

The use of oxygen activity measurements to determine compacted graphite structure

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Outline

- **Background**
- **Previous work on ductile iron**
- **Experimental Results**
- **Two Step method**
- **Accuracy of sensor**
- **Conclusions**

Background

- Higher peak pressures during combustion in diesel engines
 - Improvement of the fuel economy
 - Diminish the harmful components in the exhaust gases
- Current aluminum alloys and lamellar graphite cast iron have reached their mechanical limits
- Compacted graphite iron with pearlitic matrix has a yield strength of 350 MPa

Compacted graphite iron

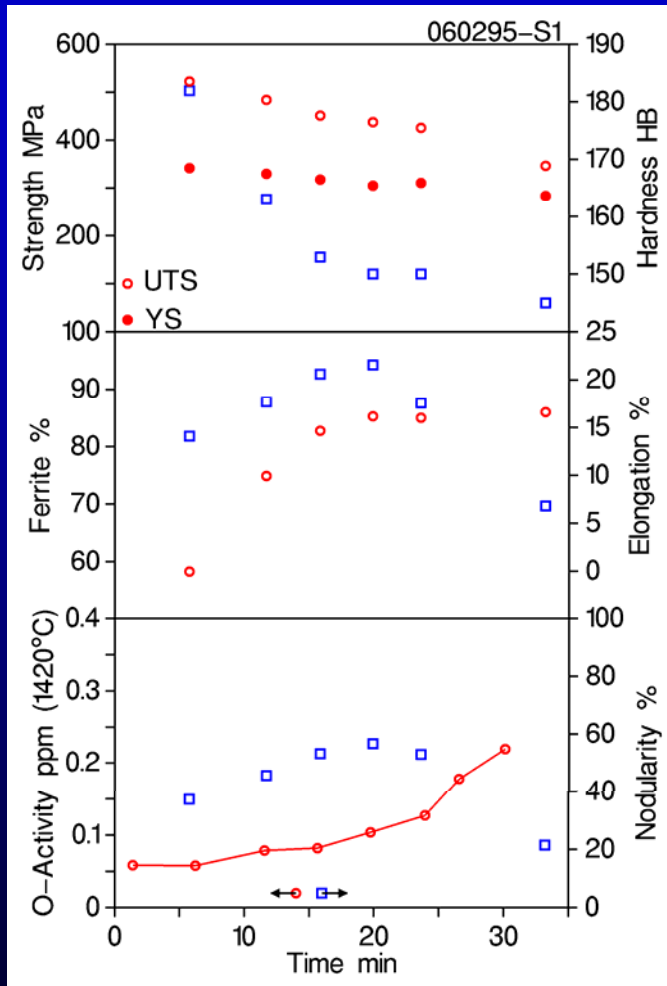
- **Small production window**
- **Production control**

Thermal analysis

Acoustic resonance analysis

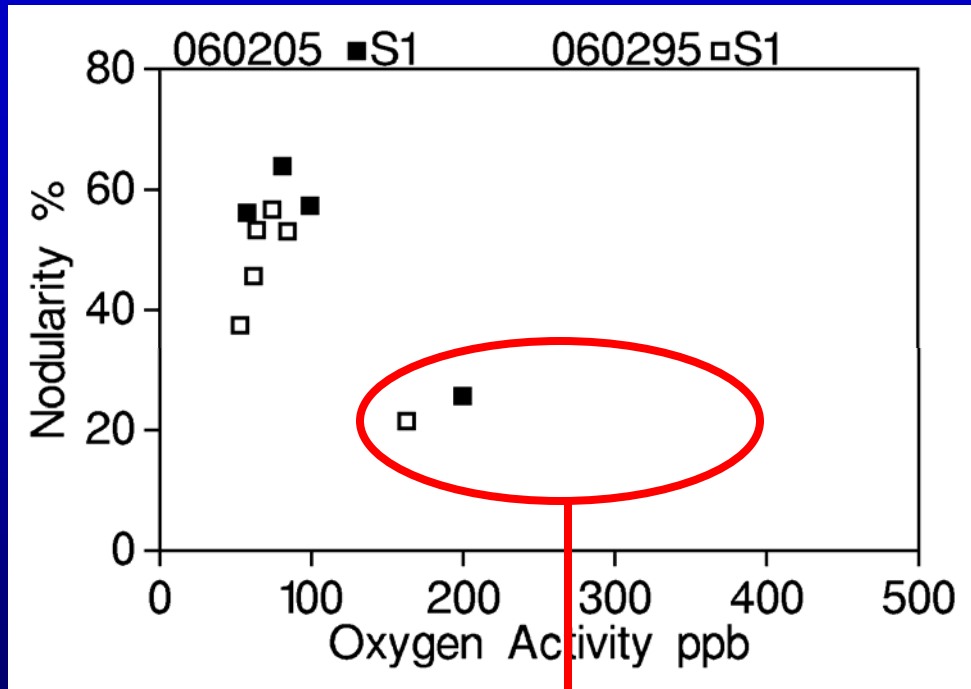
Oxygen activity measurement

Previous work on ductile iron



- Necessity to recalculate all oxygen activities to a reference temperature (1420°C).
- Nodularity
Particles with length to thickness ratio < 2

Previous work on ductile iron



- Nodularity maximum at the same oxygen activity
- Maximal nodularity and ferrite content (→ ferritic thick wall castings)

What about CGI?

Goal of the present research

Examine if a useful relation can be established between oxygen activity and the production window for compacted graphite cast iron

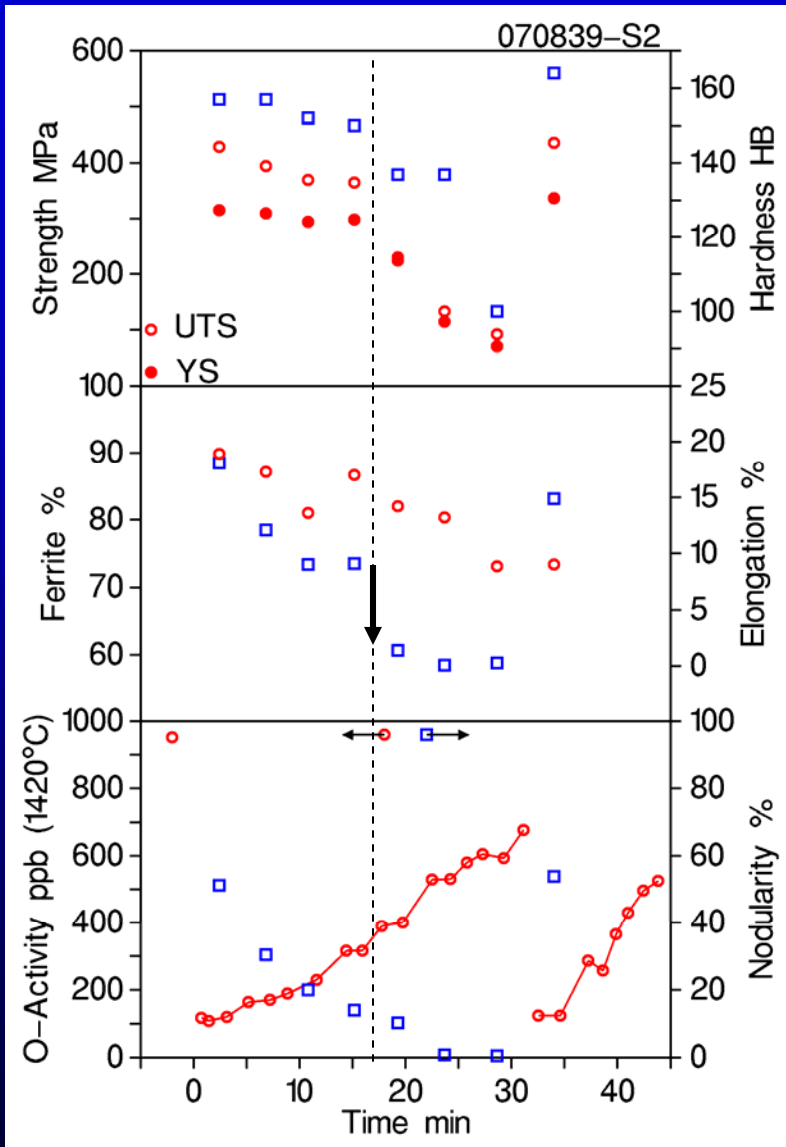
Experimental procedure

- Add Mg-wire to a melt (220 kg) – keep the melt at constant temperature (1420°C)
- Measure oxygen activity
- Regularly pour Y-blocks
 - mechanical properties +
graphite morphology +
ferrite/pearlite
- Sorel iron – Cu, Mn, Sn (Pearlite increase)

Follow transition from ductile iron (too low Mg) → compacted graphite cast iron → lamellar graphite cast iron

Ferritic matrix

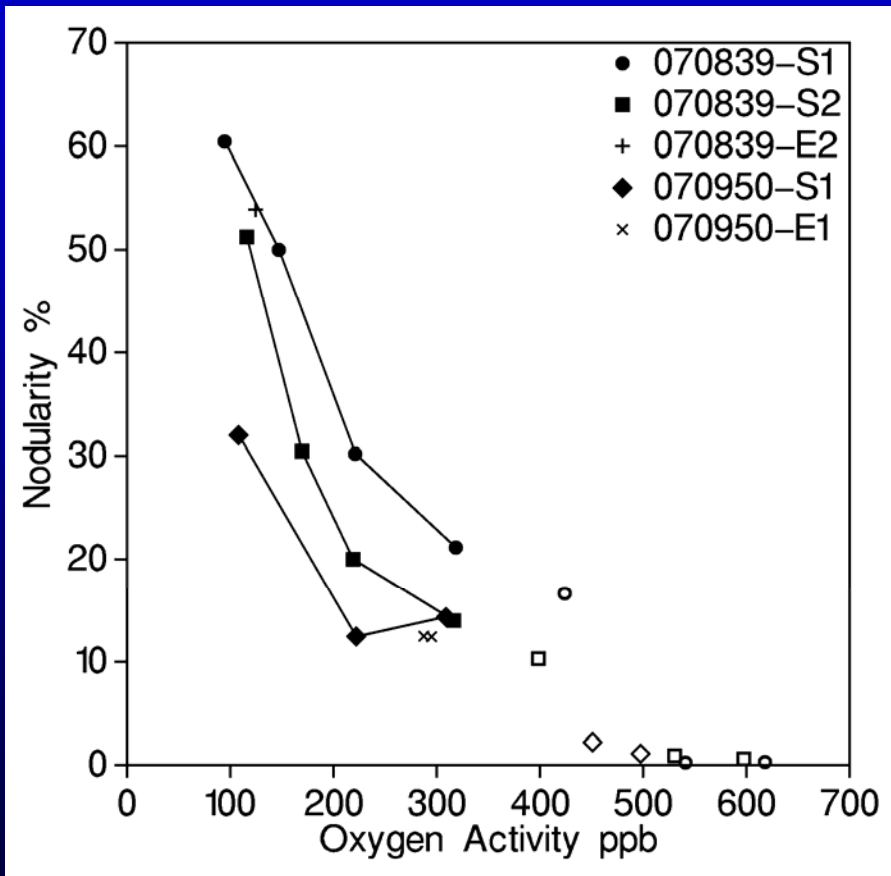
- Sudden drop of elongation and tensile strength (advantage of the ferritic matrix)
- In the vicinity of the transition, nodularity often hardly changes
- ISO Standard



Mg fade (and a_o) may be discontinuous
as a function of the time
(depending on furnace power on/off)

→ plot properties as a function of a_o

Ferritic matrix

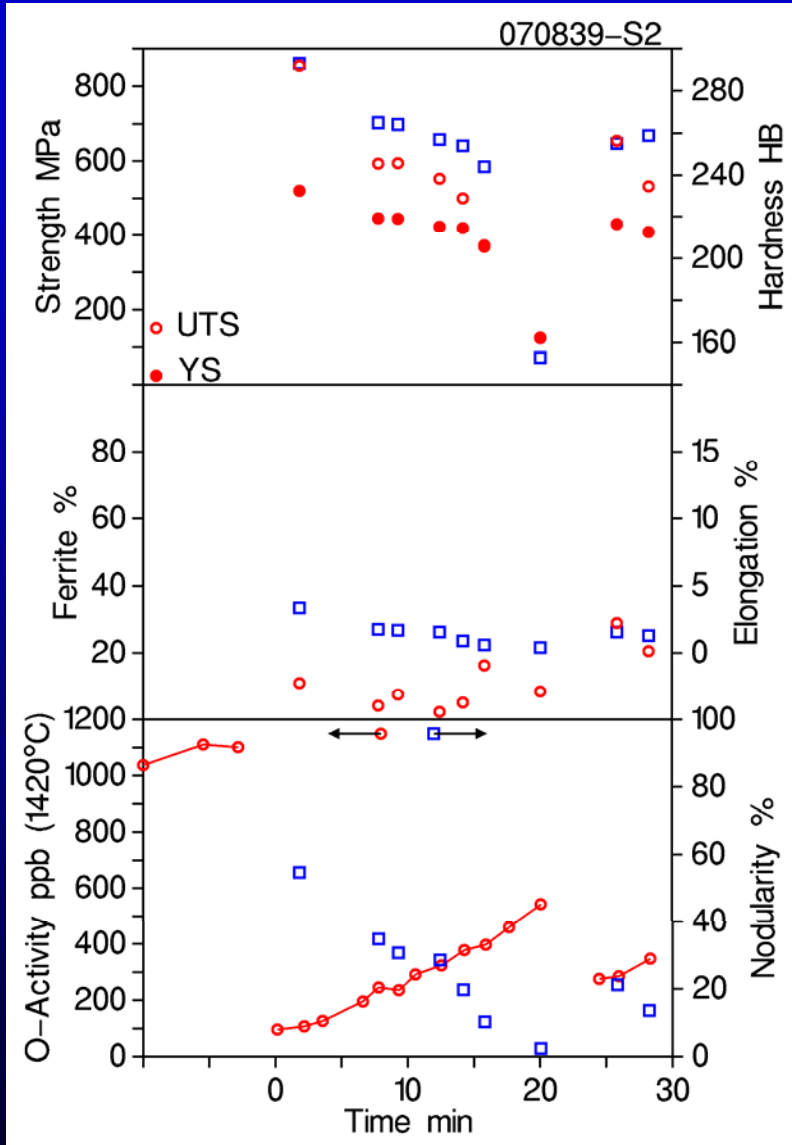


- Lower values of nodularity occur when initially less magnesium is added
- Open symbols do not comply with the ISO standard

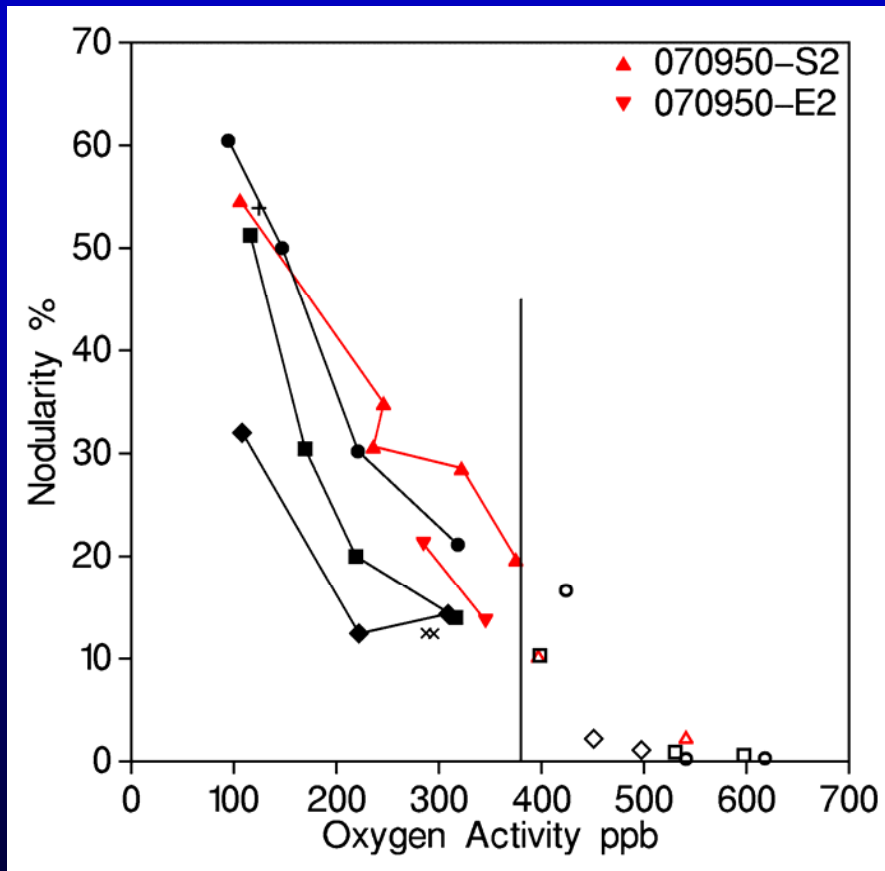
- **The previous experiments also show that mechanical properties are needed to determine if a Y-block meets the ISO requirements. Examination of the graphite structure alone is not sufficient.**
- **Extra Y-blocks poured after an extra magnesium addition to the melt, are in line with the 'normal' data**

Pearlitic matrix

- ISO Standard
16112/JV/500/S
**Tensile Strength
500 N/mm²**
**Yield strength
350 N/mm²**



Pearlitic matrix

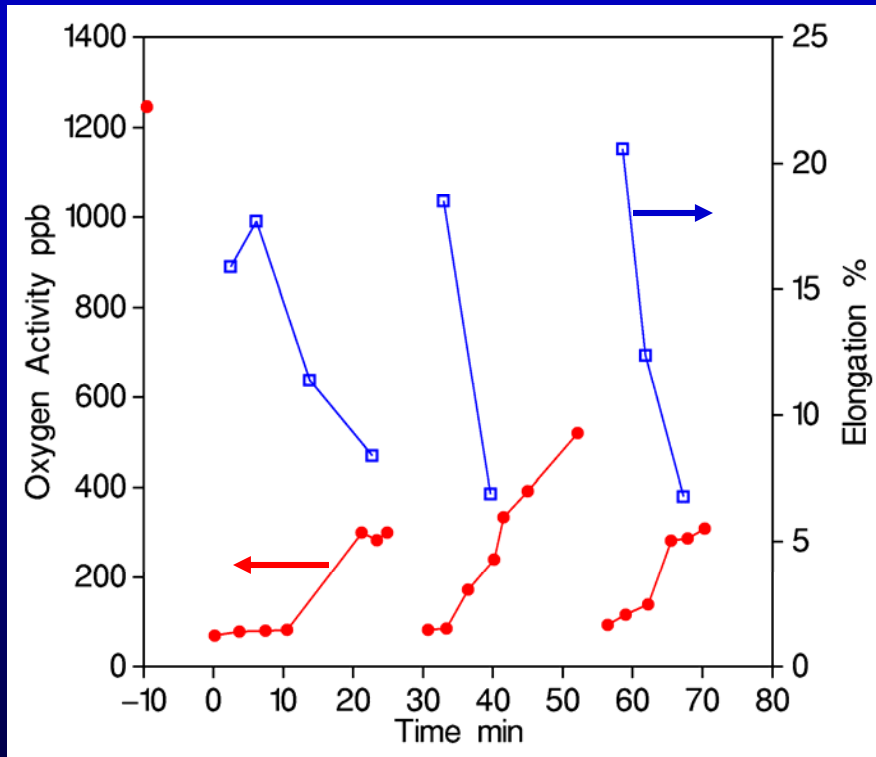


Pearlitic (red)

Ferritic (black)

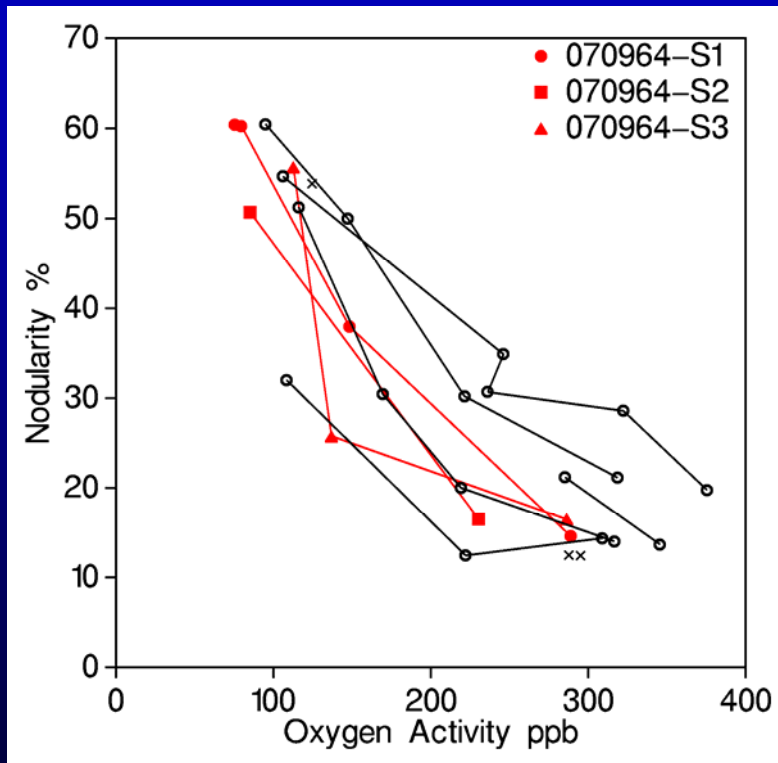
Left of the vertical line, minimal mechanical properties for compacted graphite are met.

Influence of repeated Mg additions



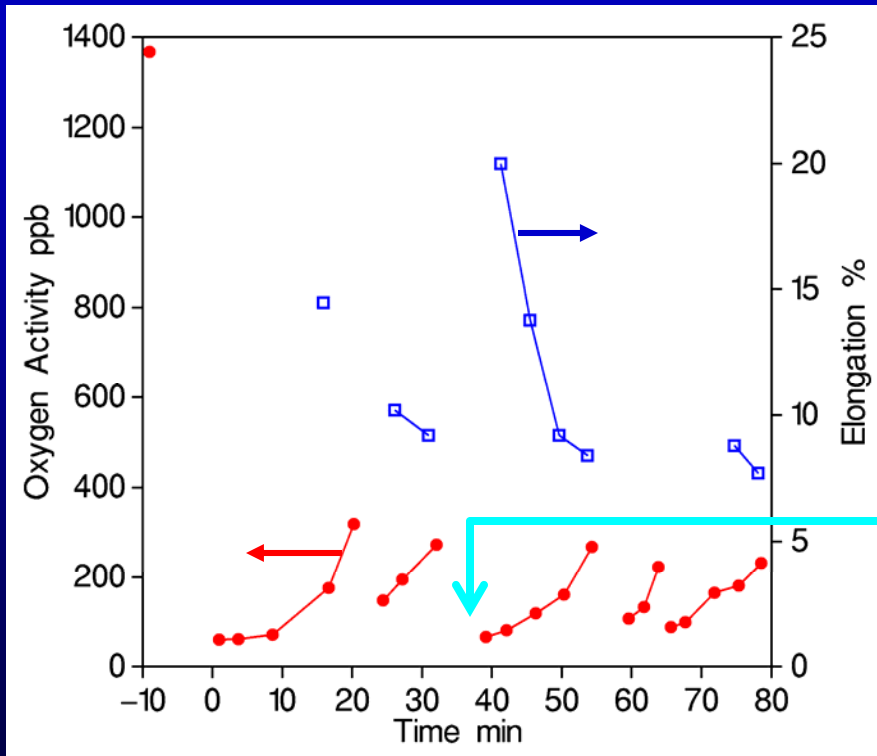
- Ferritic matrix
- Si 2.0 → 3.0%

Influence of repeated Mg additions



- Previous results (black)
- All points shown comply with the ISO standard

Influence of inoculant type and sulfur



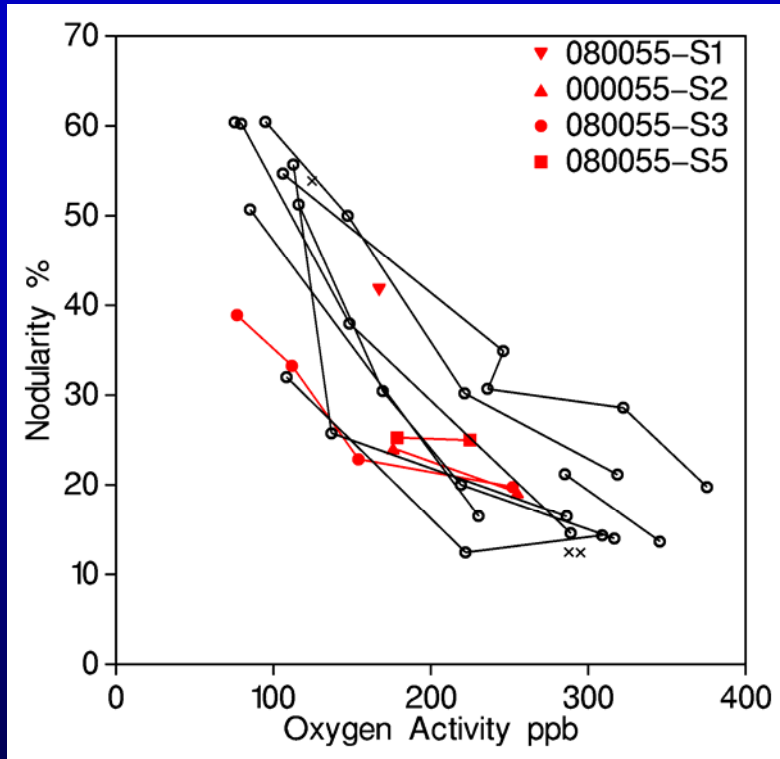
**General purpose
inoculant (Zr)**

**Ce-Bi based
inoculant**

**Extra addition of
sulfur**

(30 → 80 ppm)

Influence of inoculant type and sulfur



- Ce-Bi based inoculant (red) previous results (black)
- Extra addition of sulfur (S3)

The addition of fresh sulfur results in lower nodularity at a certain oxygen activity

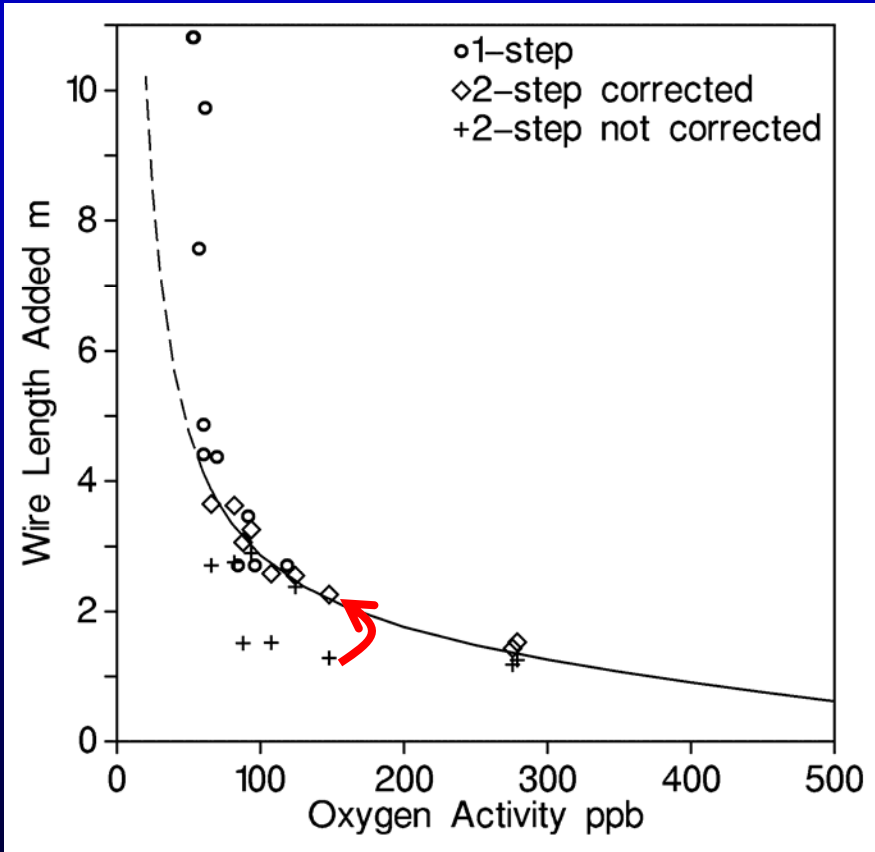
One step Mg method

- **Industrial melt contains S and oxides (variable amount) which consume Mg**
- **Not suited for the small production window of CGI**

Two step Mg method

- **First Mg addition → too low a Mg content to produce CGI**
- **Measure oxygen activity**
- **(Target – measured) oxygen activity
→ length of Mg wire**

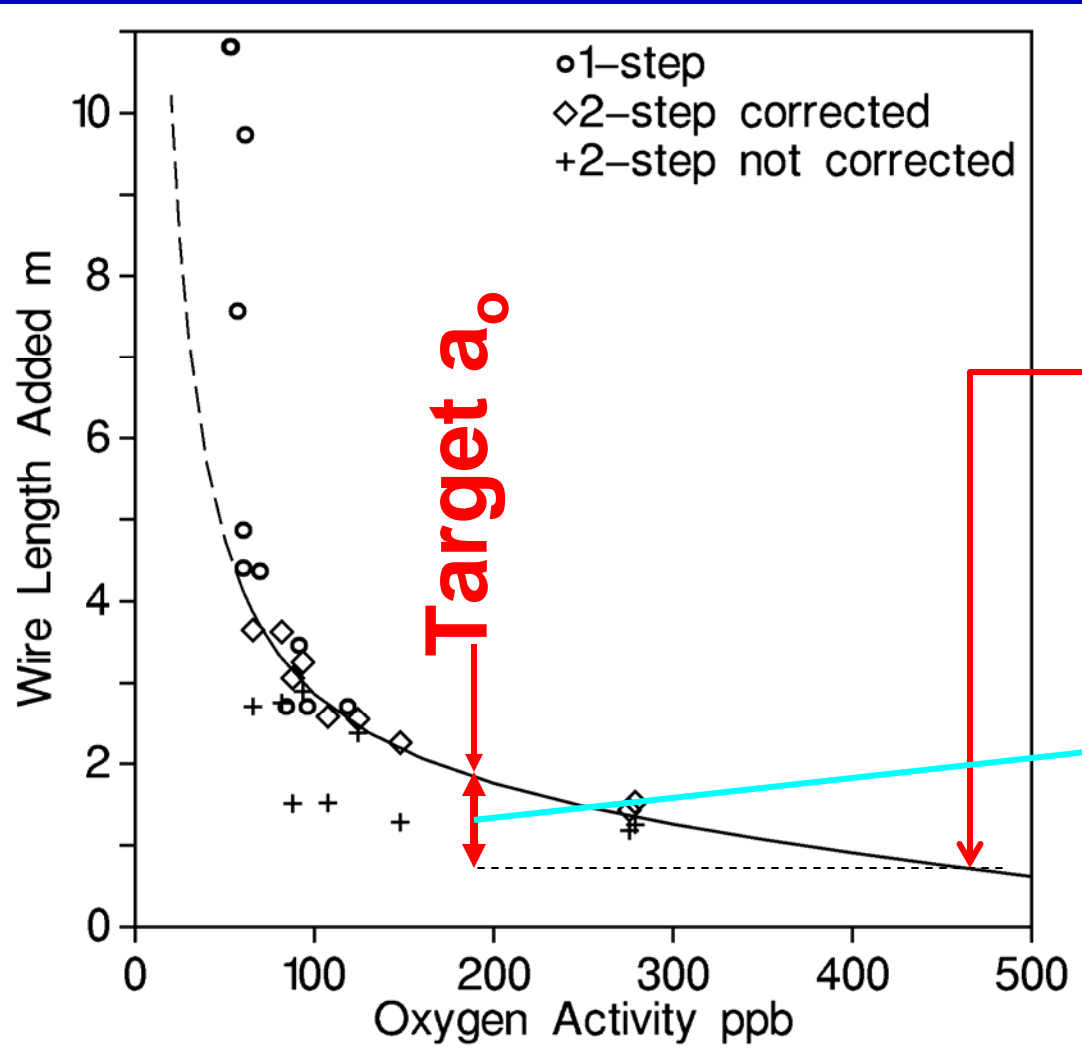
Two step method



Total wire length =
length 1st addition
plus
length 2nd addition

→ Unique curve

Two step method

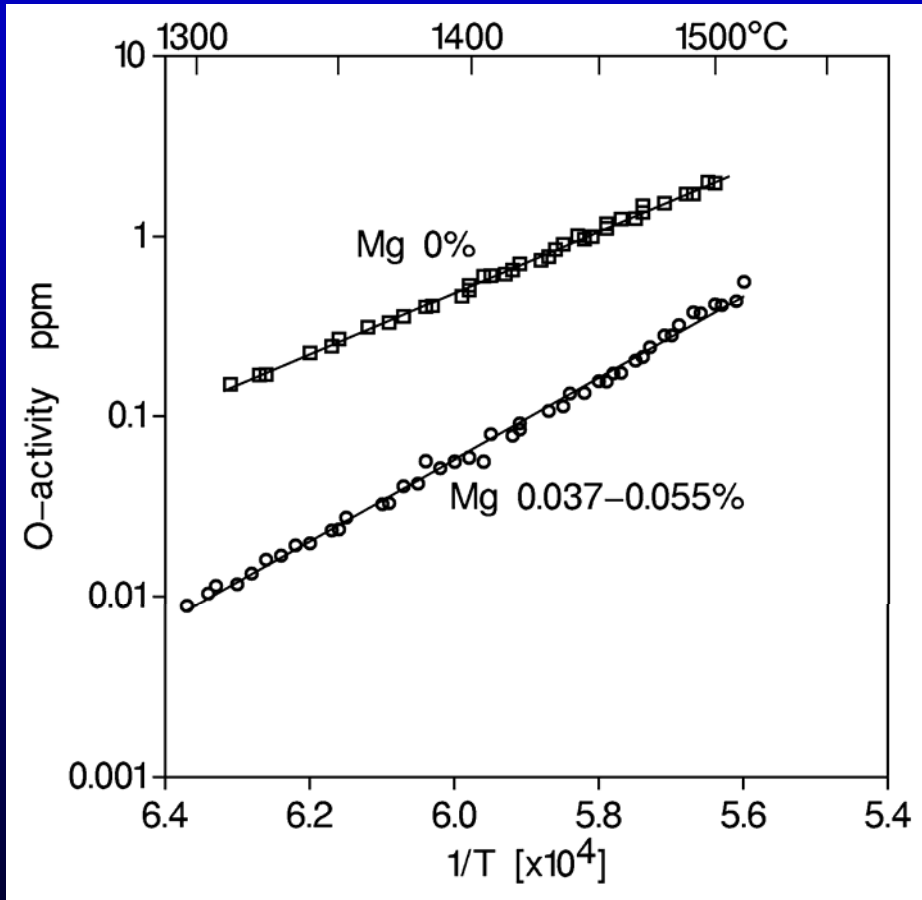


Add Mg

Measure a_o

Length 2nd addition

Accuracy and Reproducibility



Gray iron

ppb	σ
100	3.69
300	11.1
1000	36.9

Ductile iron

104 3.73

Conclusions

- A new sensor for oxygen activity
- A well defined oxygen activity for the upper limit of CGI (380 ppb)
- $a_{\text{O}} > 380$ ppb : min values of ISO standard, are not met anymore
- $a_{\text{O}} < 380$ ppb : range of nodularities exists, lower ones for higher S content
- Measurement is easy and quick (12 s)