.8 ksi - this helps to explain why VSR's propagate the way they do, especially under high impact loads

Residual Stress Measurements from the Wheel Tread Surface

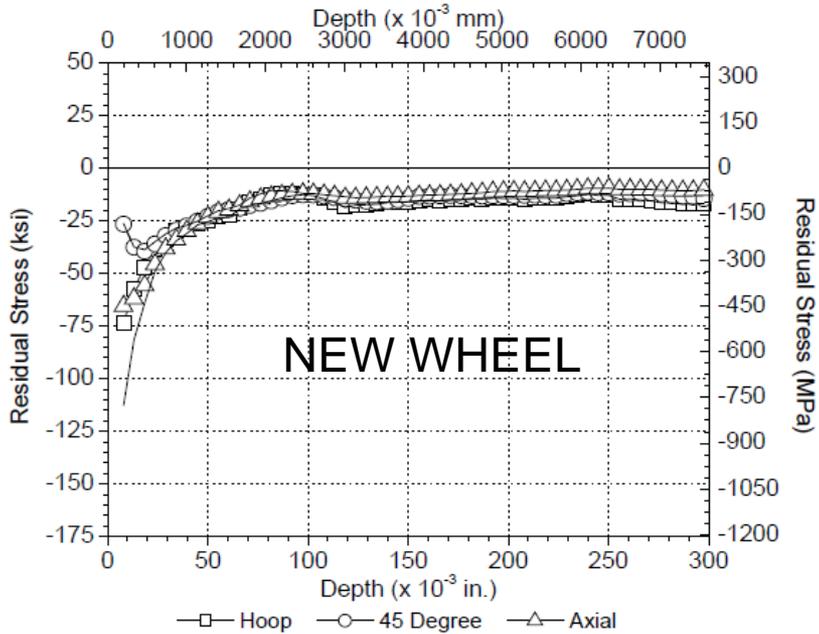
- Contacted Lambda Research in Cincinnati
- Started with x-ray diffraction and core drilling from the tread surface
- Axial residual stress measurements (not hoop, not radial)
- Initial testing to see if there were differences between new and VSR wheels



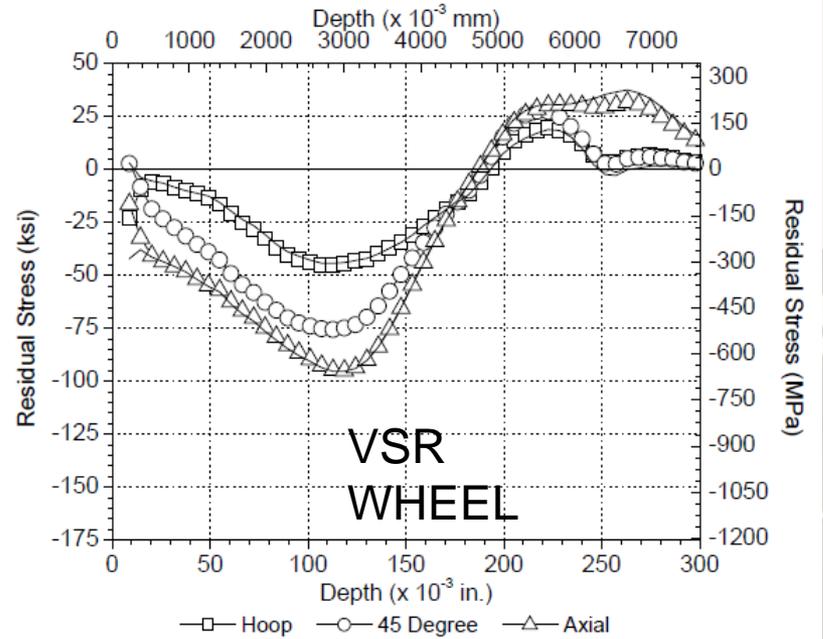
Core
drill
from
tread
surface



RESIDUAL STRESS DISTRIBUTION



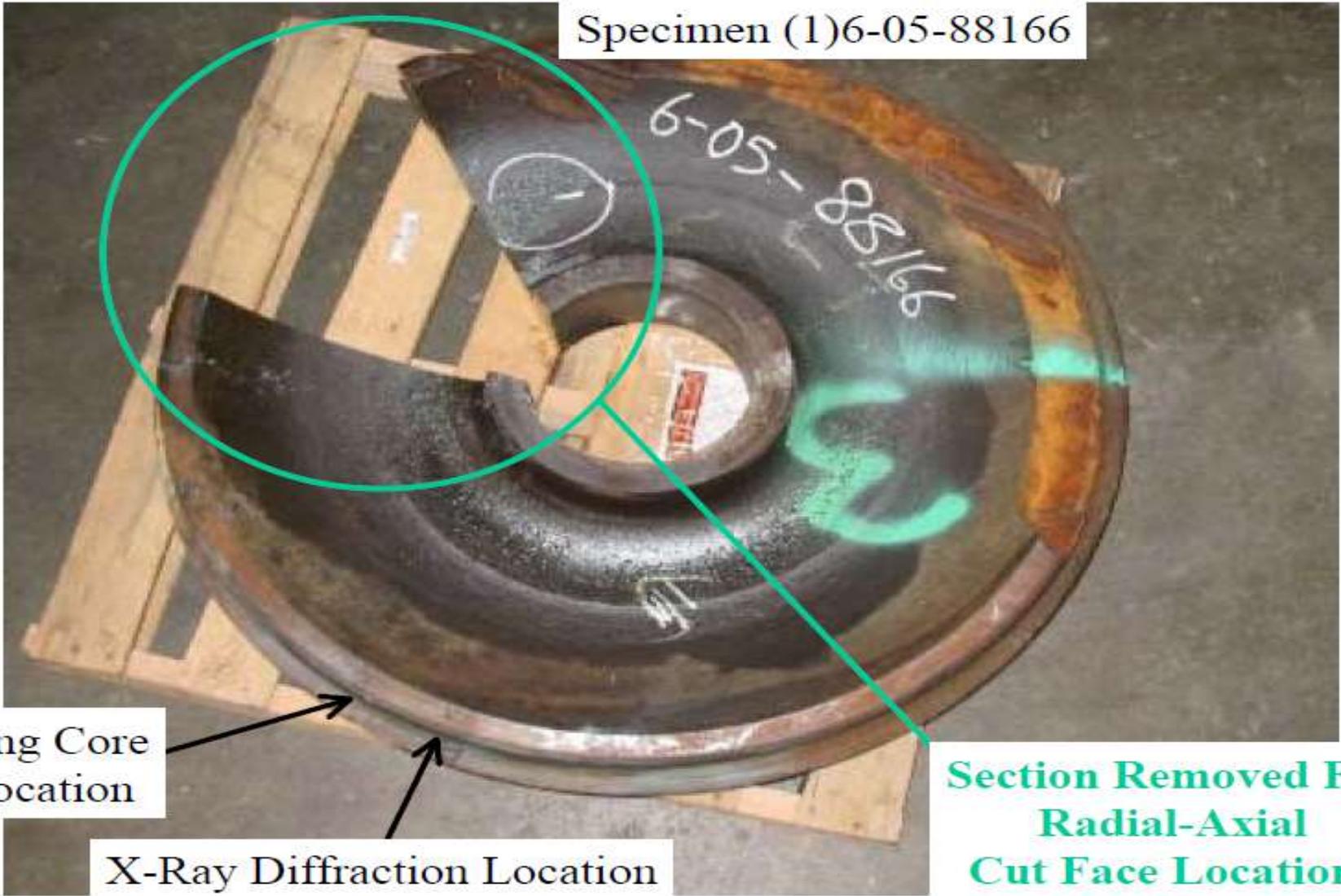
RESIDUAL STRESS DISTRIBUTION



Radial slices – X-ray diffraction

- Core drill and x-ray diffraction from tread surface only provided residual stress measurements up to a depth of 1/3 inch
- Needed to determine stresses at locations below tread surface in the wheel rim
- Asked Lambda Research for assistance
- Focus on axial residual stress measurements
- Did we need to strain gauge wheel every time before cutting slices, or can relaxation effect be ignored?
- Also used American Stress Technologies, Pittsburgh

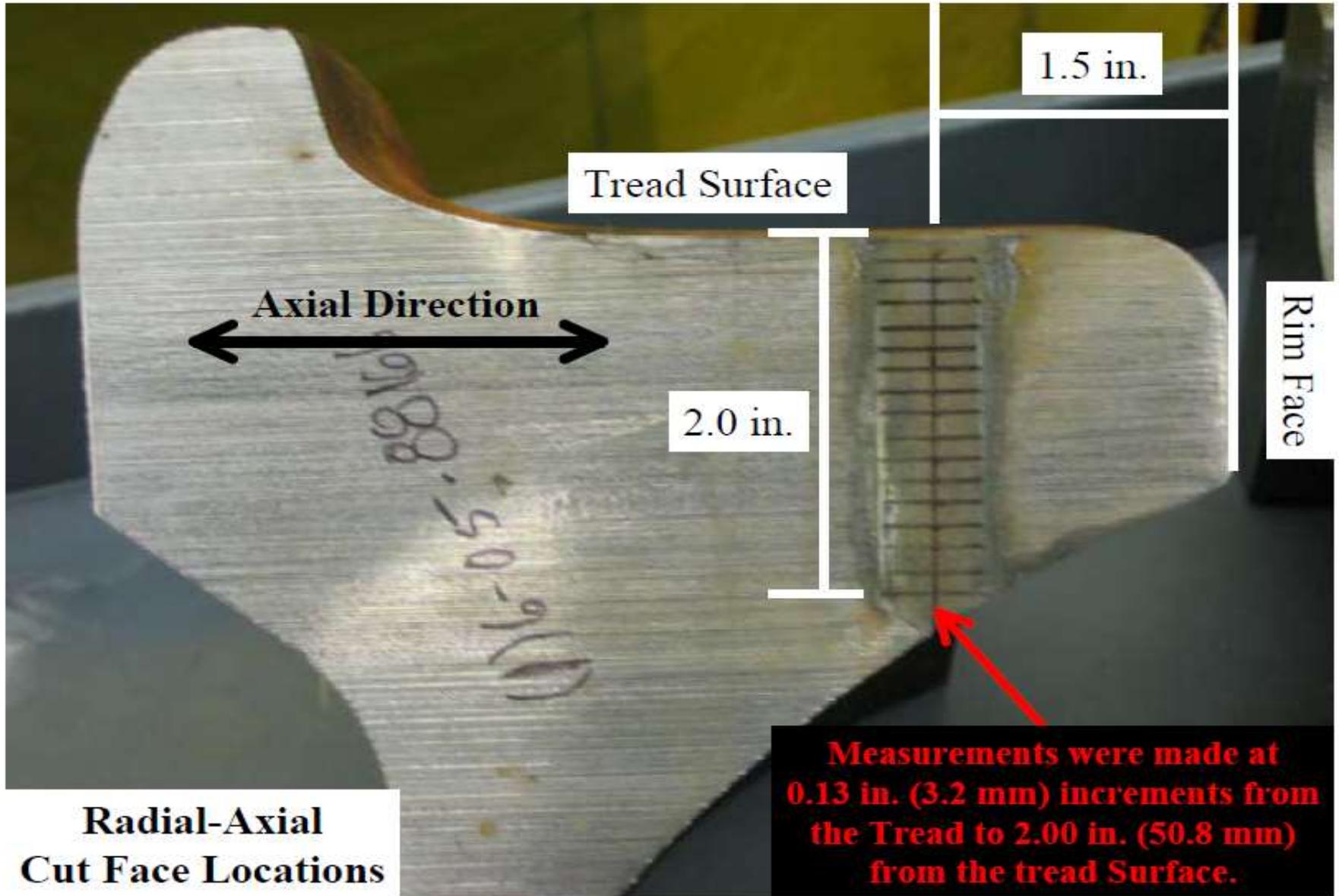
Specimen (1)6-05-88166



Ring Core Location

X-Ray Diffraction Location

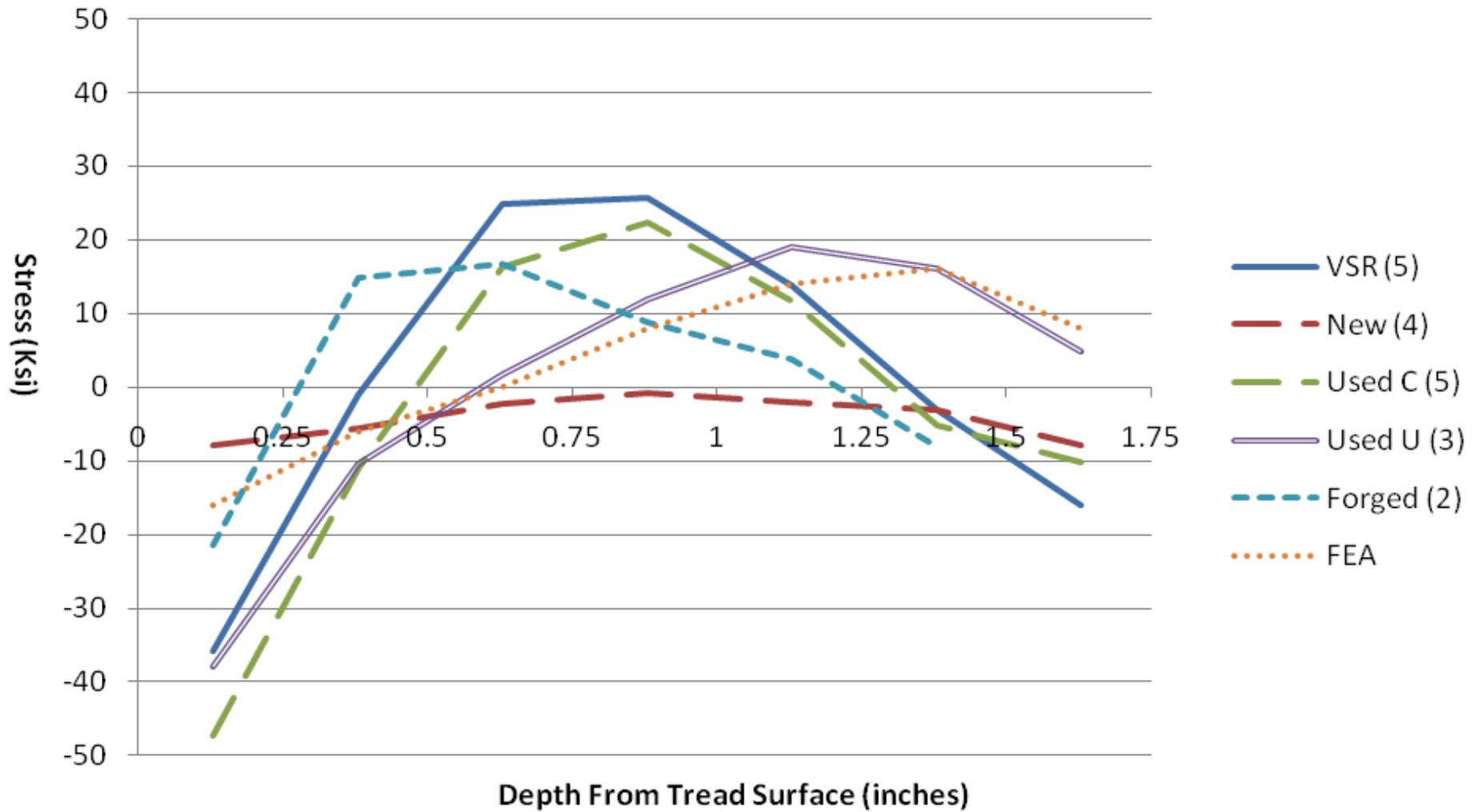
Section Removed For Radial-Axial Cut Face Locations



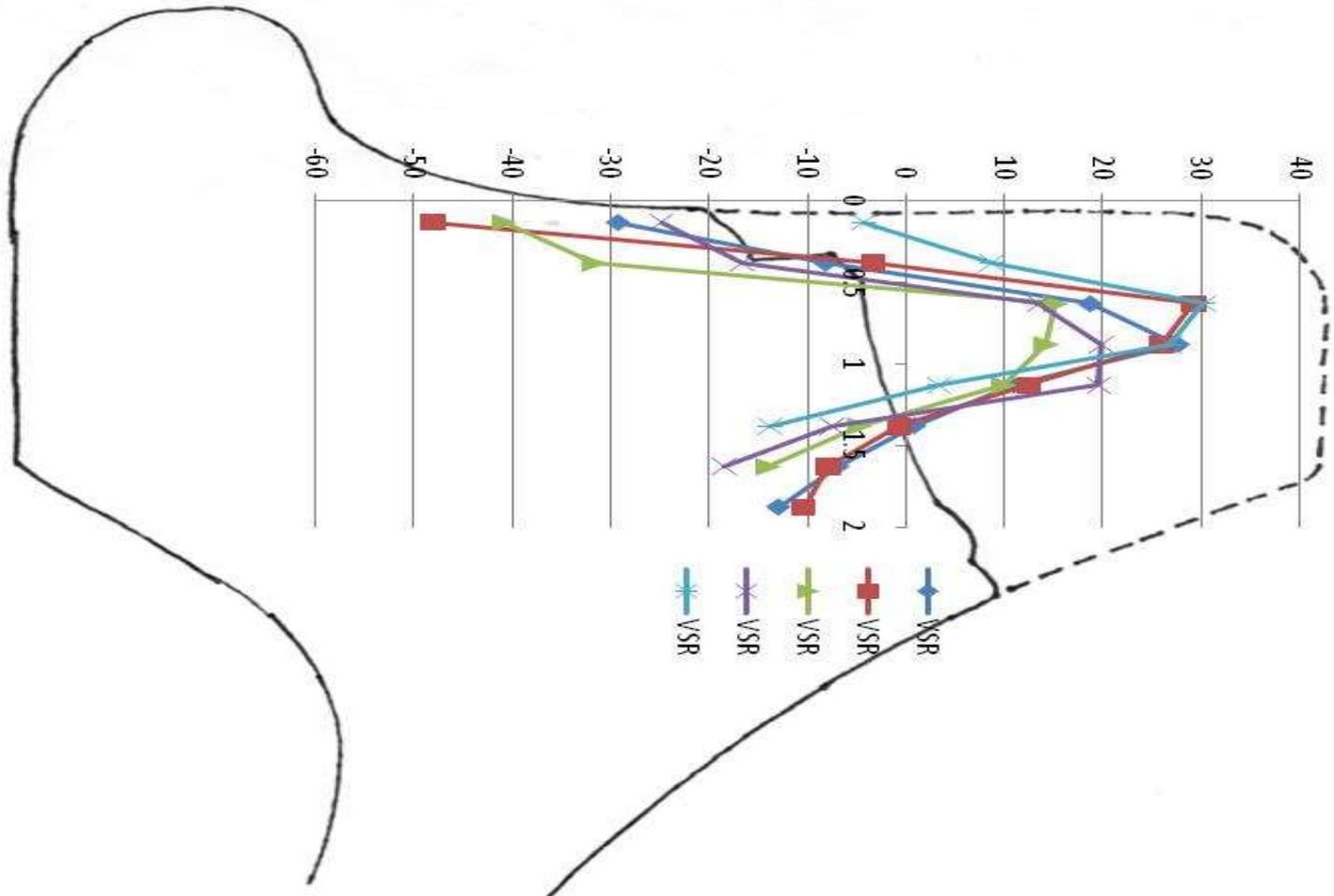
**Radial-Axial
Cut Face Locations**

**Measurements were made at
0.13 in. (3.2 mm) increments from
the Tread to 2.00 in. (50.8 mm)
from the tread Surface.**

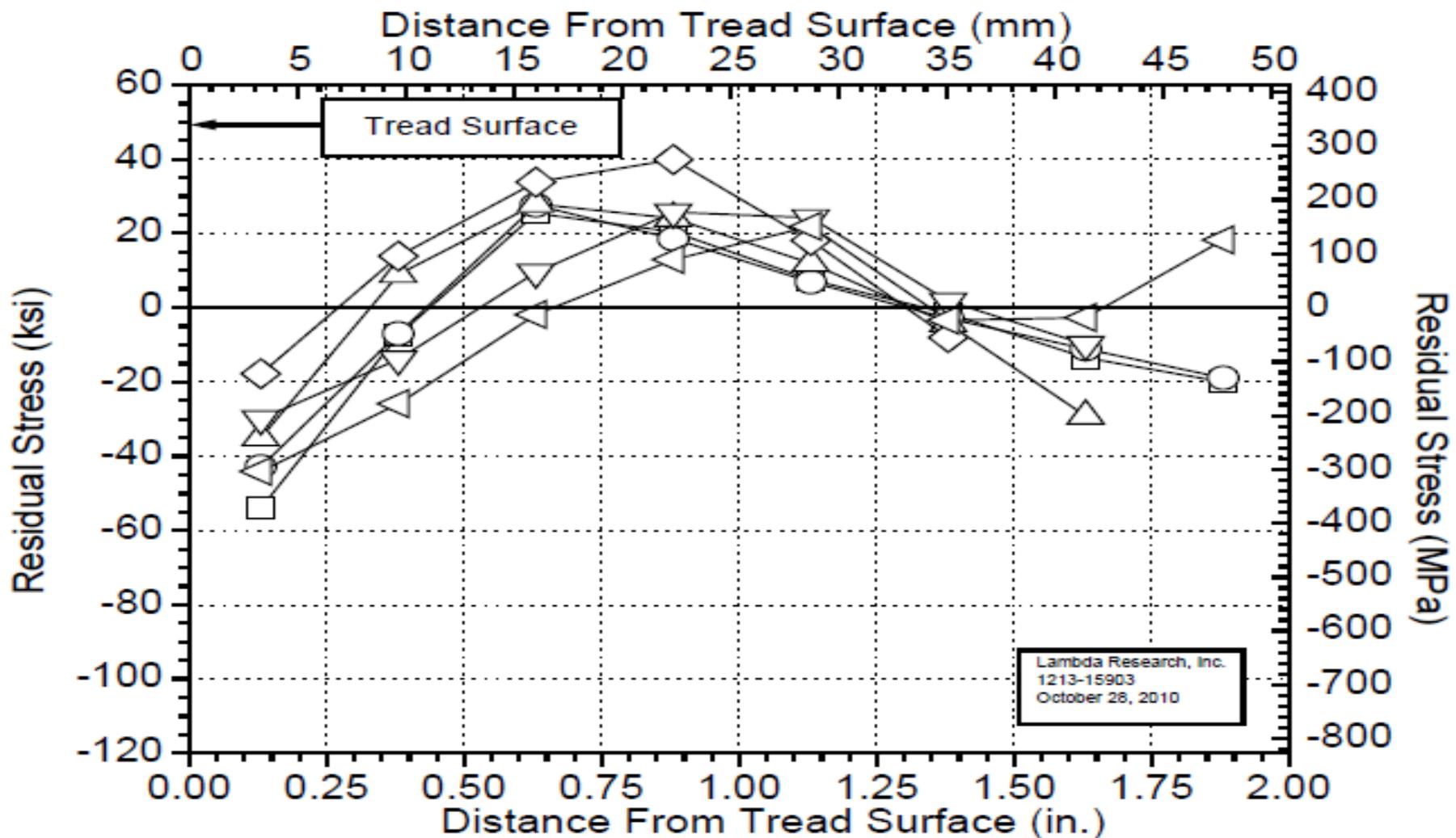
Axial Residual Stress 1.5 inch From Front Rim Face



VSR Profile With Results Superimposed



AXIAL RESIDUAL STRESS DISTRIBUTION



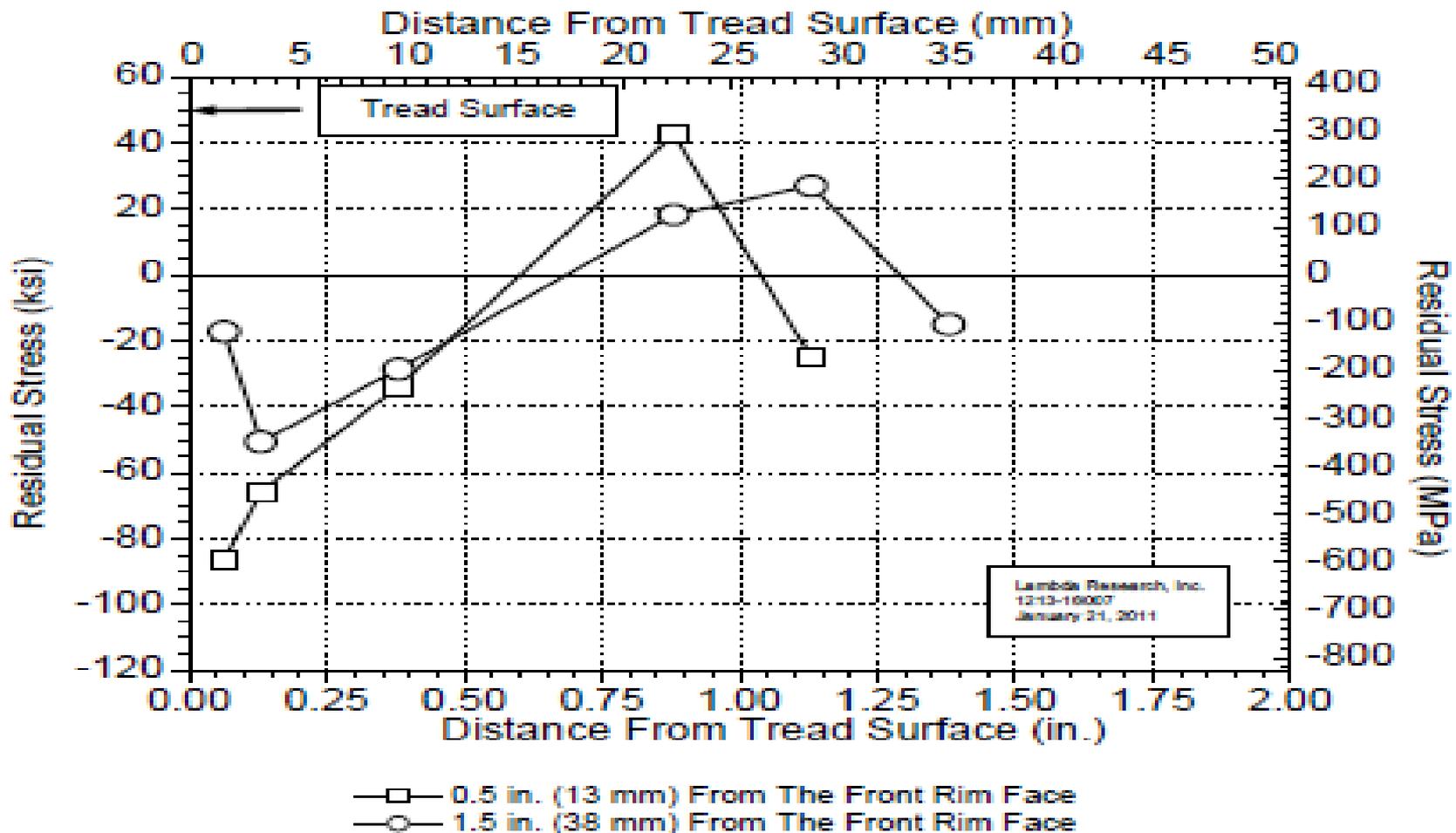
- 3/98 90100A Away From The Failure
- 3/98 90100A Near The Failure
- △— 11-99-82576 GK CH36
- ▽— 7-96-70824 GC CH36
- ◇— 12-05-03938 CH36 GK
- ◁— Drop Hammer (8-1-97835)

Lambda Research, Inc.
1213-15903
October 28, 2010

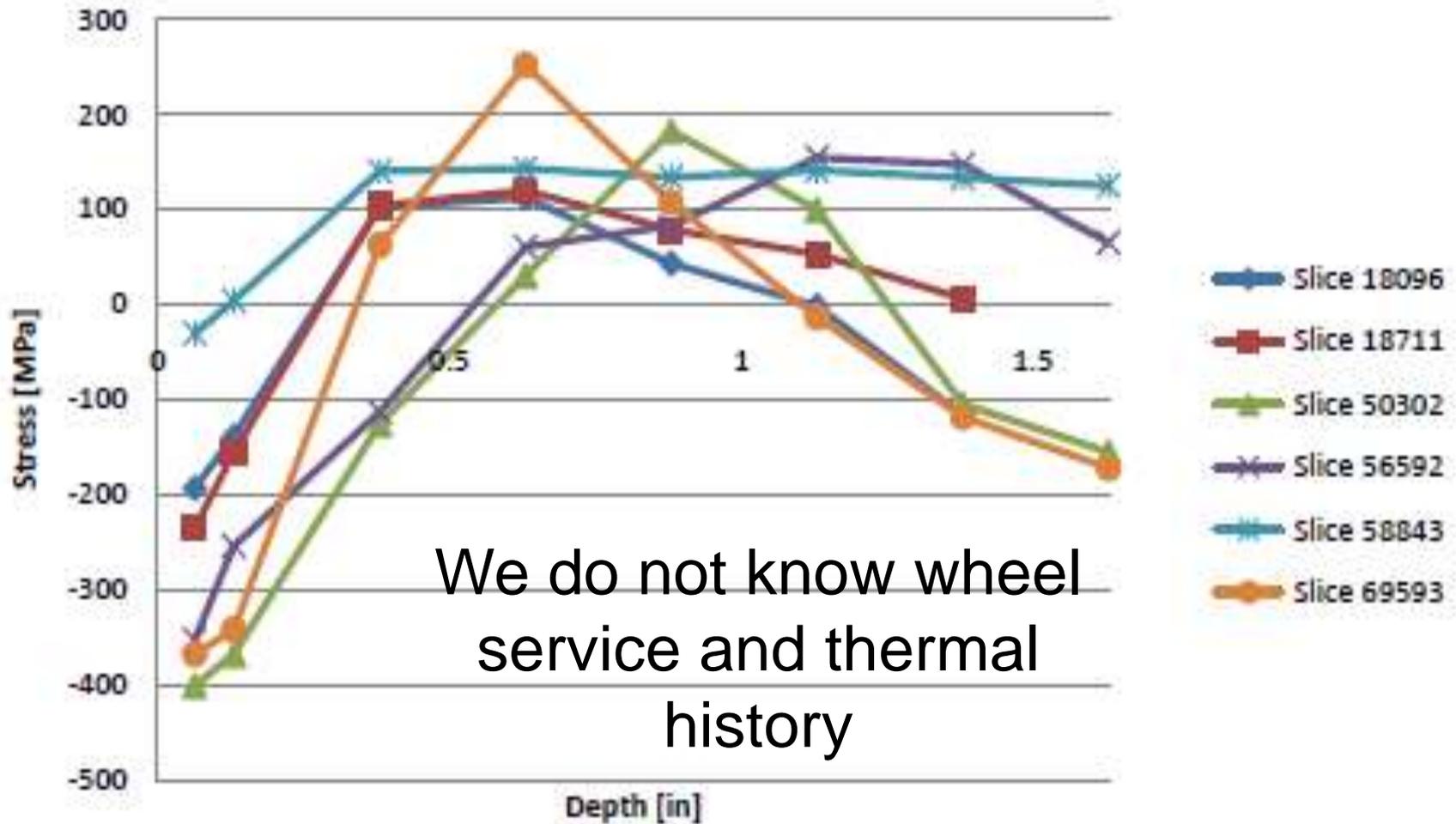
Drop Hammer Test Wheel

31,000+ hits, 250-300 kips

AXIAL RESIDUAL STRESS DISTRIBUTION



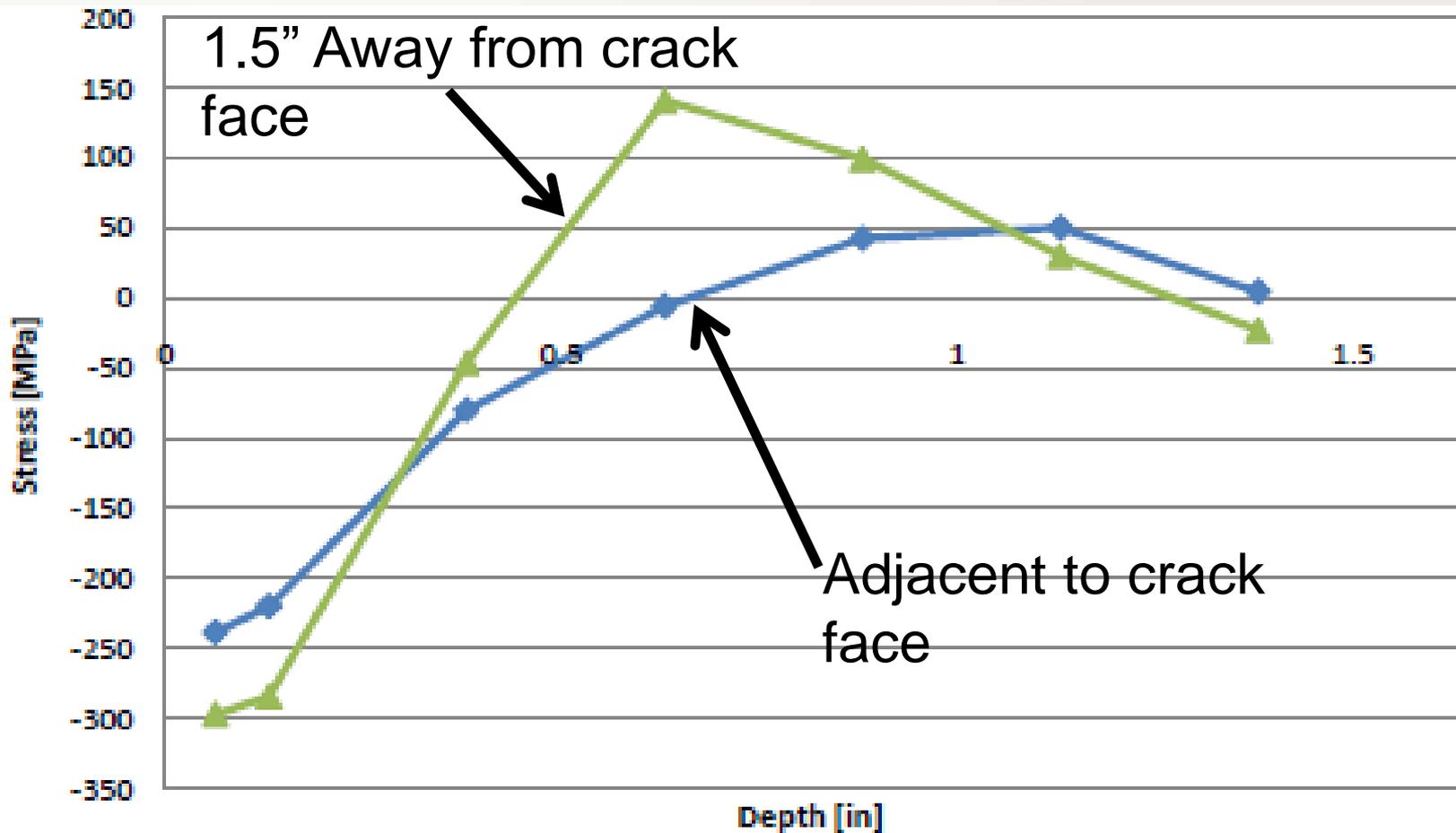
Axial Residual Stress Data – Used Wheels



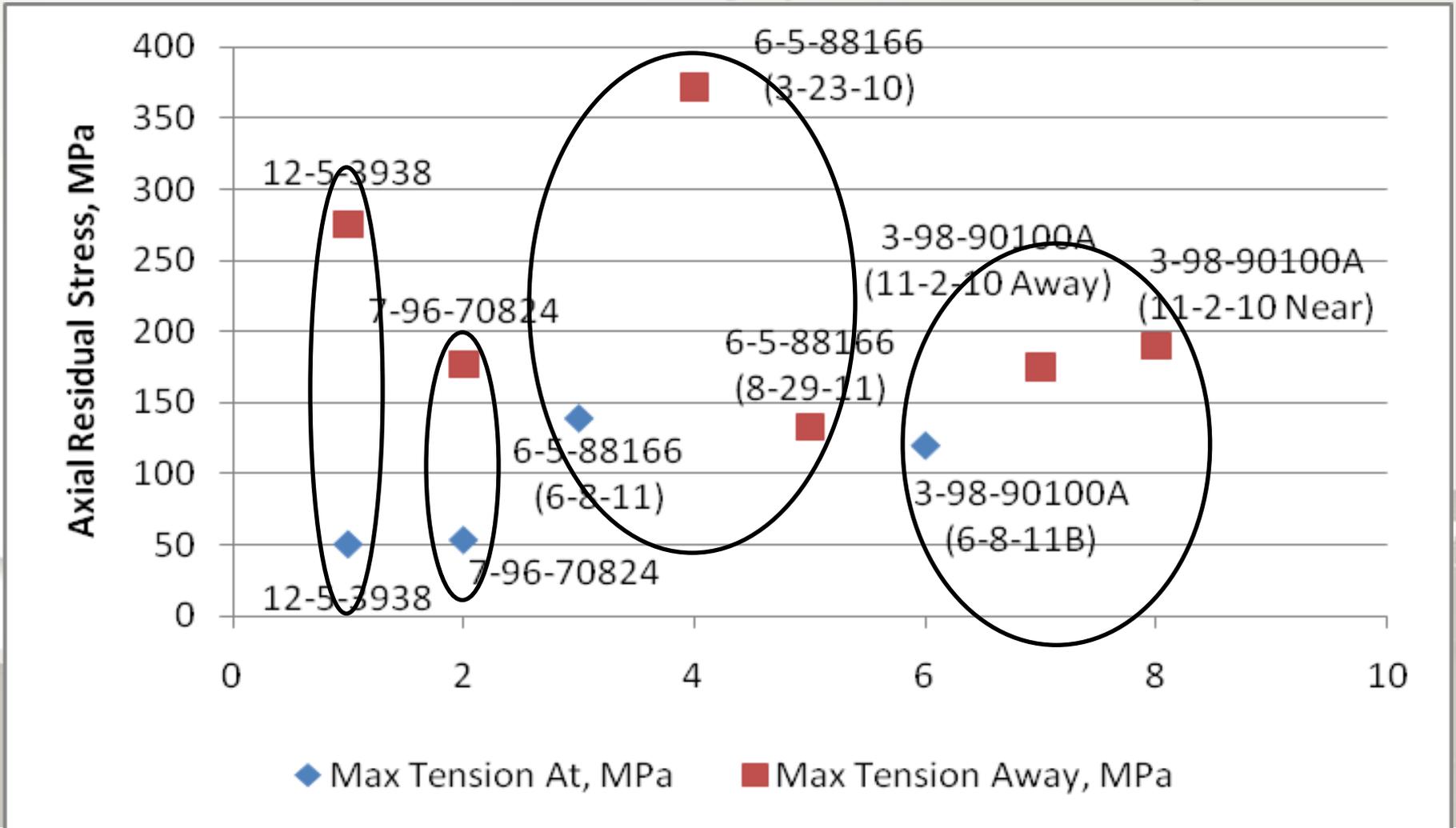
Testing At & Away From VSR



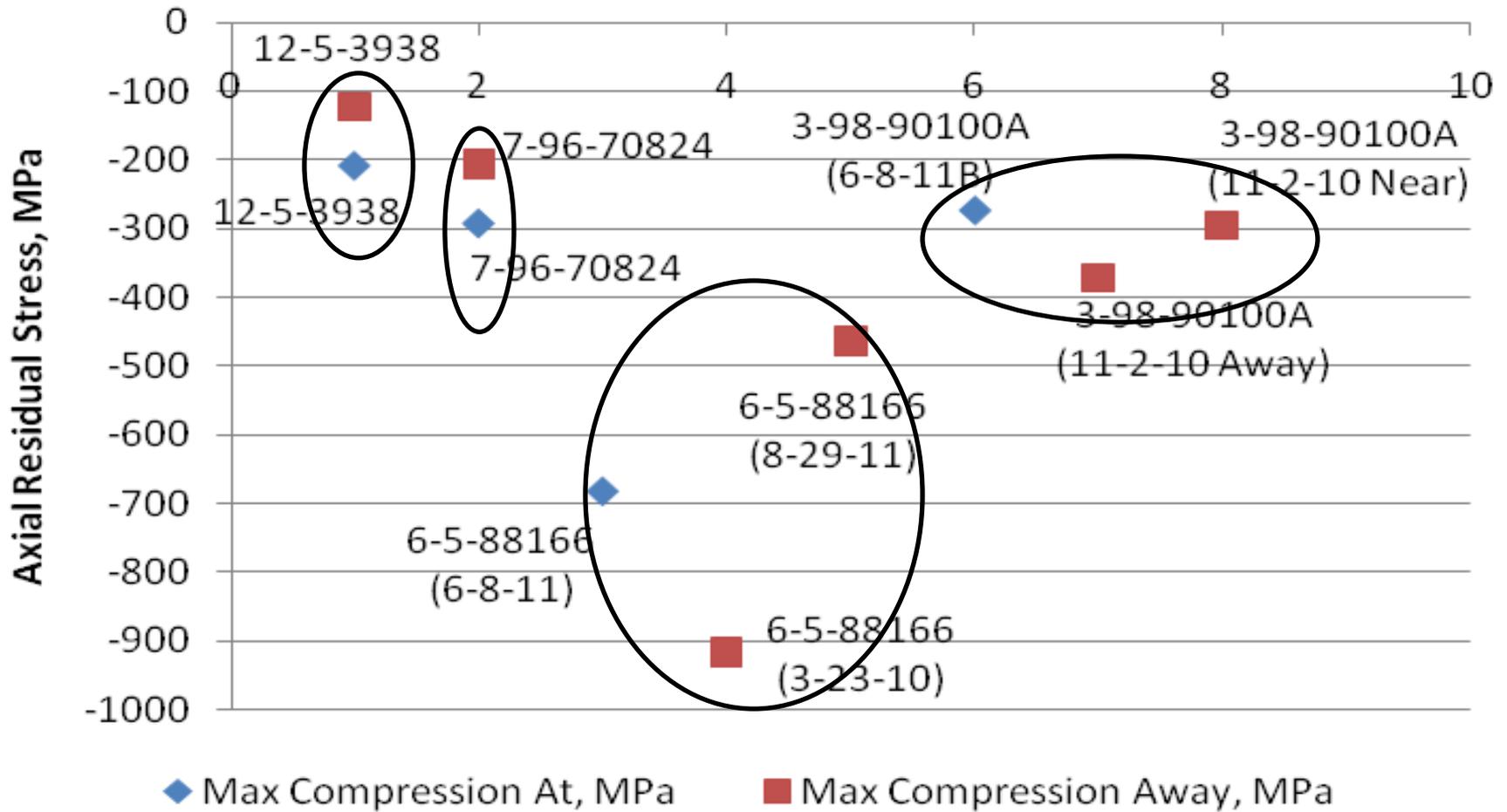
Axial Residual Stress At and Away From Failure Edge



Max Axial Tensile Stress Values For Slices Tested At and Away (1.5" from FRF)



Max Axial Compressive Stress Values For Slices Tested At and Away (1.5" from FRF)



TIR & Axial Residual Stress

Wheel ID (Note: Both cast and forged wheels tested)	TIR value, inches	Max. Compression, MPa	Max. Tension, MPa
CJ36 3-5-32720	0.090	-348	+93
CJ36 3-5-34490	0.075	-286	+167
CJ33 10-2-35474	0.127	-252	+172
H36 3-5-21205024	0.2	-253	+199
B38 7-10-5S0120	0.125	-337	+175
H36 3-5-21205078	0.2	-286	+142
B38 8-10-5S1888	0.097	-328	+167

TIR and Axial Residual Stress

- Higher out-of-round wheels tested exhibited a greater average maximum compression value and greater average tension value than low out-of-round wheels.
- The average values for maximum axial compression and tension of the high out of round slices is -298.5 MPa and +159.2 MPa, respectively.
- The average values for maximum axial compression and tension of the low out-of-round slices is -202 MPa and +153.5 MPa, respectively.

Detailed Testing of CB38 Wheel

Used, D steel (not expected to be different than C for as-mfg axial residual stress), 0.050 in. difference in TIR between 2 points, looking for max compression and max tension...

90 mm from BRF, high OOR point

➤ -230 MPa and +199 MPa

90 mm from BRF, low OOR point

➤ -213 MPa and +154 MPa

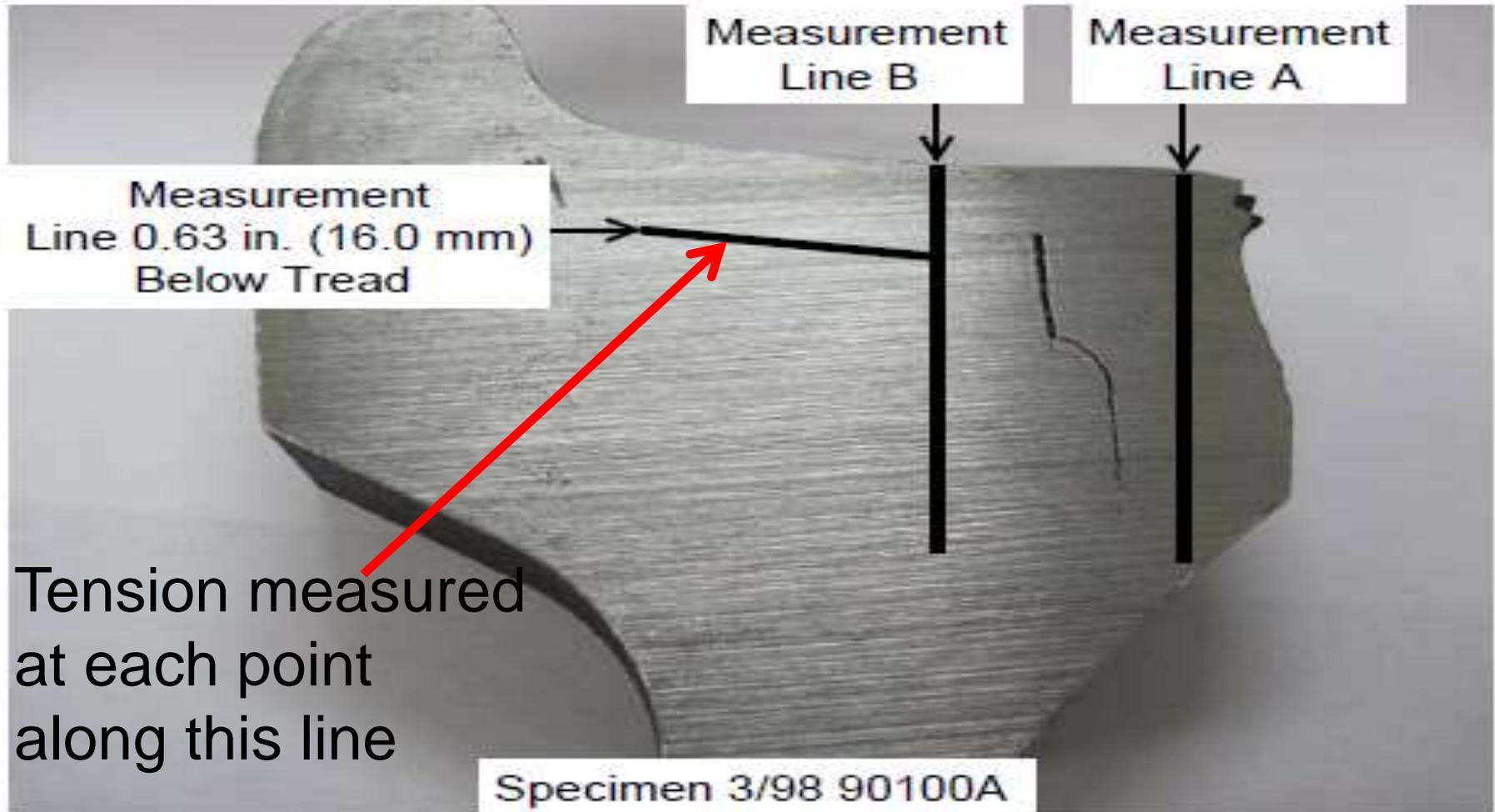
70 mm from BRF, high OOR point

➤ -236 MPa and +180 MPa

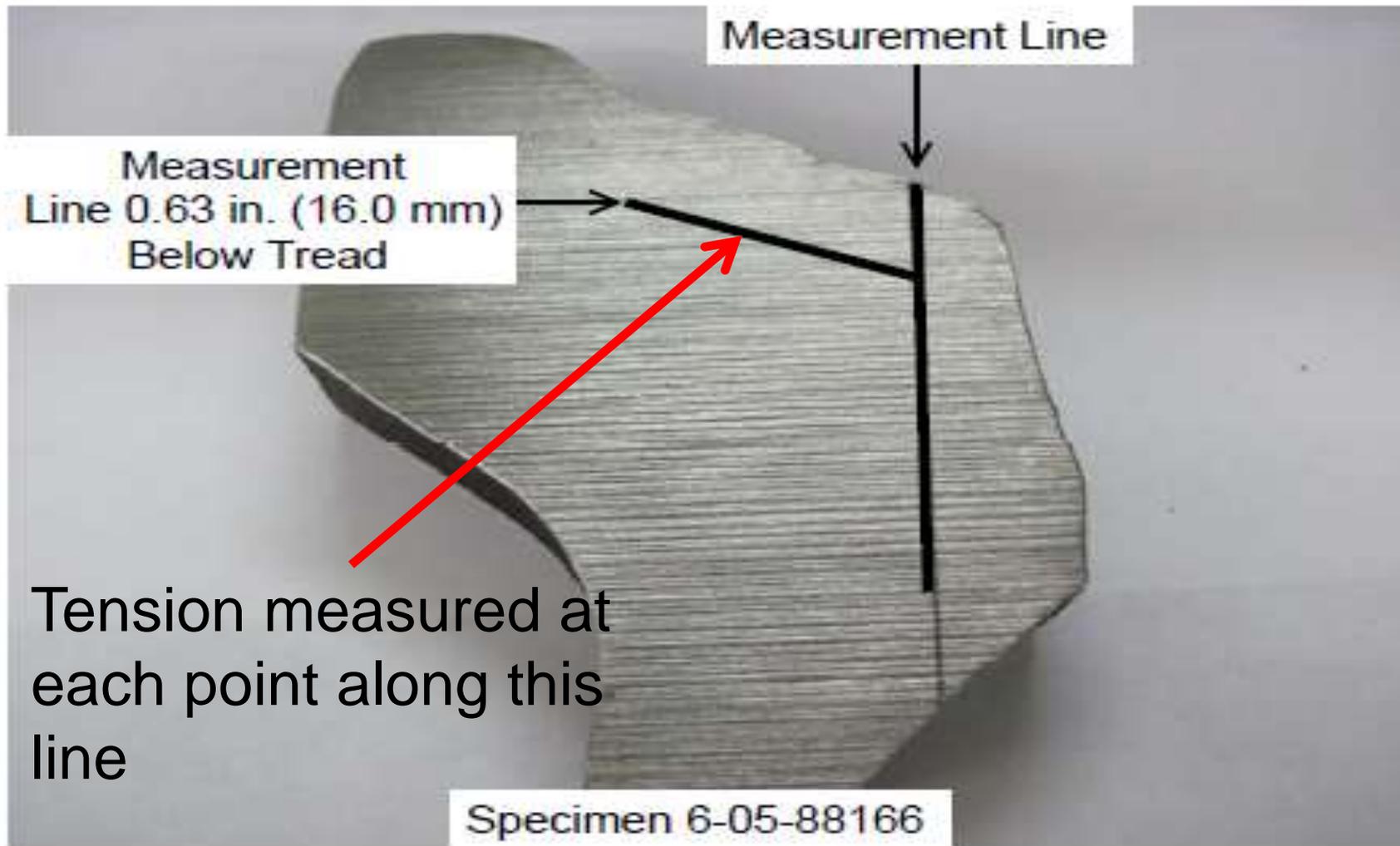
70 mm from BRF, low OOR point

➤ -246 MPa and +142 MPa

Two Adjacent VSRs, Axial Residual Stress Measurement Pattern



Radial Slice Cut at VSR Origin



Proposed VSR Failure Mechanism

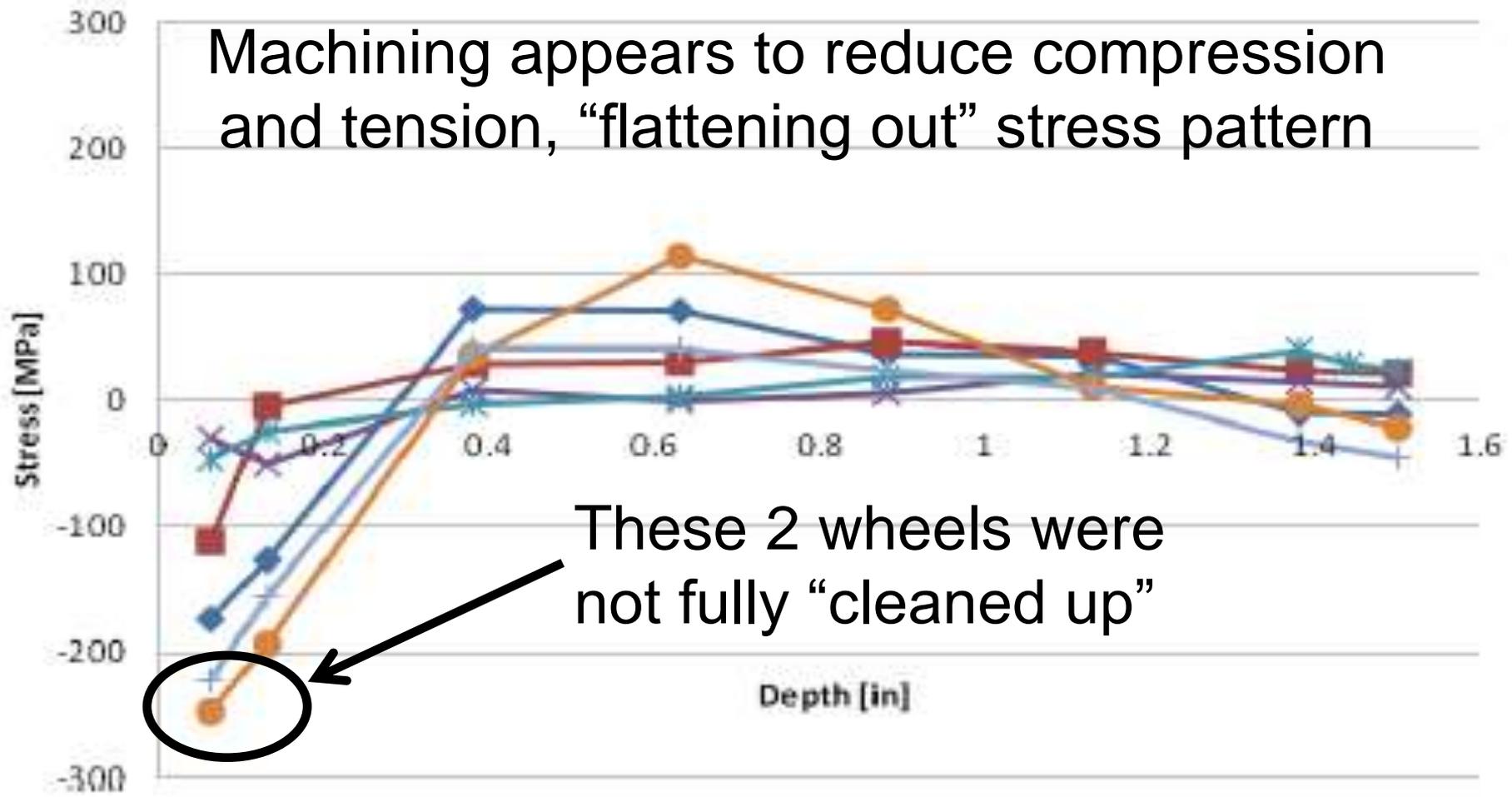
From ASME RTDF 2011

- Tread damage occurs due to shelling (RCF/thermal-mechanical shelling) or spalling (wheel slides)
- Cracks propagate under rolling and pounding loads
- Highly compressive layer at tread surface must be balanced by tension deeper below the surface
- When cracks propagate into this tension zone, cracks can rapidly change direction in service, making VSRs more likely
- Class U wheels had the tension zone much deeper below the tread surface – this, and lower loads, meant that U wheels did not often suffer VSRs

Effects of Machining on Axial Residual Stress

- Wheels are re-machined to remove tread damage
- 6 wheelsets with tread damage selected at a RR wheel shop
- 2 wheelsets likely would have been scrapped for thin rim – were machined anyway
- What does truing do to the residual stress distribution?

Role of Wheel Truing on Axial Residual Stress in Used Wheels



Axial Residual Stress Work Continues

- X-ray diffraction testing, 2 suppliers
- 6 original machined wheels from CN
- 12 additional machined wheels from CN
- 12 machined wheels from BNSF
- Out-of-round wheels, testing at high OOR and low OOR points around the wheel
- FAST train test

BNSF Havelock Machining/Residual Stress Tests

Does wheel truing reduce axial residual stress pattern?

6 tread damaged wheelsets selected, forged and cast

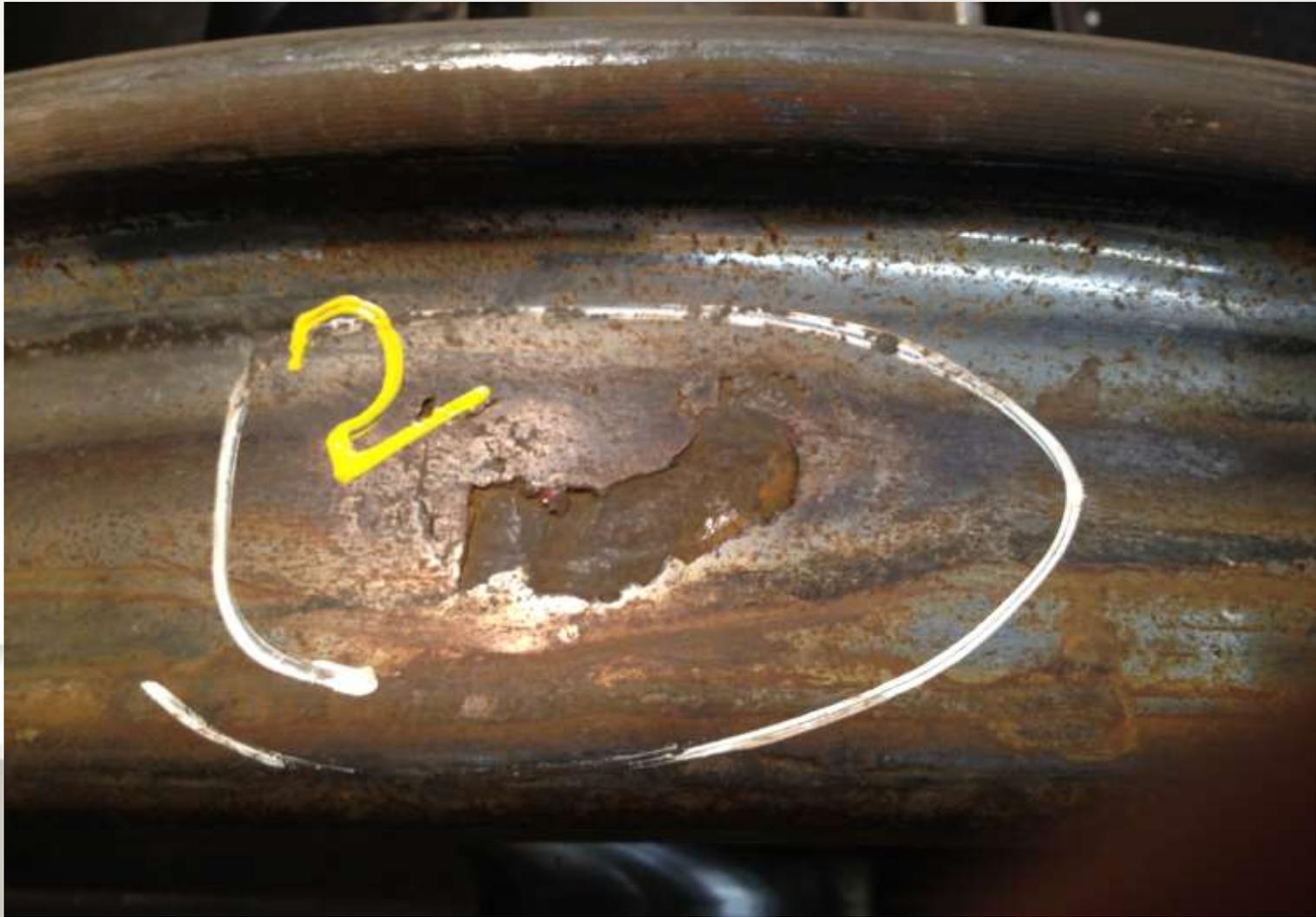
All machined to remove tread damage

Amount of metal removed recorded: 1 - 6/16, 2 - 8/16, 3 - 6/16, 4 - 6/16, 5 - 6/16, 6 - 3/16

Slices cut out at Anderson for axial residual stress testing using x-ray diffraction at AST, Pittsburgh

Other BNSF out-of-round wheels with impact history also to be tested.

Examples of Tread Damage, Wheel 2



Example of Tread Damage



Examples of Tread Damage, Wheel 5

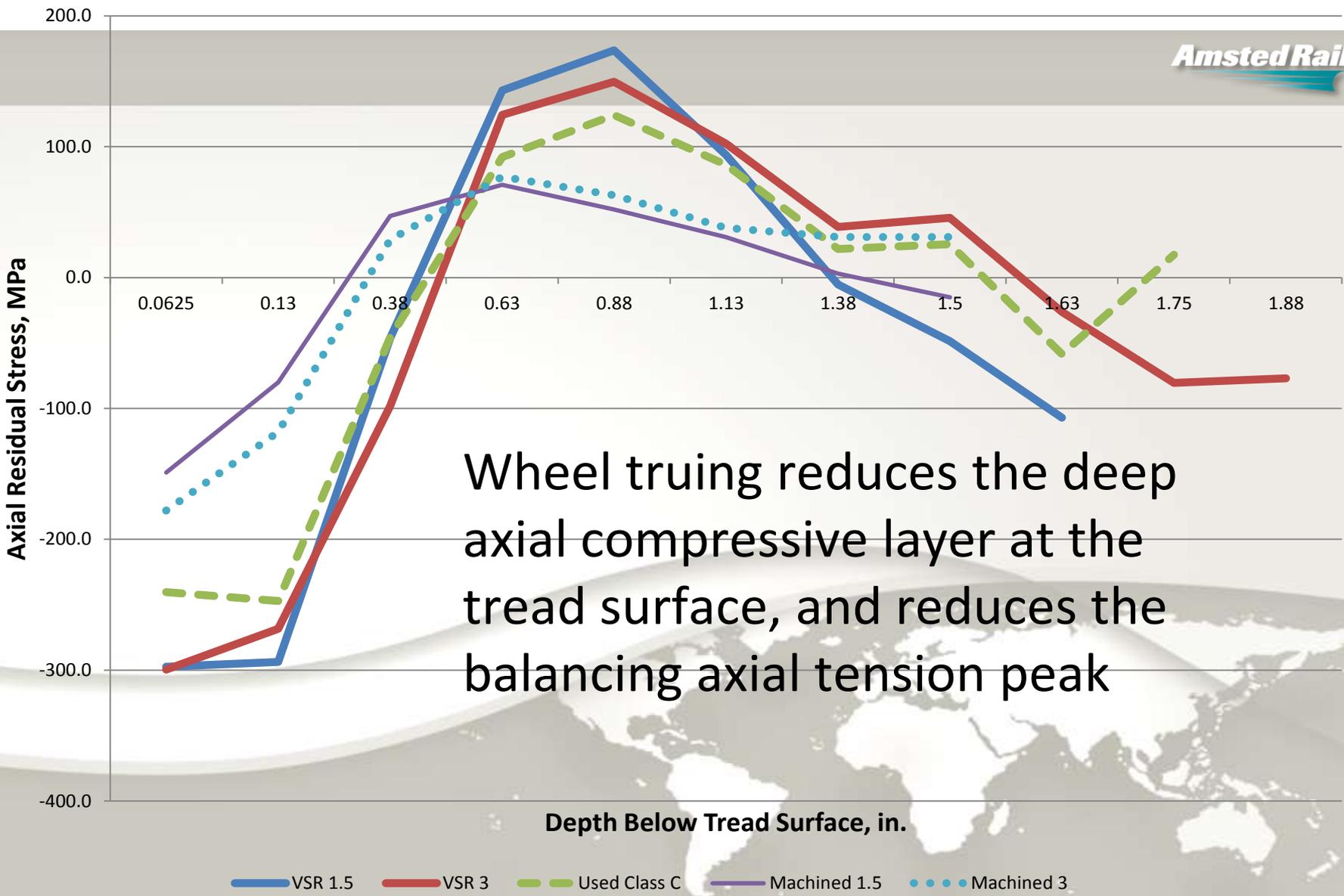


Wheelset Machined at BNSF Havelock



Average Axial Stress Values - Machined

- “VSR 1.5” average is made up of 26 data sets from 21 different wheels
- “VSR 3” average is made up of 19 data sets from 14 wheels
- “Used Class C” average is made up of 22 data sets from 13 wheels
- “Machined 1.5” wheel average is made up of 28 data sets from 28 wheels
- “Machined 3” wheel average is made up of 24 data sets from 24 wheels.



Wheel truing reduces the deep axial compressive layer at the tread surface, and reduces the balancing axial tension peak

Wheel Truing Tests - Conclusions

Wheel truing not only corrects tread/tread profile and removes tread damage, it reduces the magnitude of sub-surface axial tensile stress

For VSR wheels, average axial tensile stress was around 25 ksi (172 MPa) on the 1.5" line of x-ray shots

Maximum axial residual tensile stress seen in machined wheels was about 120 MPa, or 17.4 ksi

Wheel truing reduces the chance for VSR.....A VSR needs:

- 1) Tread damage
- 2) Propagating cracks into the rim under service rolling and impact loads
- 3) An axial tensile stress of sufficient magnitude below the surface to get the crack to run....

Questions?

