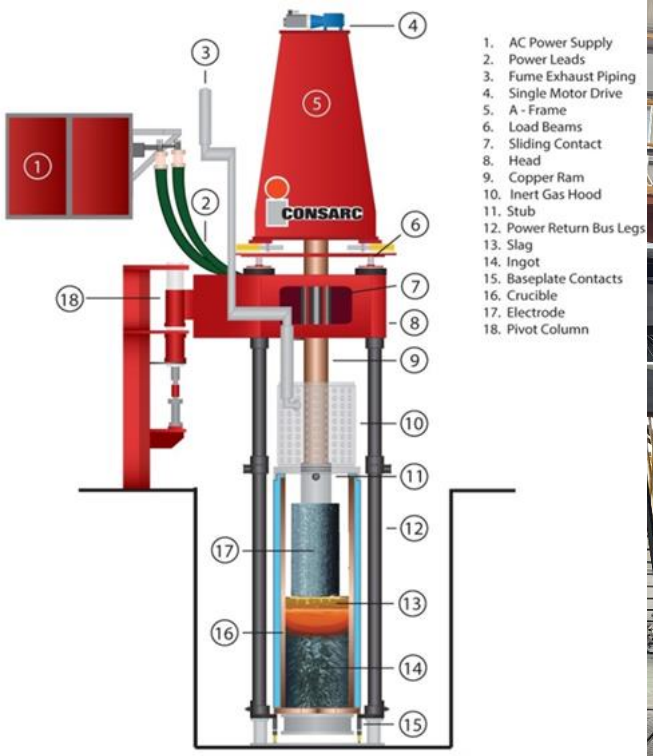

1. AC Power Supply
2. Power Leads
3. Fume Exhaust Piping
4. Single Motor Drive
5. A - Frame
6. Load Beams
7. Sliding Contact
8. Head
9. Copper Ram
10. Inert Gas Hood
11. Stub
12. Power Return Bus Legs
13. Slag
14. Ingot
15. Baseplate Contacts
16. Crucible
17. Electrode
18. Pivot Column

Importance of Electrode Properties and Preparation to Achieve Consistent High Quality ESR Ingots

CONSARC
An Inductotherm Group Company

Eike Schmilinsky
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Consarc Corporation

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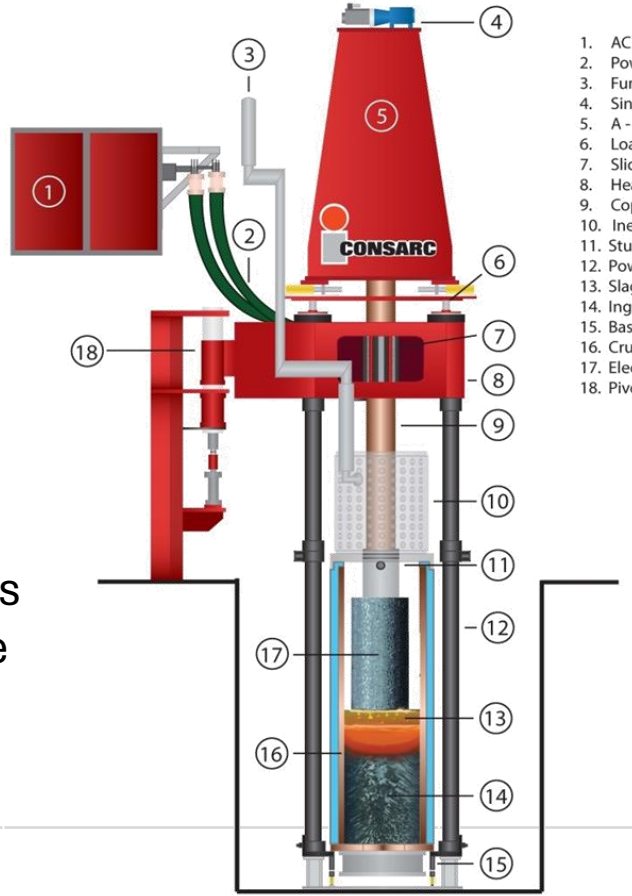
Content

- ESR process
- ESR electrode quality
- ESR electrode preparation tools
- ESR electrode final inspection
- ESR starter plate and slag handling
- Melt rate deviations due to lack of heat treatment
- Ask your customers for feedback
- Summary

1. Introduction to ESR

- Air or inert gas remelt
- AC power heats slag between electrode and ingot
- Faster melt, deeper pool (compared to VAR)
- Most inclusions dissolve as the drops pass through the slag



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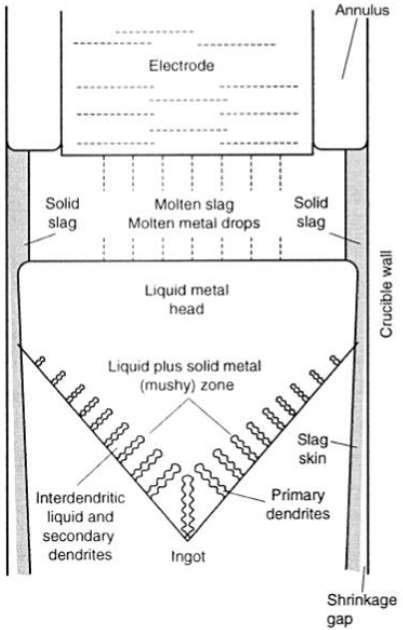
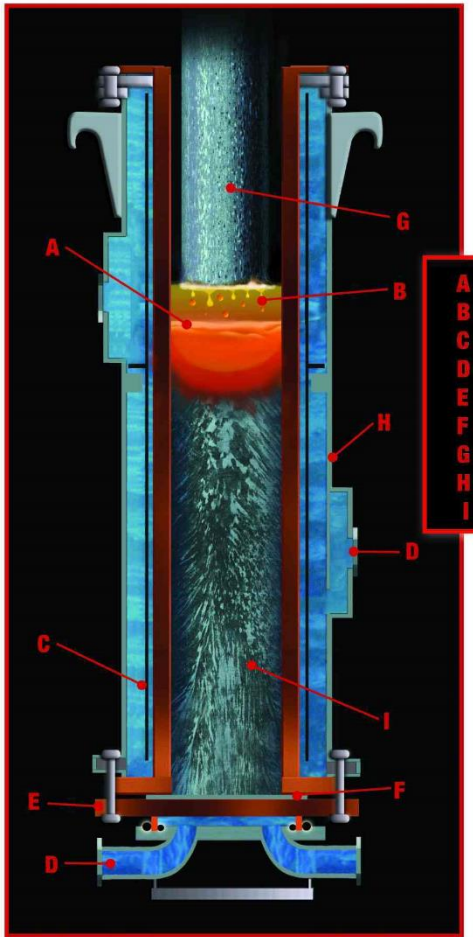


1. Introduction to ESR

ESR challenges (some of them…)

- **Consistent high-quality electrodes are the foundation for a stable ESR operation & high-quality ingots**
- Includes feedback from your electrode supplier (VIM, air-melt) and your ESR ingot customer (forging shop)
- Check list guided startup preparation – don't cut corners
- Good slag storage & handling to avoid quality issues
- Starter plate preparation needs careful attention
- Continuous operator training in safety & quality issues
- Preventive maintenance to avoid damage of equipment
- ESR shop should always be ready for visits or audits of OEM
- Do everything, as if you would produce rotating parts



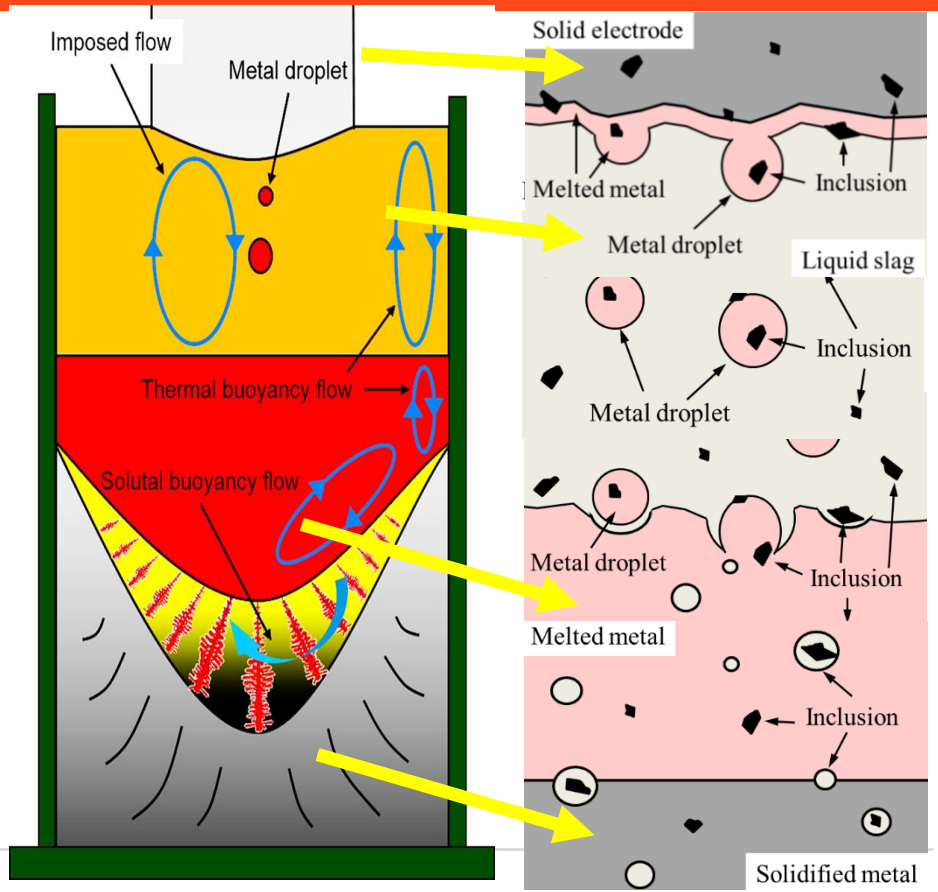
Inclusion Removal in ESR

- **Inclusions are inevitably present in electrodes; removal by either ESR or VAR has limitations (“garbage in = garbage out”)**
- Inclusions dissolve *to some extent* during electrode melting, but most are still present when the liquid contacts the high temperature region (the ESR slag)
- High temperature (1600°C to 1750°C) contact is short, large inclusions will not be removed
- Inclusions formed by solidification precipitation are not removed
- ESR dissolves most ceramic inclusions (from e.g. hot top) in the slag
- Any moisture (cooling liquid from band saw cutting or starter mixture turning, moisture from the slag, water leaks) can cause gas bubbles in the bottom of the ingot

Reference 1

Inclusion Removal in ESR

- Primary inclusions, Al_2O_3-MgO inclusions containing >10% MgO and <10% CaO (Type AM), are assumed to be **electrode inclusions** trapped in drops that have fallen from the electrode tip, through the slag bath to the steel pool, **without being overheated and dissolved.**
- According to the literature, the **diameter of the (ESR) droplets** leaving the electrode is generally in the range of 1-10 mm but **usually about 5 mm i.e. much larger than the individual inclusion size.**



References 2, 3

Feedback from your (internal) electrode supplier will help

Air-melt shop / VIM – should cooperate with the remelt shop to get the best electrode quality (raw material, pouring, hot top, mold maintenance, timely transfer into heat treatment after pour etc.

2. ESR Electrode Quality – Pouring Ring

- Pouring Ring is formed when there is an interruption in electrode pouring process
- Defect must be identified, recorded and marked
- The defect can be ground out of the electrode

2. ESR Electrode Quality – Common Issues

Transverse Crack

- Can be obvious or beneath the surface

Poor quality refractory base

- Washout

Incomplete hot top fill

Large shrinkage cavity

- could be full of oil, turnings from cutting, slag etc.

2. ESR Electrode Quality – Shrinkage Cavity

- Measure diameter
- Measure depth
- Inspect if it is empty or full
- Any contamination with non-metallic material (slag, etc.) could influence your ESR process and might change the slag chemistry
- Take measures to remove it or at least be aware
- If the top is having a clean 90° cut, it could be beneficial to weld the stub on the hot top side

2. ESR Electrode Quality – Surface Issues

- Double skin is dangerous for ESR ingot quality
  - Might not get completely melted in the slag and could cause a major inclusion in the finished ingot
- The inner side of this overrun is oxidized and there is only a little connection to the electrode, pieces could fall off during ESR and enter the ingot partly unmelted

OUTSIDE

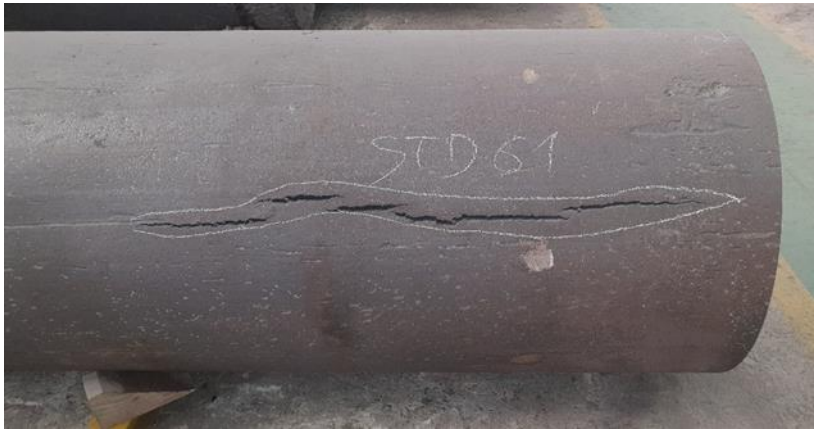
INSIDE

2. ESR Electrode Quality - Double Skin

- Double Skin defect must be identified, recorded and marked
- Thin layer of metal must be removed
- After removal it is still advised to remelt the electrode with Hot Top up

2. ESR Electrode Quality – Surface Cracks

- Transversal cracks should not be present
  - Pose a potential brake away danger
- Longitudinal cracks
  - A consequence of improper casting
- Cracks are to be inspected, measured, location recorded and documented



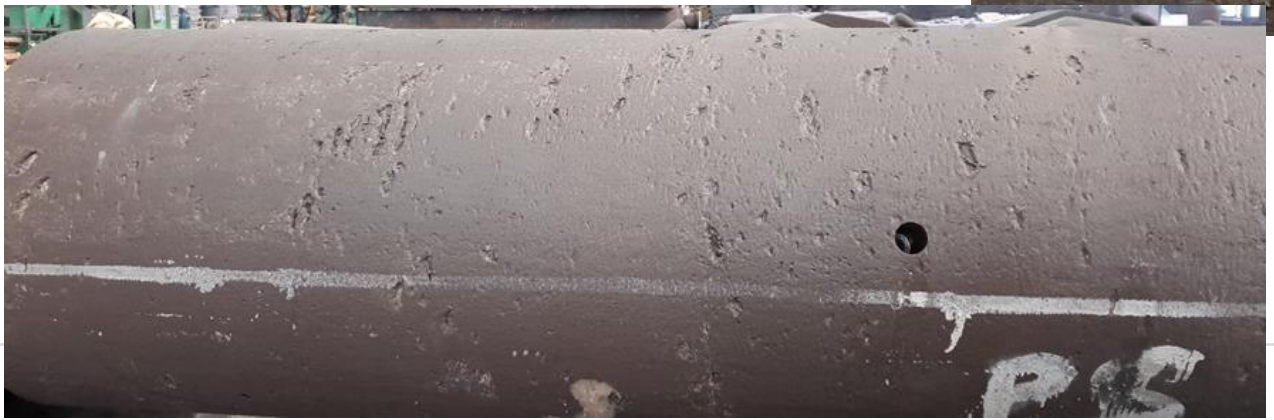
2. ESR Electrode Quality – Surface Cracks

- Cut away part with cracks
- Remove cracked area
  - Should be minimal oxide surface originating from crack removal

2. ESR Electrode Quality – Other Defects

- Trapped Casting Flux / Sand Marks
- Shells
- Teeming laps
- Subcutaneous Blowholes
- Porous electrode
- Fire Crack Marks

- Tension Cracks
- Longitudinal Scoring
- Transverse Scoring
- Fins
- Rippled Surface



3. Electrode Preparation Tools – Band Saw Cutting

- Cutting top and bottom with band saw might cause issues but is still most common
  - Non vertical cut because band saw is drifting away
  - Shrinkage cavity causing band to tarnish or even break
  - Time consuming and remaining shrinkage is covered in cooling liquid

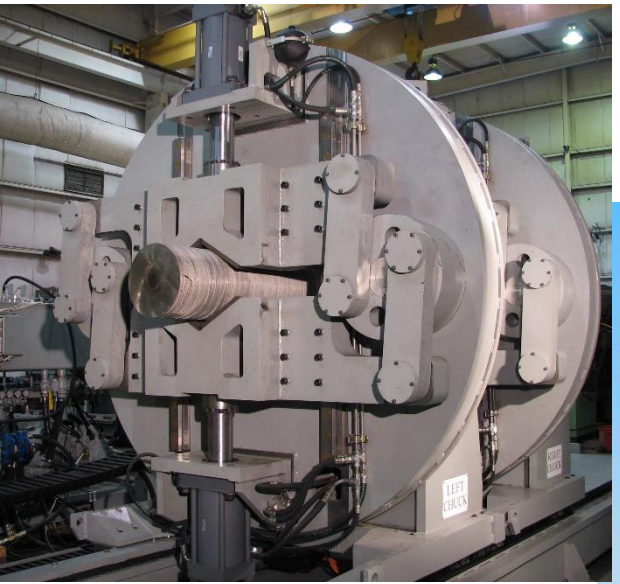
3. Electrode Preparation Tools – Band Saw Cutting

Negative effect of band saw cooling liquid:

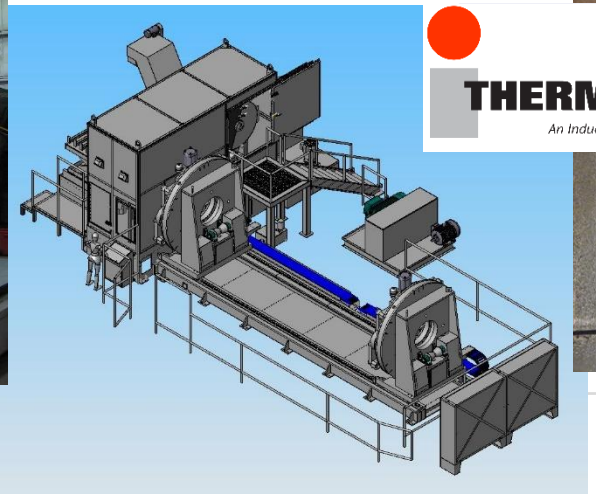
- Due to the cooling liquid which is used during the cutting of electrode top and bottom, the surface of the electrode is contaminated with cooling liquid.
- Turnings for the starter box could also be contaminated with cooling liquid
- Both are potential source for gas bubbles in the ingot bottom

3. Electrode Preparation Tools – Abrasive Cutting

- Improved cut quality (90° cut, no cooling liquid)
- Reduced cut time



Ø	Cut Time Savage Saw	Cut Time (Band Saw)
600 mm	15 min	450 min
900 mm	35 min	1000 min



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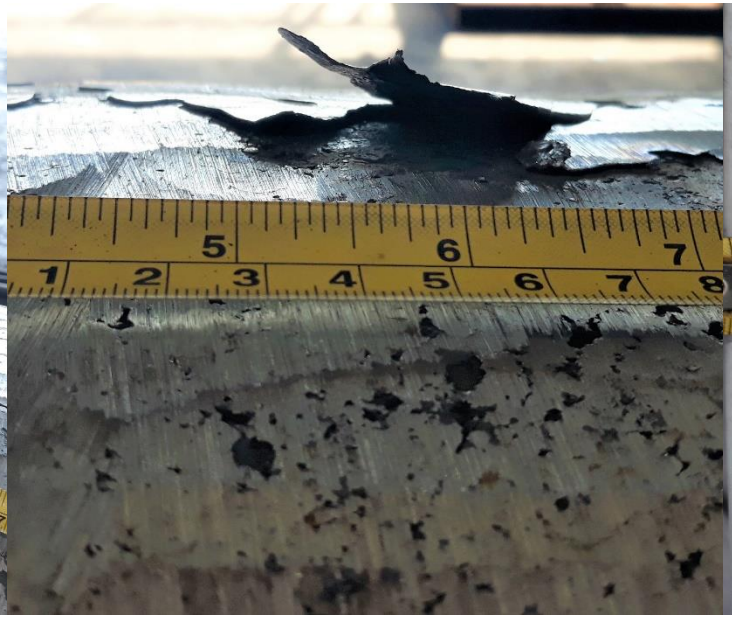
Reference 4

3. Electrode Preparations Tools – Surface Grinding

- After final inspection from a plant engineer, shift foreman, or CONSARC team, the electrode surface should be cleaned via hand grinder, shot blaster, grinding machine, or lathe

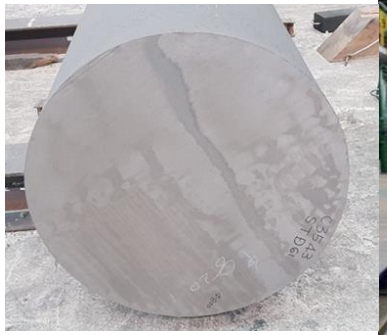
4. ESR electrode Final Inspection

- After grinding, the electrode must be finally inspected for potential double skin
- Double skin is dangerous for ESR ingot quality;
  - May not get completely melted in the slag



4. ESR electrode final inspection

90° Cut
NO shrinkage
Perfect for
TOP & Botom



Machined surface
perfect finish

Shot blasted
less material loss

Machined surface
BUT rusty, not good

4. ESR Electrode Final Inspection

- If there is still a shrinkage cavity after cutting, cut again
- Clean fluxes out of the cavity by heat treatment

Electrode has been cut but it is still NOT suitable for ESR:

Massive Shrinkage

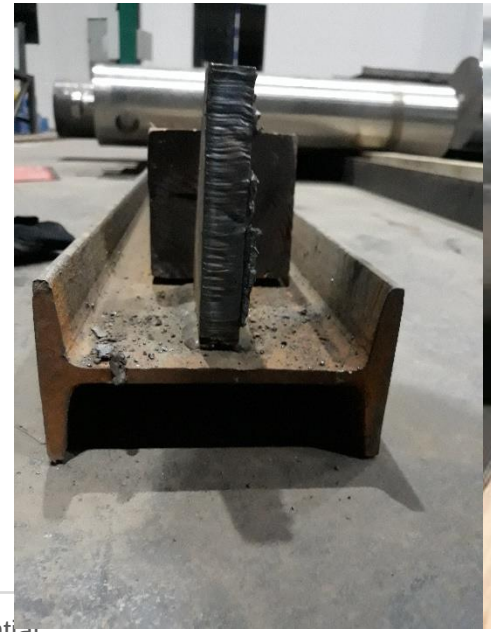
Remaining shrinkage “lid“

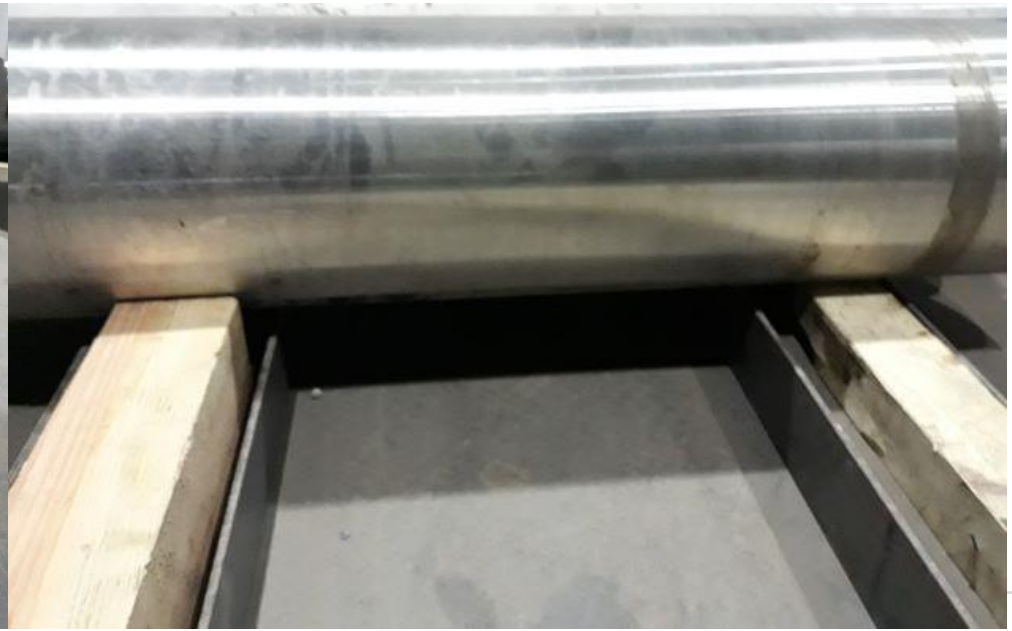
Massive contamination

Spider Crack

4. ESR Electrode Final Inspection

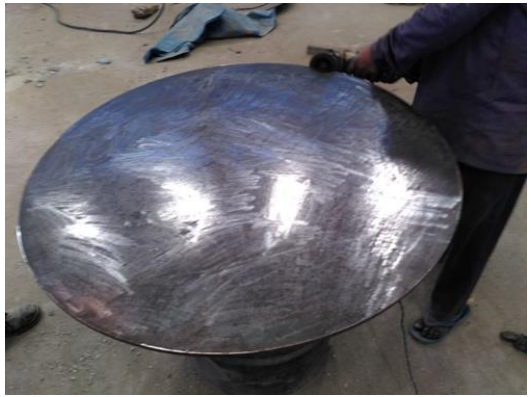
- Electrode storage
- On the floor or on steel rails, leads to rust
- Wooden beams inside an steel H-Beam, easy to replace and prevent pickup of rust





5. ESR Starter Plate and Slag Handling

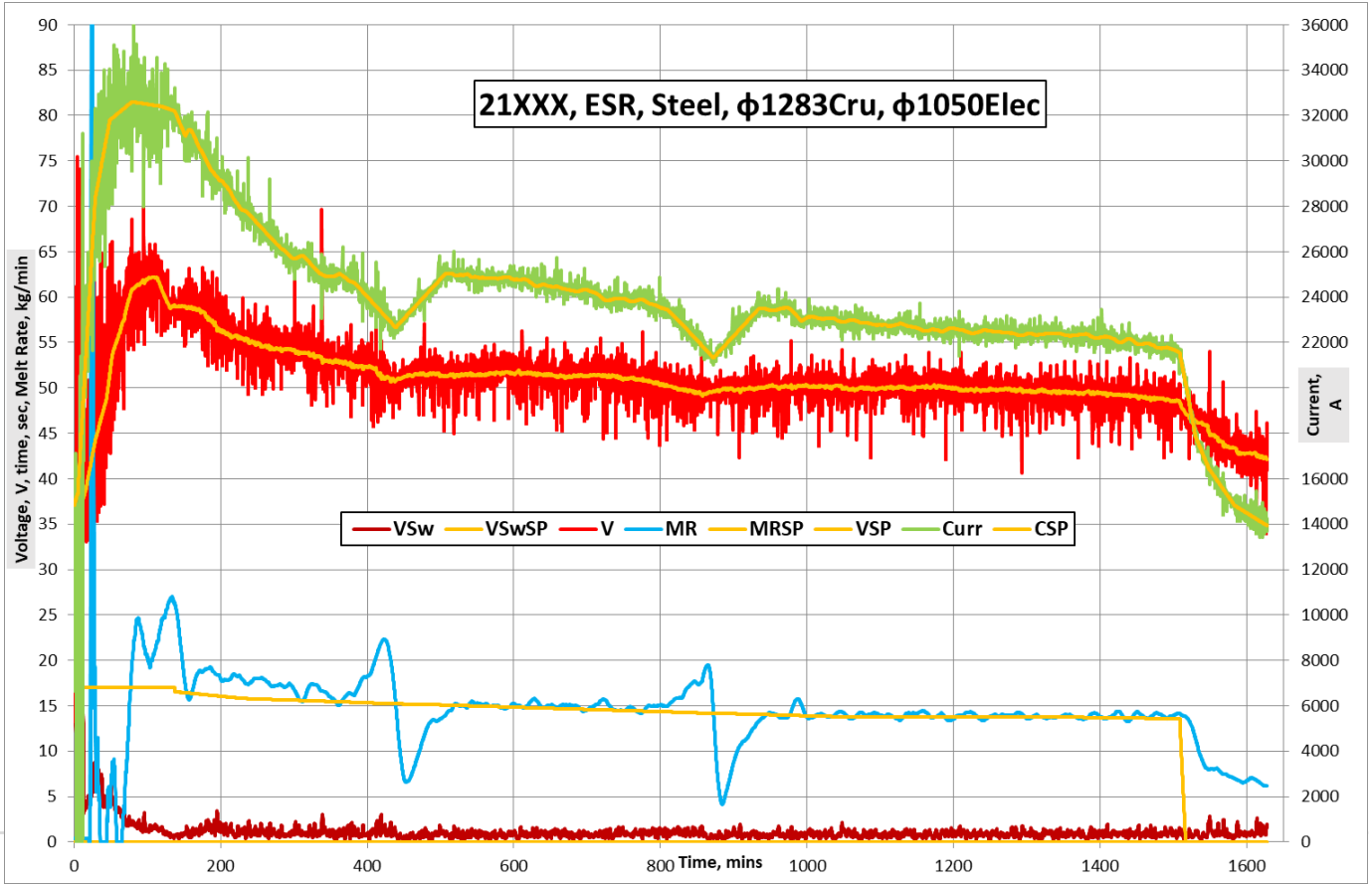
- Keep the copper base plate clean
- Starter plate cleaning on both sides
  - Scotch brite
  - Hand grinder
  - Shot blasting
- Once slag is placed on the starter plate, get the liner on & crucible into melt station/under argon to reduce moisture pickup
- **Start the ESR ASAP**



6. Melt Rate Deviations – Lack of Heat Treat

Melting through a crack

- Initial Melt Rate increase causes Current to drop,
- Slag Starts to cool down
- As the post crack cold face reaches the slag
  - low current
  - Cold slag
  - Cold electrode face
- Result: Big drop in Melt Rate and long recovery Time



6. Melt Rate Deviations – Lack of Heat Treat

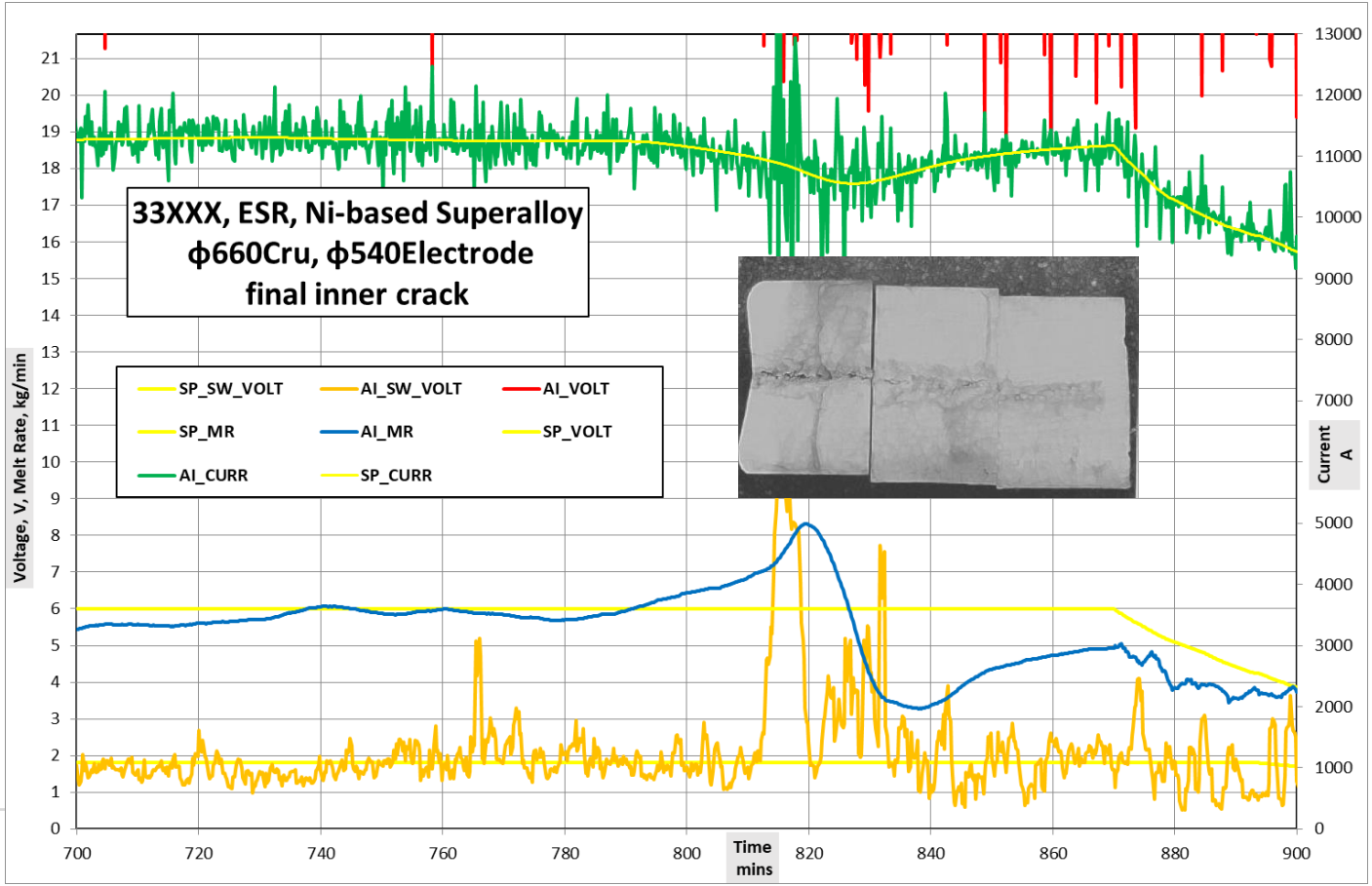
Melting trough a crack

- Crack prone superalloys
- Strip and transfer directly to heat treat for stress relief
- Serious deviation which is avoidable
- Melt rate control can only compensate but NOT prevent

6. Melt Rate Deviations – Lack of Heat Treat

Melting trough a crack:

- Final excursion of the melt 33XXX
  - Melt rate & current reaction
- Longitudinal section of á VIM electrode aborted (during VAR) because of melt rate cycles
- Transverse thermal crack in left section (Canada etch)



7. Ask Your Customer(s) for Feedback

- Talk to your (internal) customers (forging shop, rolling mill) about the performance of your ESR ingots in terms of quality (cracks during forging, surface issues etc.) and safety –
  - If slag is entrapped in the ESR head, (dangerous for the forging team) remelt manager needs to know this
- Be aware of wrong heat treatment, forging damage (too hot or too cold), lack of datamining etc.

References 5, 6

Summary

- Consistent high-quality sound electrodes are the foundation for a stable ESR operation & high-quality ingots
- The control system of modern ESR furnaces rely on good input material (electrodes) to produce high quality ESR-ingots
- To produce the highest value product, quality must be maintained throughout the whole production process

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60th ANNIVERSARY 1962-2022

Cross References

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