

Ladle Stirring Monitoring for Inclusion Flotation

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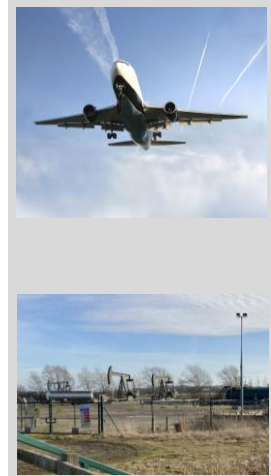
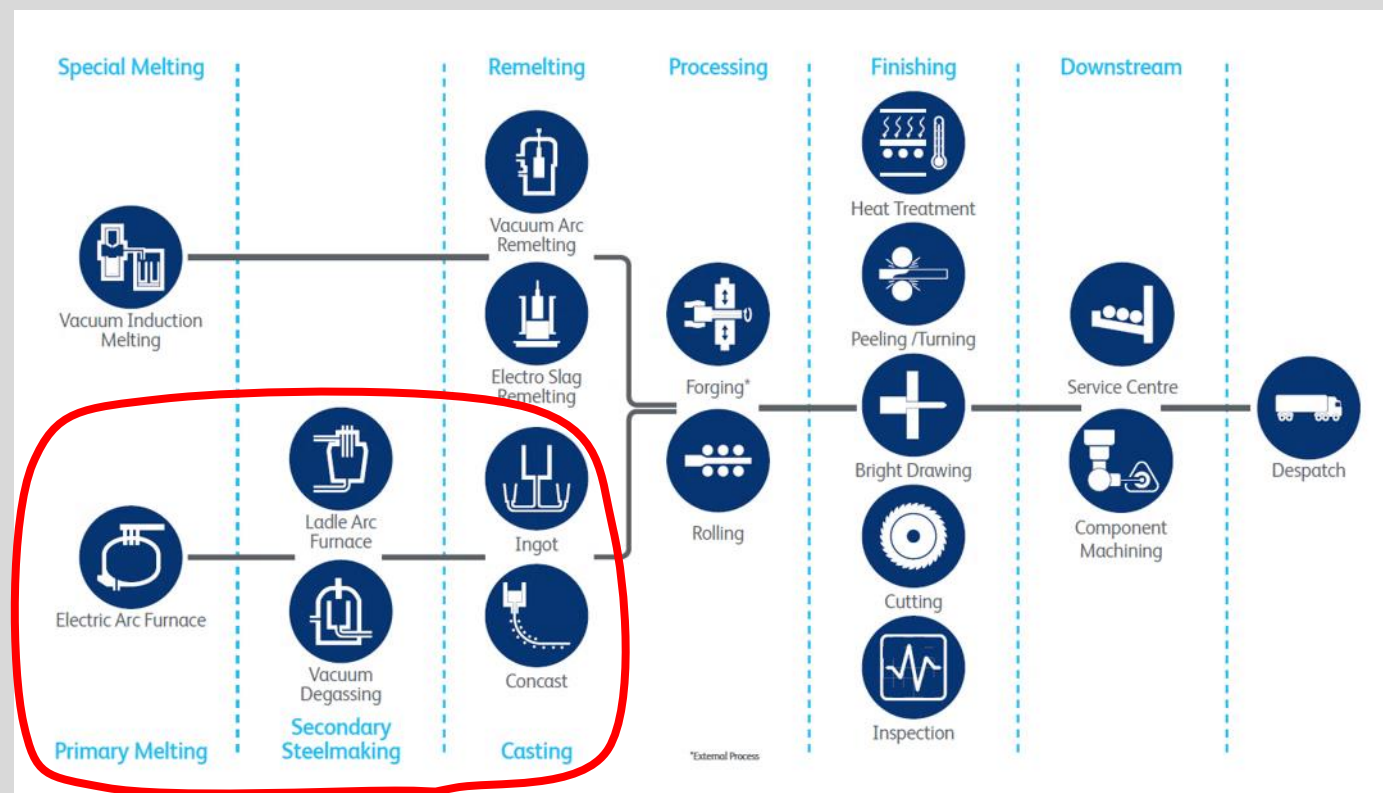
Mr Gareth Griffiths (Liberty Speciality Steels),

Eur Ing Paul Kitson (Materials Processing Institute)

Outline

- Introduction and Background
- Opportunity
- Equipment
- Vibration Data Analysis
- Quality Data
- Results so far
- Conclusion

Liberty Speciality Steels



Aldwarke Cast Products
Meltshop

EngD Programme in ACP

- Influence of Steelmaking Parameters on High Value Alloy Steels for Use in Critical Applications
- The wider EngD programme literature review and company benchmarking exercise identified **ladle stirring monitoring** as a way to answer the research question:

What technologies can link process and product quality?

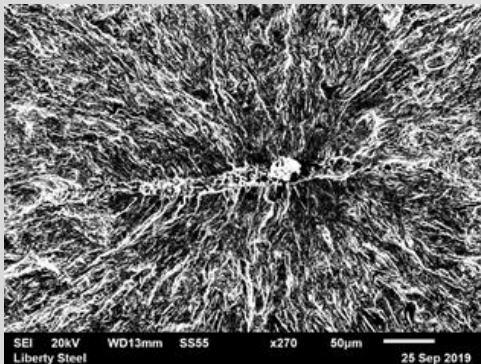
Ladle Stirring Monitoring

Inclusion Monitoring

Slag Chemistry

The Effects of Inclusions

Product quality and processing can be detrimentally affected by non metallic imperfections



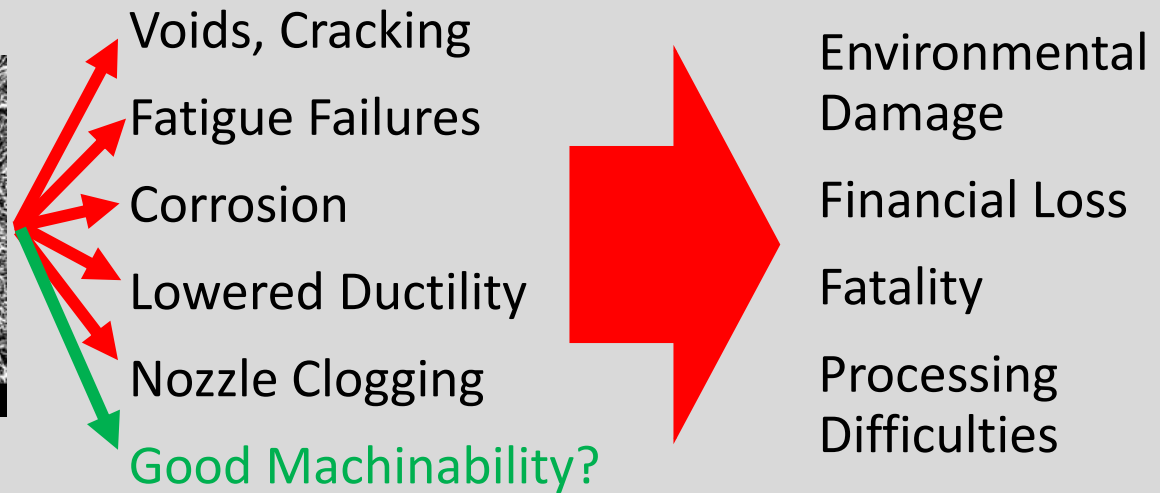
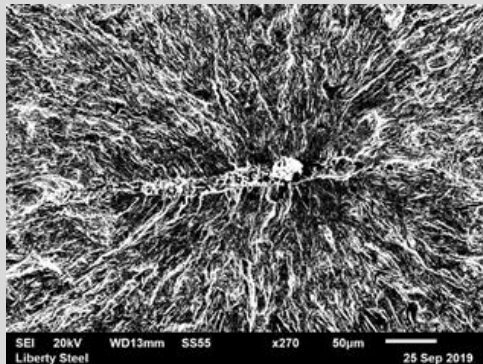
- Voids, Cracking
- Fatigue Failures
- Corrosion
- Lowered Ductility
- Nozzle Clogging



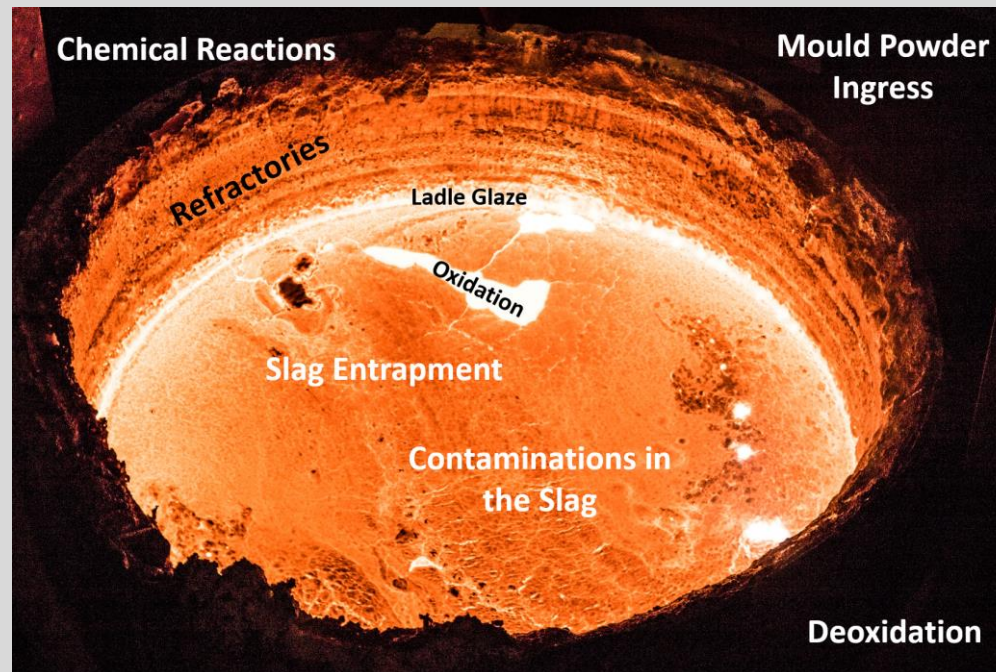
- Environmental Damage
- Financial Loss
- Fatality
- Processing Difficulties

The Effects of Inclusions

Product quality and processing can be detrimentally affected by non metallic imperfections



Sources of Inclusions



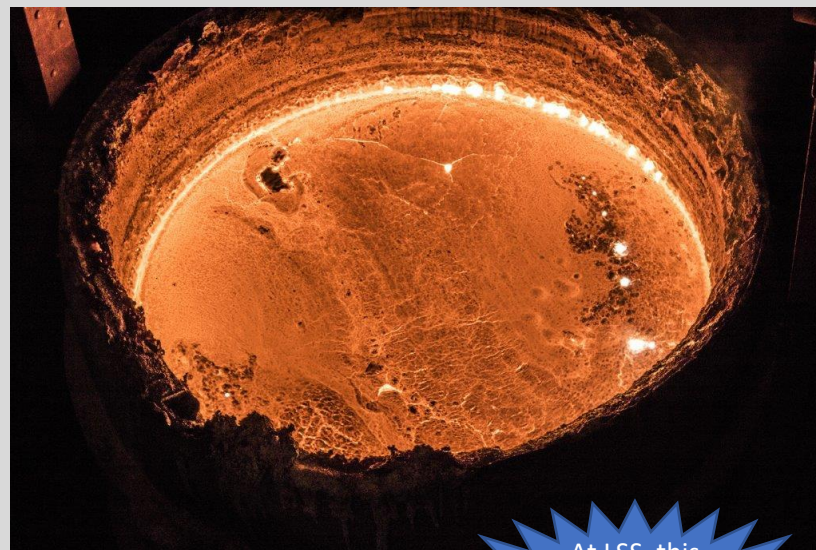
Clean Steels

- Clean Steel: requirements for inclusion content and chemistry
- Huntsman's crucible steelmaking process was the first modern clean steel process
- Clean steels now used in **Critical** applications
- Many factors now driving increased performance



Inclusion Floatation

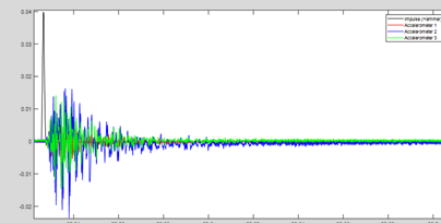
- Steelmakers have developed gentle stirring treatments (termed inclusion floatation) in order to encourage inclusions to move from the steel into the slag...
 - Typically monitored by **observation by the operator**



At LSS, this process typically takes place sub 200 mbar

Inclusion Floatation Monitoring

- There is the opportunity to introduce quantitative measuring by analysis of **vibrations, video and sound**
 - Improved Cleanness → Reduce rework, Improve properties
 - Reduced argon gas and aluminium use → Reduce environmental and manufacturing costs
- Technique can be refined by linking back to product data



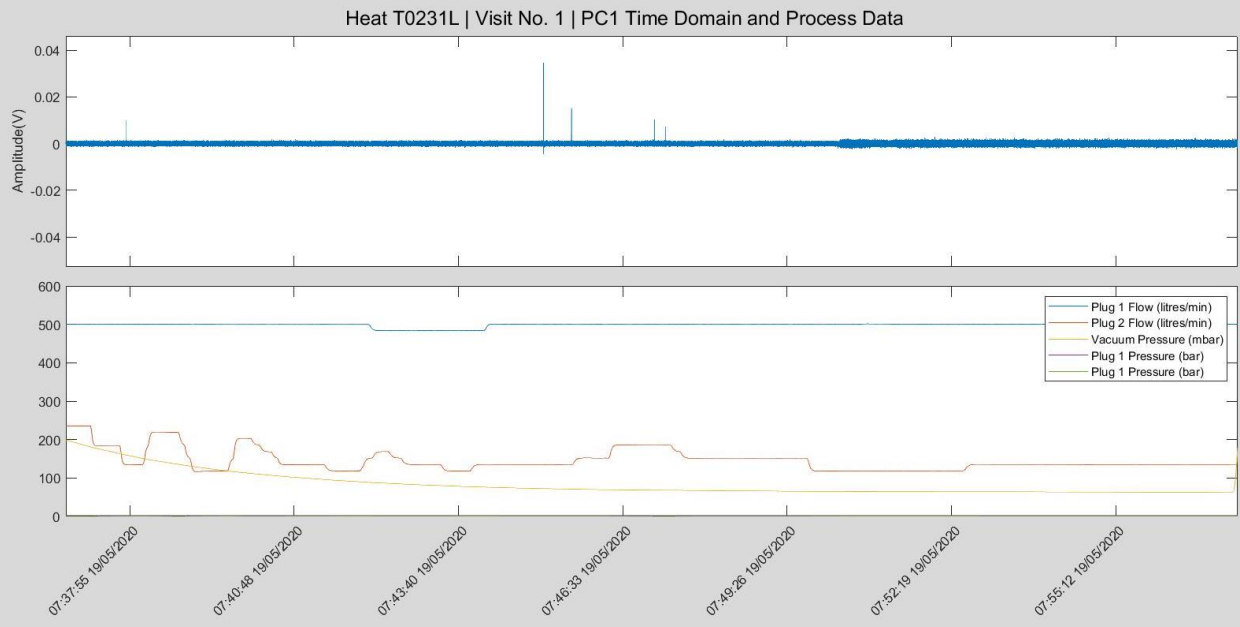
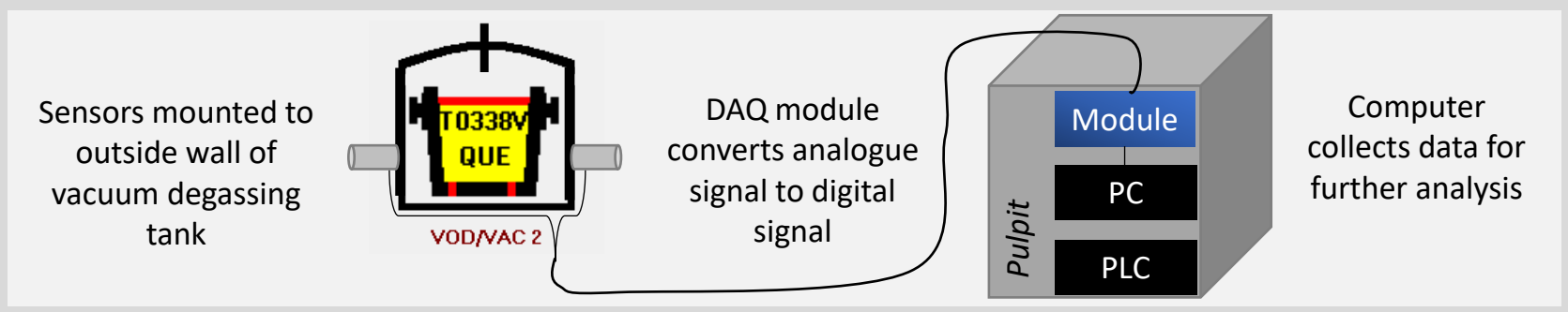
Previous Work using Vibration

Also commercial solutions such as Nupro's system

Work/Year	Physical Modelling	Industrial Trial	Nozzle / Plugs	Experimental Set Up
Burty et al. / 2006-2007	LF	LF	1	1 sensor on ladle wall
Odenthal et al. / 2010	AOD	AOD		1 sensor at vessel bottom
Wuppermann et al. / 2013	AOD	AOD		1 mono-axial at vessel bottom
Nadif et al. / 2012	VTD	VTD	2 eccentric	
Behara et al. / 2014		LF	2 eccentric	1 sensor on ladle car
Yenus et al. / 2016	LF		1 centered	1 triaxial on ladle wall (tested at three different heights)
Pylvänäinen et al. / 2016		VTD	2 eccentric	1 horizontal and 1 vertical on tank
Yenus et al. / 2017-2018	VTD	VTD	2 eccentric	1 triaxial (tested on ladle, support and tank wall)
Alia et al. / 2019	LF		2 eccentric	8 horizontal sensors (different radial and axial positions)
Pylvänäinen et al. / 2020		VTD	2	
Palm et al. / 2020		CAS-OB		2 triaxial on ladle car
<i>Current Work</i>		VTD	1 centered and 1 eccentric	1 triaxial on tank wall

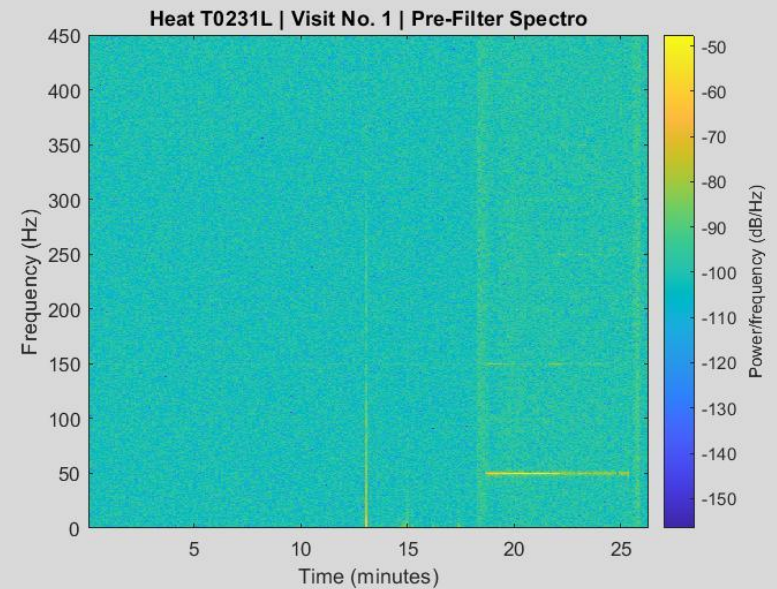
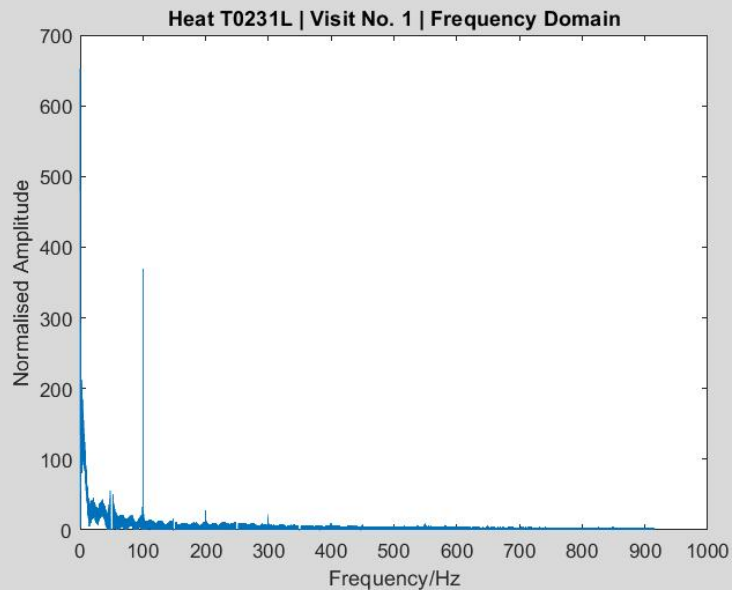
Work in bold summarised by Alia et al. (2019)

Equipment Overview



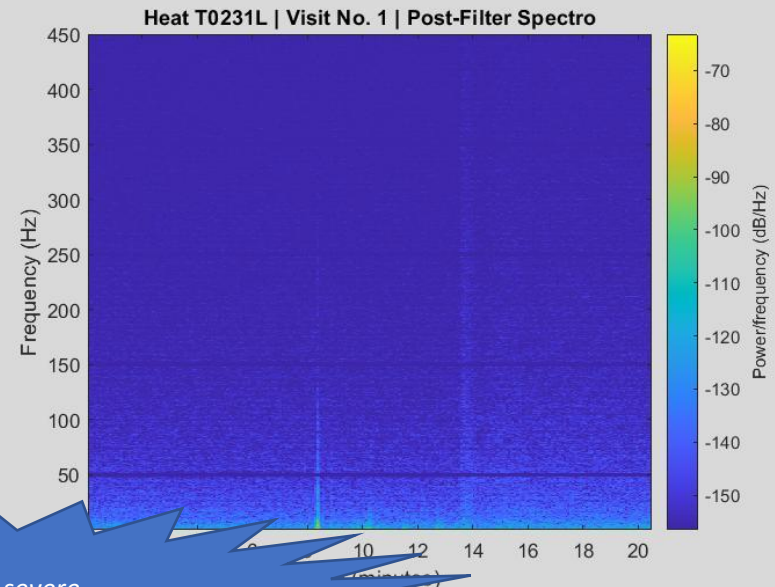
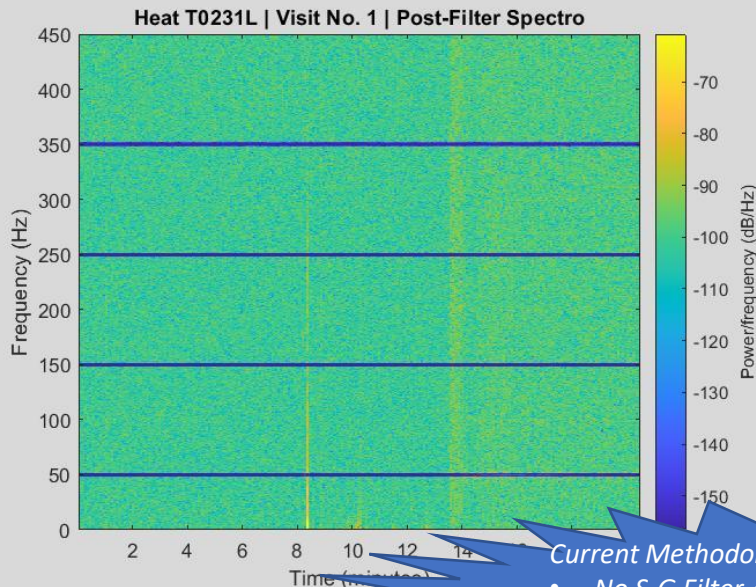
Vibration Data Analysis

Technique	What it does
Fourier Transforms	Reveals what frequencies are present
Spectrogram	Plots frequency and amplitude response over duration of recording



Vibration Data Analysis

Technique	What it does
Band Stop Filter	Removes noise (constant noises, e.g. furnaces)
Savitz-Golay (S-G) Filter	Removes noise (discrete noises, e.g. cranes)

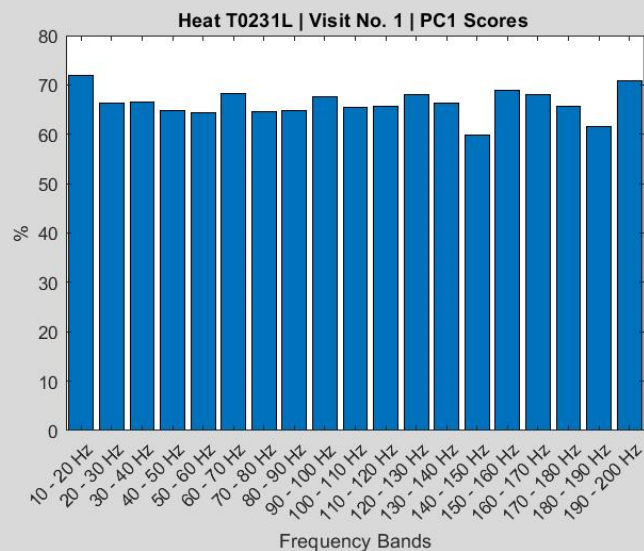
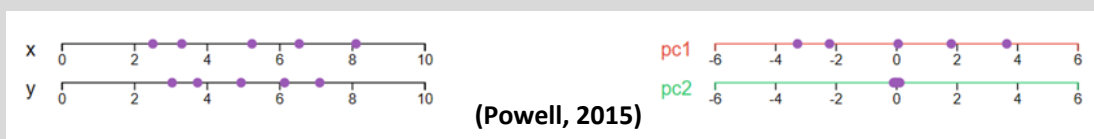


Current Methodology:

- No S-G Filter → too severe
- Band stop (4Hz width) on identified noise frequencies: 50 Hz, 150 Hz, 250 Hz & 350 Hz

Vibration Data Analysis

Technique	What it does
Principle Component Analysis	Recombines multiple variables into one and method of frequency selection for monitoring – TO DO
Root Mean Square	Characterise response of a given frequency band – TO DO
Partial Least Squares	Link vibration data to process and product data – TO DO

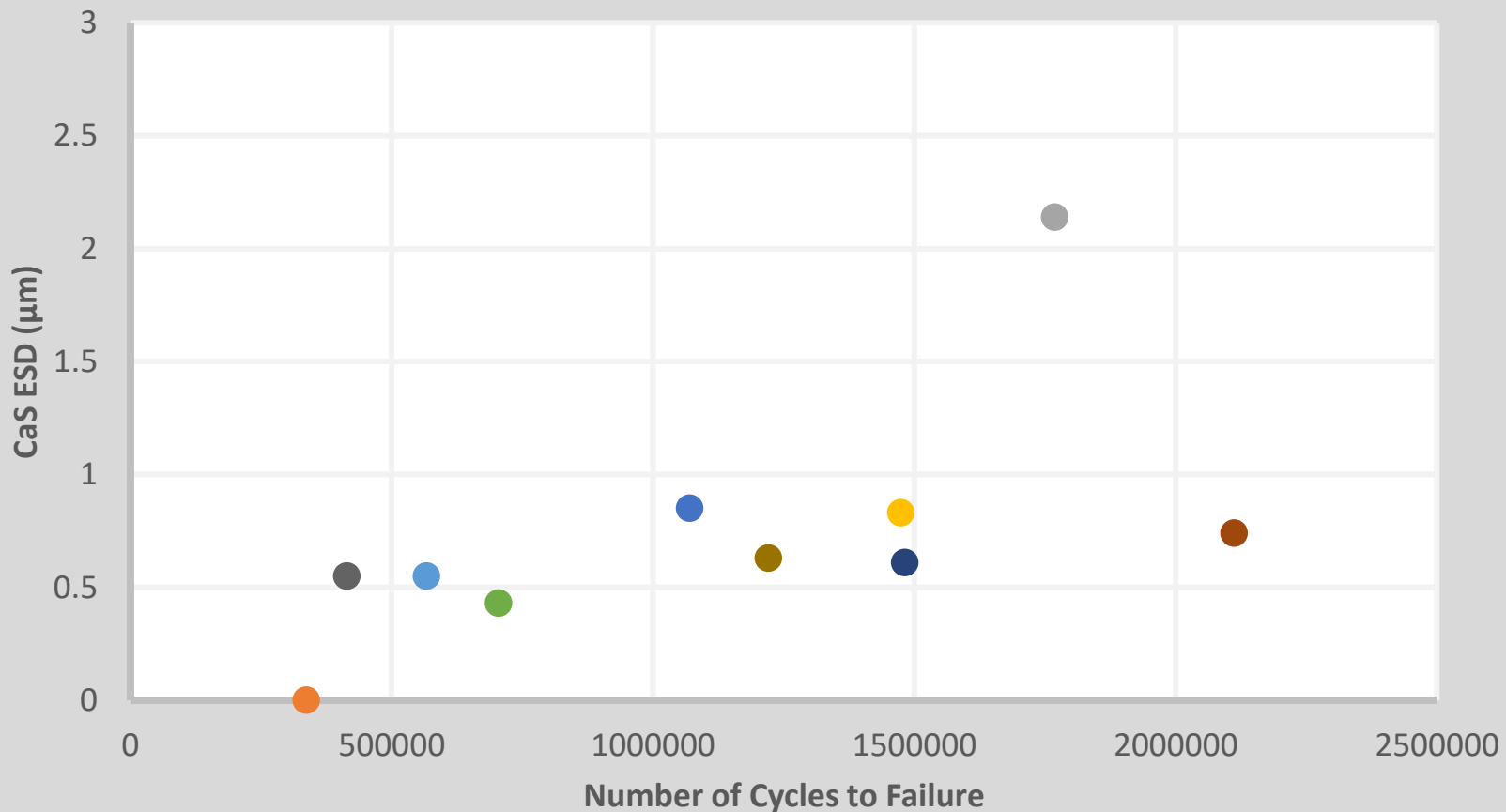


Quality Data

- A single grade was initially targeted with **fatigue** performance as the critical indicator of cleanness
- Other methods have been used:
 - **Lab based Ultrasonic Testing (UT)**
 - number of targets and size
 - **Optical Emission Spectroscopy w/ Pulse Discrimination Analysis (OES-PDA)**
 - snap shot of inclusion types and pseudo-size (ESD)



CaS ESD (μm) vs No of Cycles to Failure



Impact Thus Far...

- Initial Evaluation of Ladle Stirring Technology:
 - In target application (inclusion floatation)
 - In potential future applications
 - Connections made
 - Lessons learning
- Documented Approach to OES-PDA
- Ongoing Work:
 - Finish Data Analysis and Write Up... wavelets???

What technologies can link process and product quality?

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