Wheel Manufacturing Upgrade For Improved Steel Cleanliness & Quality

Cameron Lonsdale & Jay Galbraith
Standard Steel, LLC

MARTS, Minneapolis, MN 10-6-15

Innovative Capital Projects in Steelmaking and Wheel Forging

- Projects totaling more than $50M USD
- Steelmaking
  - New basic electric arc furnace
  - Twin-tank ladle refining and vacuum degassing station
- Synchronized Inclined Rotary Dishing Press (SIRD) Installation
- Goals: Produce ultra-clean, low-stress, high-precision wheels
- Preliminary results and implications for heavy haul service

Melt Shop Installation Update

Phase 1 of project completed at the end of Dec 2013:

- Revamped Electric Arc Furnace #4 (continued acid practice)
- Replaced 30 MVA transformer with a 50 MVA
- Installed new water cooling system
- Installed new 110-ton crane
- Bag house upgraded

Phase 2 completed Jan 2014 - 2015:

- Twin tank ladle refining/vacuum degassing facility
- Slag rake system
- Change-over to basic steelmaking practice – January 2015

Electric Arc Furnace #4 Revamp

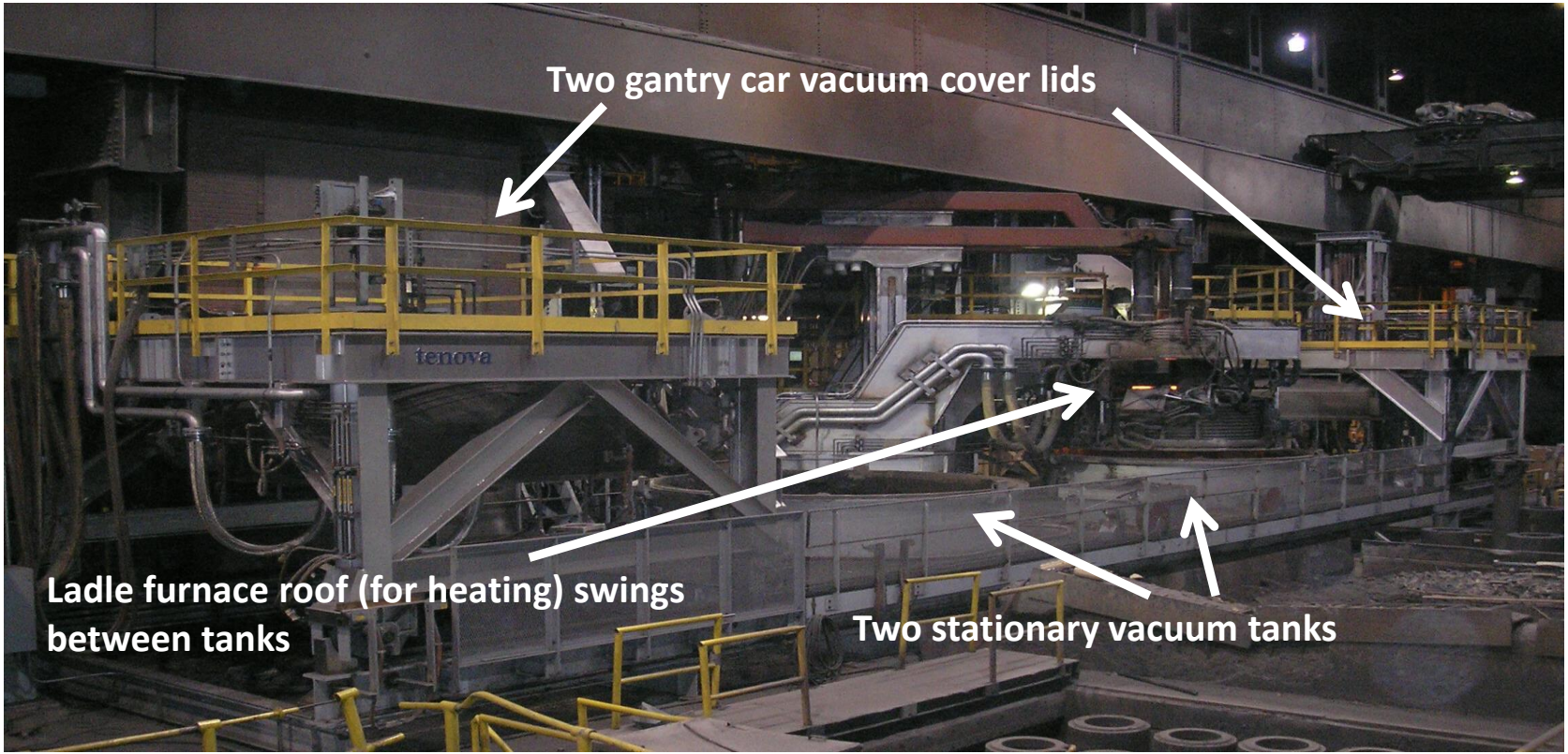
Ladle Tilt Stand/Slag Rake System For Removing EAF Slag

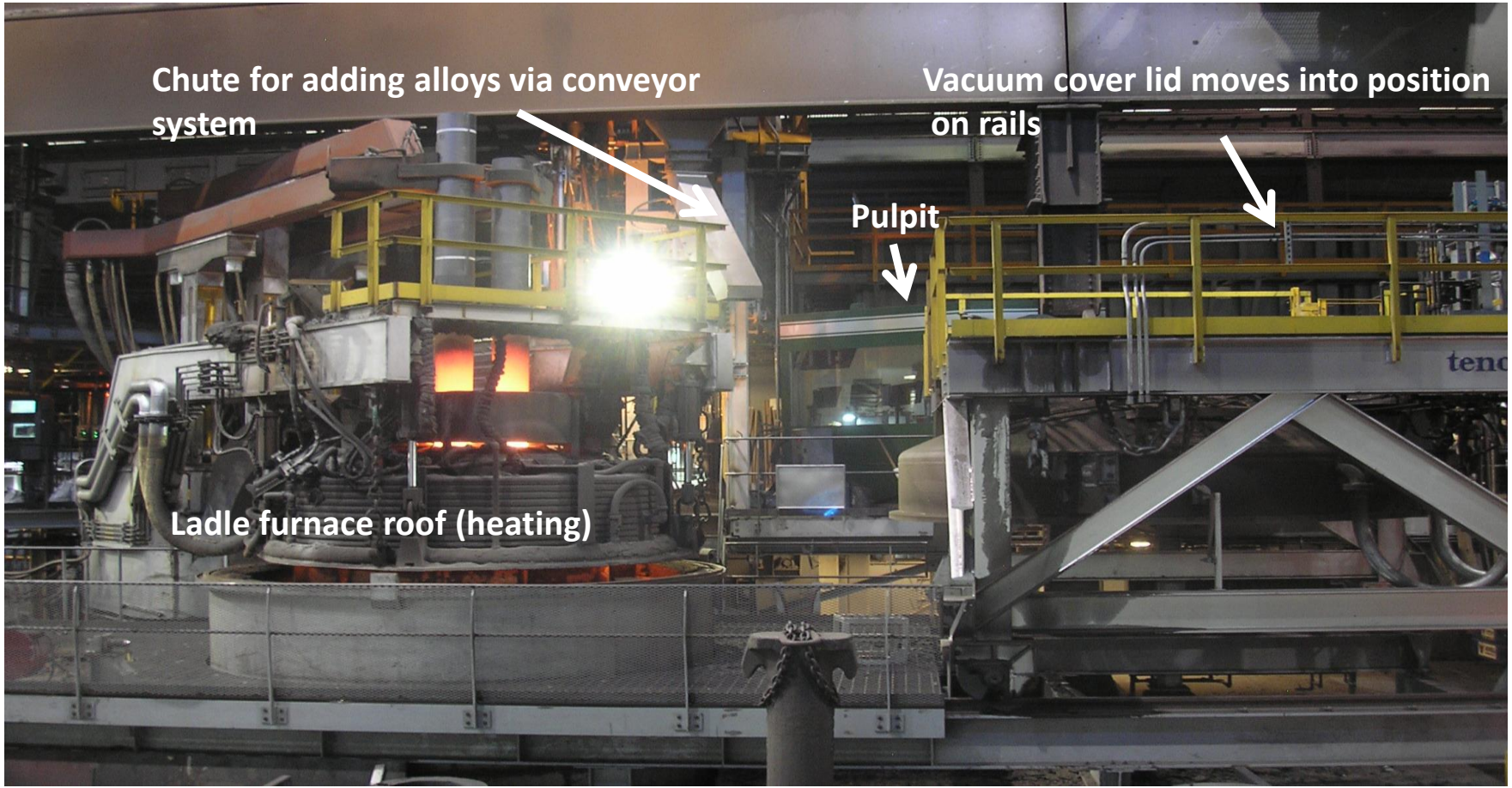
Water Cooling System and Baghouse Upgrade

New Twin-Tank, Ladle Refining / Vacuum Degassing (LFVD) Station

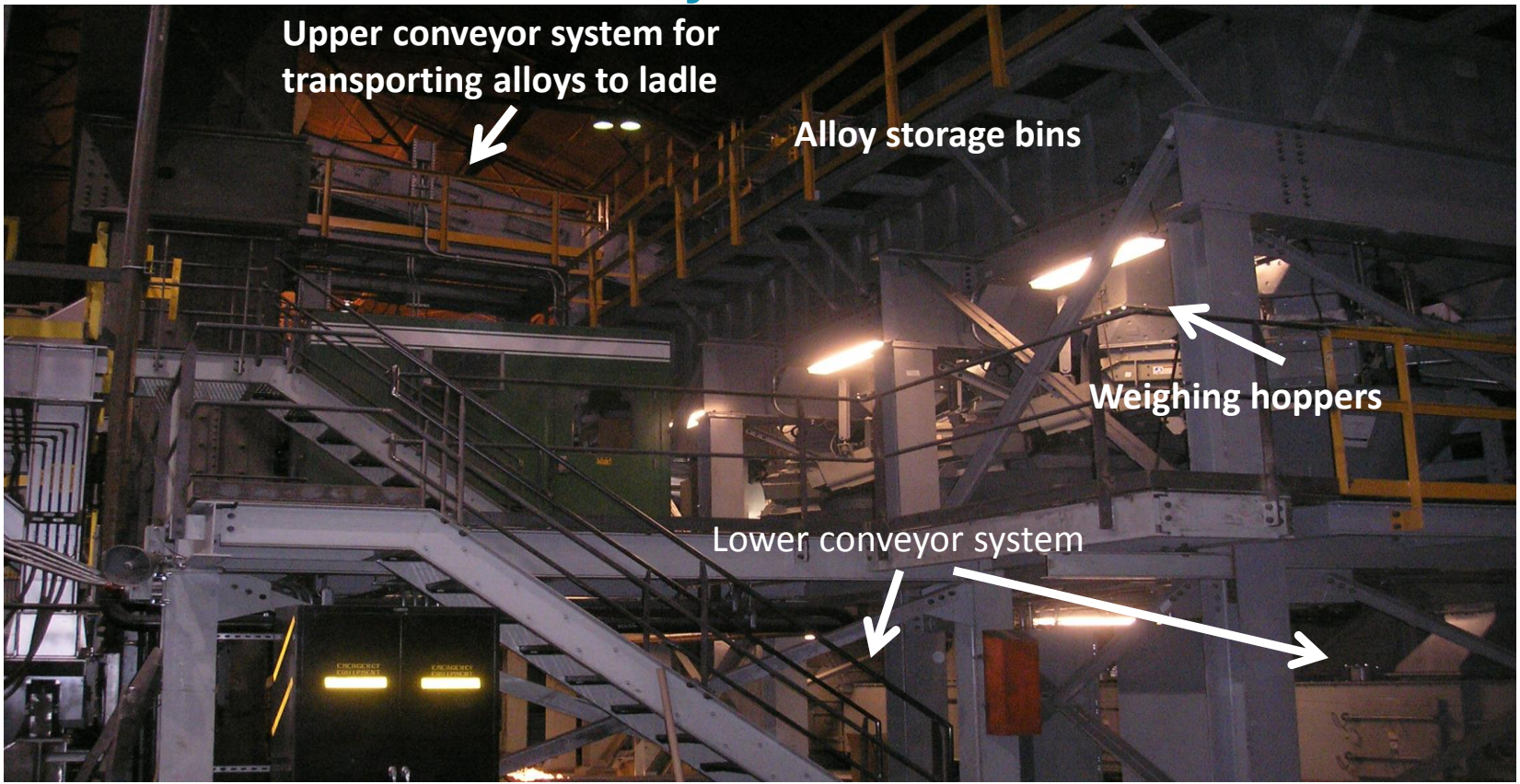
Overview of Ladle Refining & Vacuum Degassing Station

Twin-Tank LFVD Station

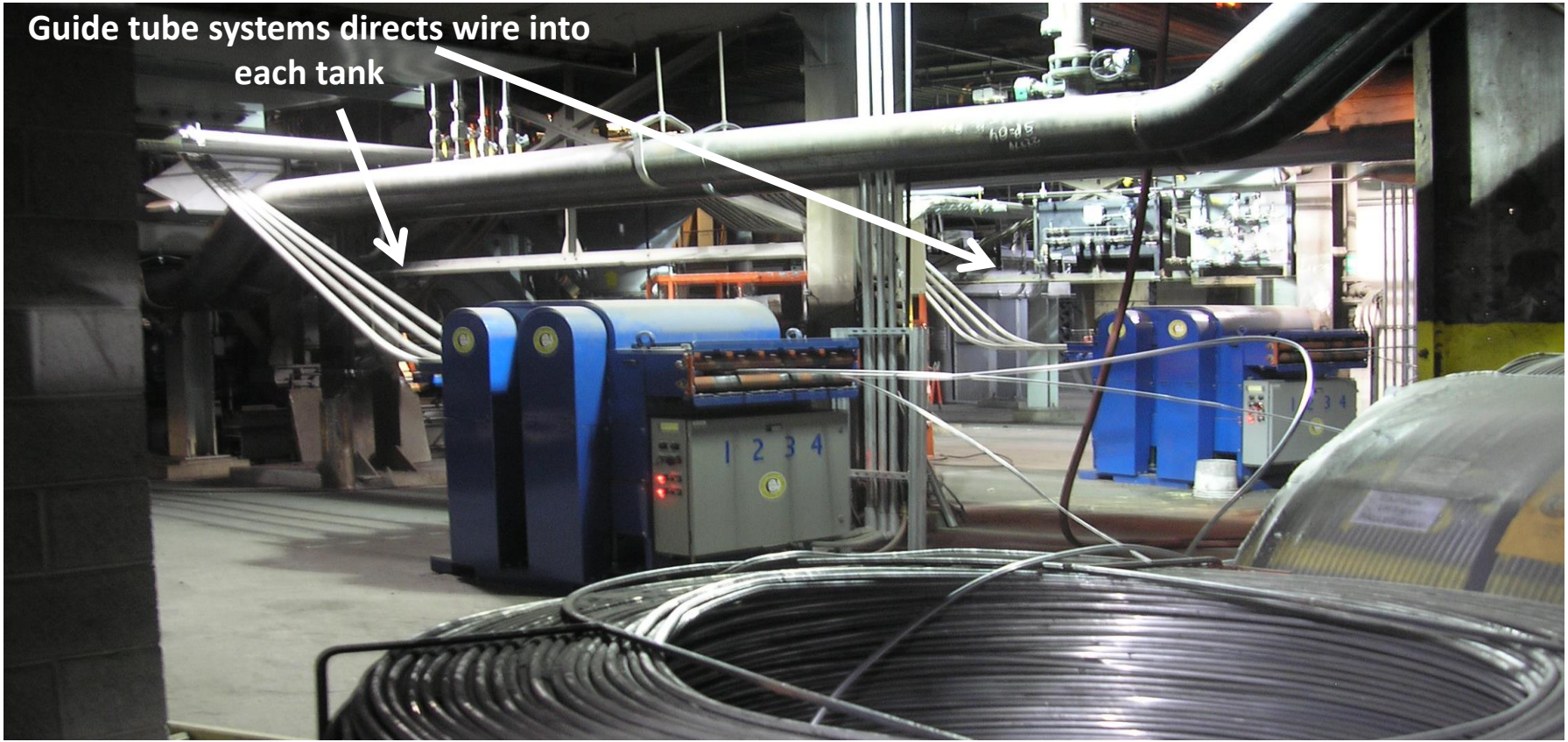



Chute for adding alloys via conveyor system
Vacuum cover lid moves into position on rails
Pulpit
Ladle furnace roof (heating)

Material Handling System for Precise Alloy Additions



Wire Feeding Systems – Precise Additions



Steel Cleanliness Improvements: Implications for Wheels in Heavy Haul Service

- Wheels are subject to a dynamic loading environment - impacts
- For steels with similar strength (i.e., hardness), dynamic fracture toughness is a strong function of the steel's cleanliness, micro-porosity, and microstructure
- Under heavy axle loads, rim fatigue cracks can initiate internally at stress concentrations (i.e., voids and inclusions)
  - Hard oxide inclusions, primarily alumina, are likely sources of initiation
  - Interdendritic sulfides reduce ductility and toughness
- Evidence suggests that steels with a high degree of cleanliness are less susceptible to shattered rims & rolling contact fatigue (i.e., shelling)

Steel Cleanliness Improvements

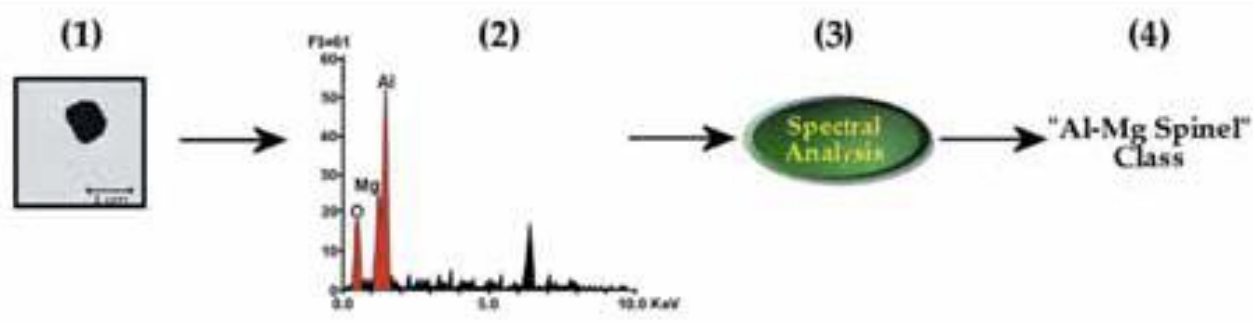
- **Verification by two methods:**
  - **ASTM Standard Practice E1245 (average & worst field area %'s of oxides, voids, & sulfides)**

	Mean Volume % Voids + Oxides	Maximum Volume % Voids + Oxides	Mean Volume % Sulfides	Maximum Volume % Sulfides
Old Steelmaking Process	0.0095%	0.150%	0.137%	0.365%
New Steelmaking Process	0.0073%	0.045%	0.120%	0.224%
% Improvement with New Process	23%	70%	12%	39%

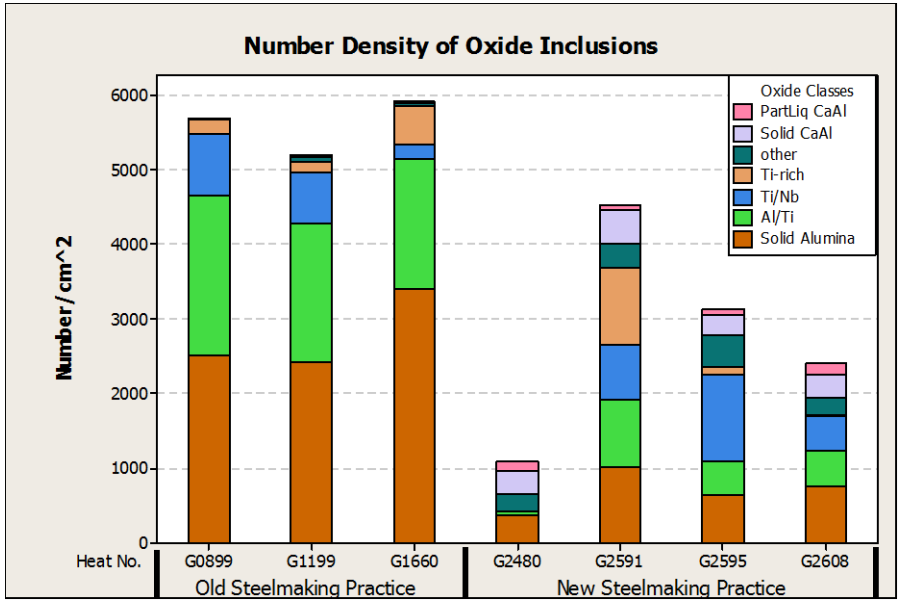
* Specified by AAR M107/M208, Section 9

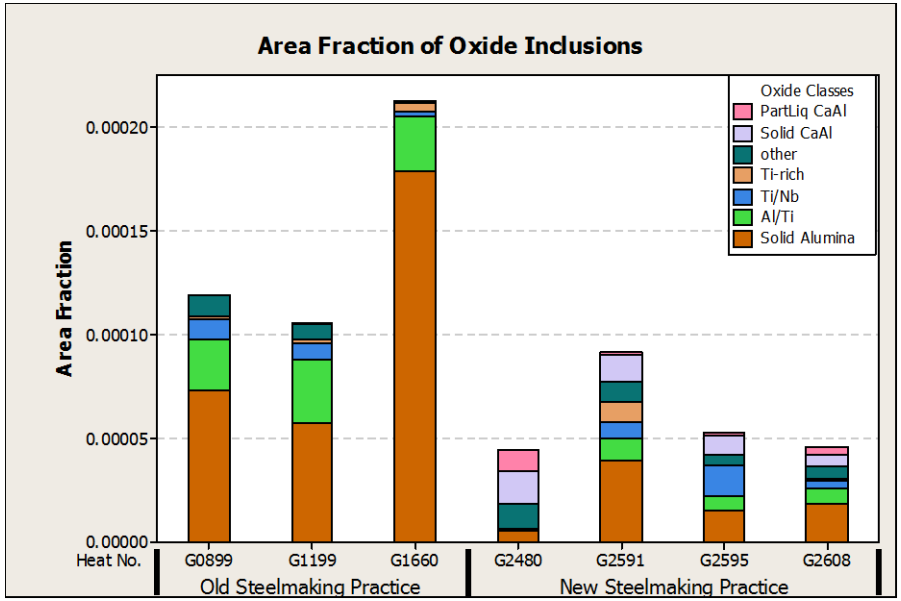
Steel Cleanliness Improvements (cont.)

- **Automated Steel Cleanliness Analysis Tool (ASCAT)**
  - **Based on computer-controlled scanning electron microscopy**
  - **Provides detailed size distribution and chemistry information of inclusions in steel**
  - **Has been shown to provide good correlation with ultrasonic test data**



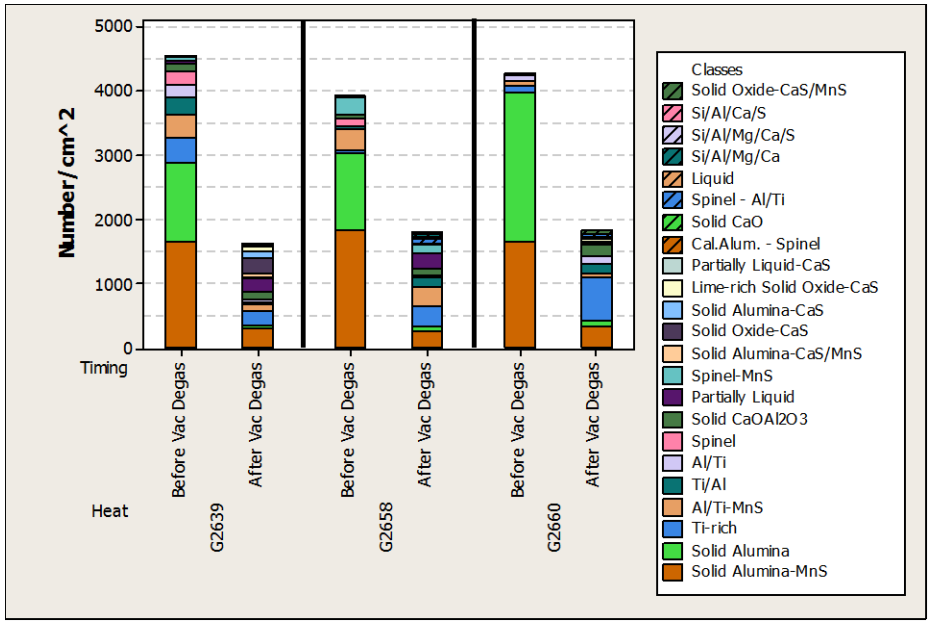
New Steelmaking Practice Results: Reduction in Oxide Inclusions

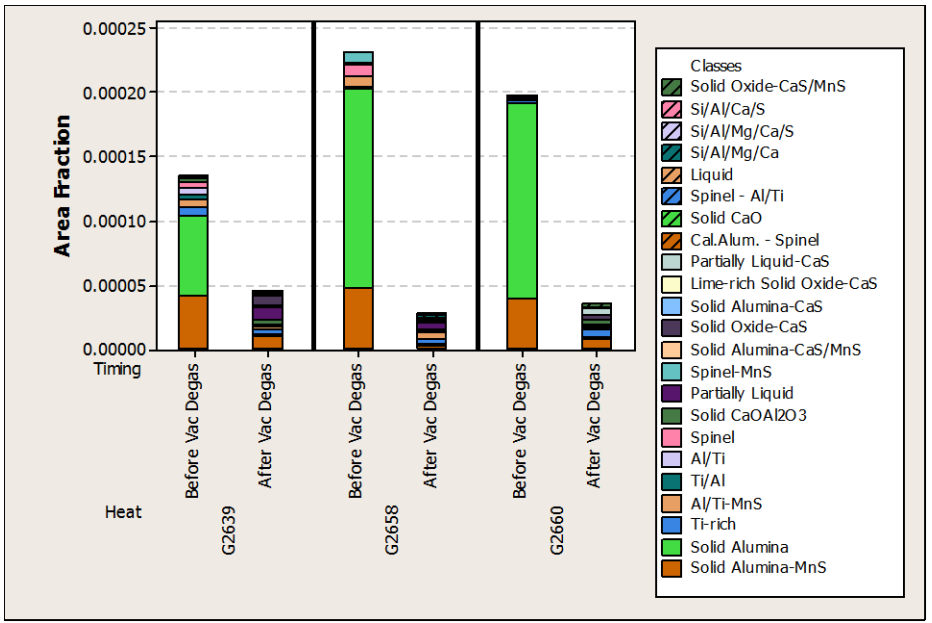




- **Most notable is the presence of smaller and fewer alumina inclusions which results in greater resistance to fatigue & fracture**

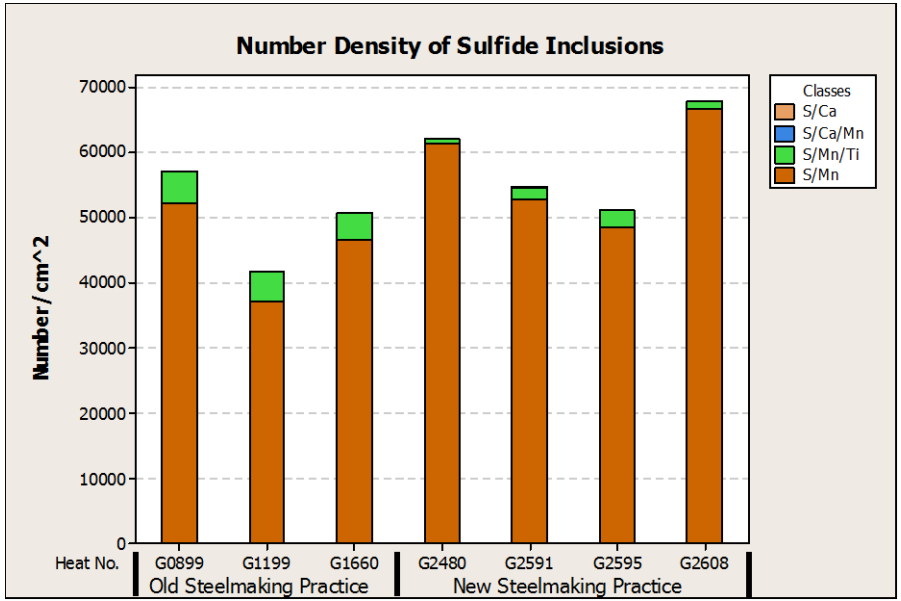
New Steelmaking Practice Results: Removal of Oxide Inclusions During Vacuum Degassing

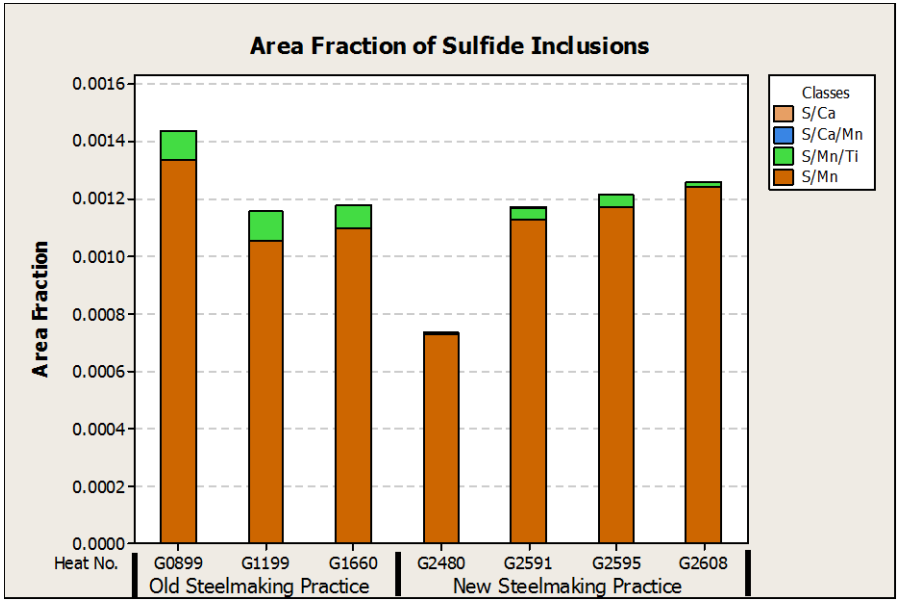




- **Removal of oxides that are deleterious to dynamic fracture toughness and rolling contact fatigue require the right combination of slag chemistry and slag/metal interaction**

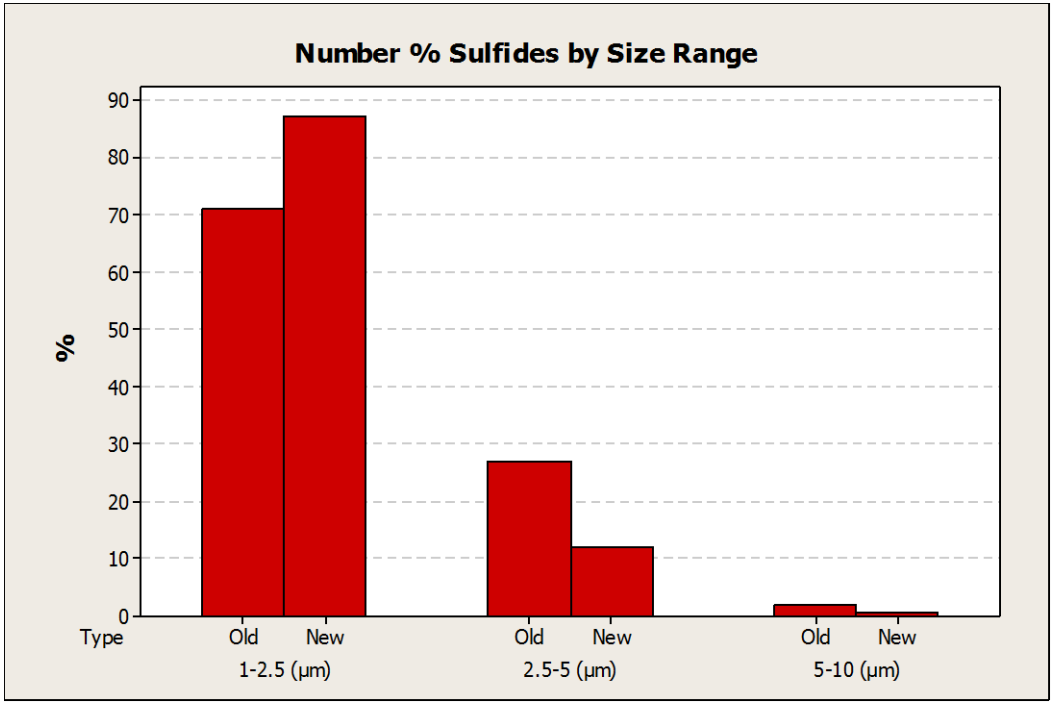
New Steelmaking Practice Results: Impact on Sulfide Inclusions





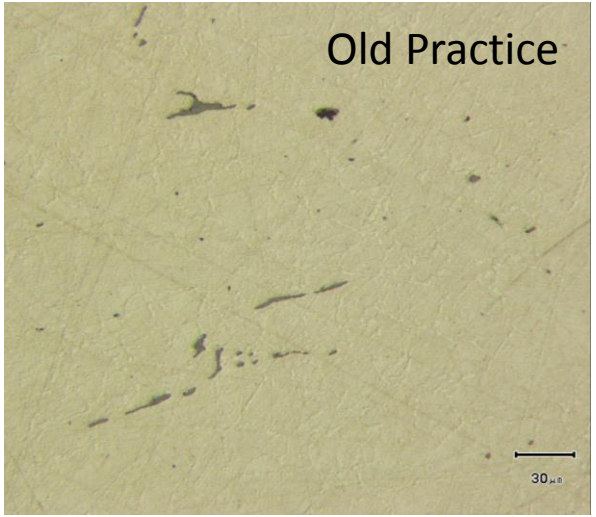
- **Similar area fraction of sulfides, but higher number density → sulfides are smaller.**

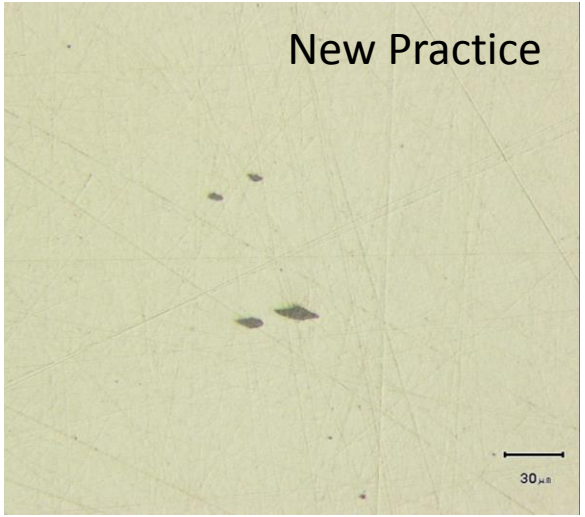
New Steelmaking Practice Results: Impact on Sulfide Inclusions (cont.)



- **17% more sulfide inclusions in the 1 – 2.5 µm range for steel produced using the new practice.**

Improvement in Sulfide Morphology





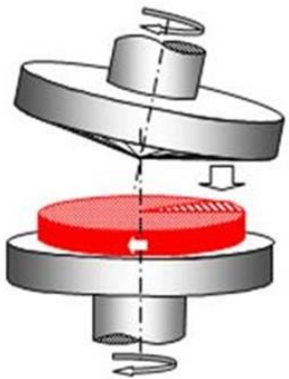
- **Even at the same sulfur levels (to maintain acceptable machinability), the new steelmaking practice results in small, globular sulfides with a complete lack of large, eutectic sulfides.**
- **Eutectic sulfides tend to reduce tensile ductility and toughness.**

New Steelmaking Practice Results: Improvement in Mechanical Properties

	Tensile Strength (ksi)	Yield Strength (ksi)	% Elongation	% Reduction in Area	ASTM Grain Size #
Old Steelmaking Process	98.1	56.9	22.9	44.9	7.0
New Steelmaking Process	98.7	57.9	24.8	48.8	7.8
Improvement:	1%	2%	8%	9%	12%

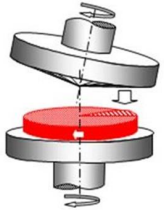
- **Room temperature tensile test data of AAR Grade F axles**
- **Clean steelmaking practices with improved deoxidation practices results in:**
  - **Finer-grained,**
  - **Slightly higher strength**
  - **Higher ductility**

Synchronized Inclined Rotary Dishing Press (SIRD) Installation: Higher Precision-Forged Wheels

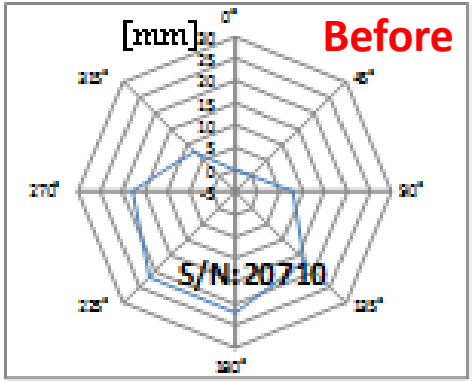


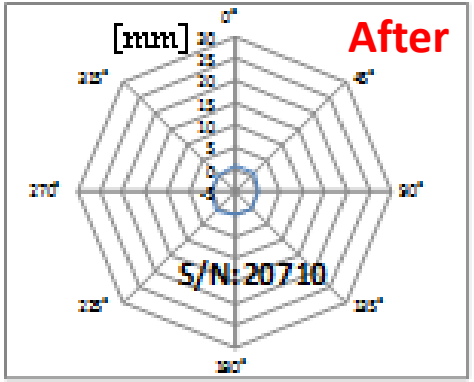
- **Principle: Incremental deformation using an inclined top forging die that maintains constant contact while both the top & bottom dies rotate to maintain work piece stability**
- **Advantages:**
  - **Closer to net-shape prior to machining**
  - **Tighter overall dimensional tolerances**
  - **Rotundity and eccentricity between rough bore and tread significantly improved → Reduction in overall stress state of the railroad**
  - **Expected to result in consistently larger tape sizes with more useable wear metal in the rim**

Synchronized Inclined Rotary Dishing Press (SIRD) Preliminary Results



- Radial run-out contour plots show improvement in the concentricity of the hub and rim with SIRD process
- Rim thickness is more consistent around the circumference
- Tape size is more uniform
- Minimal variation in front face/back face rim thickness & hub wall thickness





Questions?