EPSRC CENTRE FOR DOCTORAL TRAINING IN SUSTAINABLE MATERIALS AND MANUFACTURING

Development of Product and Process Technologies for Manufacturing High Value Alloy Steels used in Critical Applications

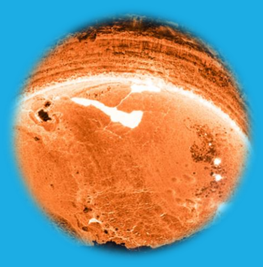
The Past: Huntsman's Clean Steel

- **Benjamin Huntsman** developed the **crucible steelmaking process** in **18th century Sheffield**. The process involved remelting steel bars, produced using the 'cementation process', to aid **removal of non-metallic inclusions** (such as oxides, sulphides and silicates) and improve homogenization. The steel produced was found to be ideal for clock springs which traditionally suffered from fatigue.
- **Crucible steel** may be regarded as one of the **first clean steels**. These are steels which require some level of **control over inclusions**.
- **Liberty Speciality Steels** continues this heritage by producing steels with strict inclusion control for **critical applications** such as **aircraft landing gear**.
- However, while **existing process parameters** have been optimised in last twenty years, there is still a **desire for increased performance** from modern **environmental and economic** drivers. Hence, this project is **trialing new product and process technologies** so that steelmaking can become even more closely controlled and create opportunities for **improved product performance**.

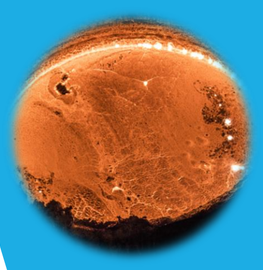
The Current Clean Steel Production Process

Process Flow with Selected Existing Parameters

Electric Arc Furnace
Scrap Mix
Temperature
Steel Chemistry



Ladle Furnace
Alloy Additions
Temperature
Steel Chemistry



Vacuum Tank Degassing
Temperature
Steel Chemistry

Uphill Ingot Teeming
Refractories
Casting Speed
Steel Chemistry

Vacuum Arc Remelting
Melt Rate
Arc Gap

Rolling and Finishing
Rolling and Turning Parameters
Heat Treatment
Drawing and Cutting

Inspection
Inclusion Size
Inclusion Chemistry
Fatigue Performance

Concorde's landing gear contained 35NCD16 steel, while Boeing's 747 contained 300M steel…

both steels continue to be produced for similar applications today!

Potential Future Clean Steel Technologies

Benchmarking and Literature Reviews were used to answer the project's research question:
What technologies can link product and process?

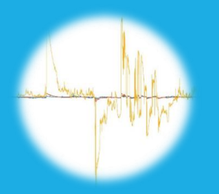
Slag Chemistry Monitoring

- **X-ray Fluorescence Analysis (XRF)** enables chemical composition monitoring of steelmaking slags during processing allowing for potential changes can be made to hit an ideal composition each time.
- Initial trials found that XRF could **successfully detect changes in slag chemistry across a campaign** despite the same slags being applied to each cast.
- Existing and newly designed slag sampling probes were also tested as part of this work.

Commercially available slag sampler prior to testing

Vibration Monitoring of Inclusion Floatation

- **Molten steel stirring** in the ladle by **injecting argon gas under vacuum encourages inclusions** to migrate to the **slag**.
- Typically monitored in the industry by manual observation, the use of **vibration monitoring** was trialed in order to quantify stirring so optimum stirring conditions can be achieved on every cast.
- Unfortunately, the technology could not find a characteristic frequency for the stirring due to equipment deterioration and background noise.



Vibration monitoring test raw data

Inclusion Monitoring by OES-PDA

- **As part of this work was also undertaken:**
  - **Optical Emission Spectroscopy (OES)** is used routinely for bulk steel analysis on 'lollipop' samples by applying a number (~100s) of sparks to the metal surface creating characteristic emissions.
  - **Pulse Discrimination Analysis (PDA)** looks at variation between individual sparks to spot when a precipitate has been analysed (i.e. non-metallic inclusions).
  - OES-PDA is a combination of these techniques in a single test.
  - Trials found **OES-PDA could map inclusion development** from the ladle furnaces to uphill ingot teeming and **potentially predict product quality** on some grades, but this relationship wasn't always clear and **there remain concerns over best practice for sampling.**

Lollipop sample used in steelmaking

Inclusion Monitoring by XCT vs UT

- Emerging techniques, such as **x-ray computed tomography (XCT)**, promise to deliver extra information on inclusions, such as morphology, which cannot be gained by existing ultrasonic inspection (UT) or microscopy techniques as proved in this work.
- Trial work proved this technology could be used on customer complaints at LSS to give morphology information and a new sample design for the technique was developed.

Conclusion

- **Vibration Monitoring** requires **further development**
- **XCT** is a useful inspection technique giving inclusion morphology
- **OES-PDA** data can be a useful description of process with possibility of predicting product quality
- **XRF data gives e**xtra process monitoring information (slag chemistry) which can also be used in development work

Use OES-PDA and XRF routinely at:

- Electric Arc Furnaces (XRF only)
- Ladle Furnaces
- Vacuum Degassing Tank
- Uphill Ingot Teeming

Use XCT as a development tool at the inspection stage

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Steel processing images courtesy of Liberty Speciality Steels

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