

# NF Wire Forum

---

Aurubis
Metals for Progress

BALLOFFET

BECHEM
LUBRICATION
TECHNOLOGY

Deutsches
Kupferinstitut

NIEHOFF
GRUPPE

NF Wire Forum

# Copper Wire Rod

## NF WIRE FORUM ONLINE EVENT

**May, 2021**

Aurubis AG, Dr. Cornel Abratis



Aurubis Metals for Progress · BALLOFFET · BECHEM LUBRICATION TECHNOLOGY · Deutsches Kupferinstitut · NIEHOFF GRUPPE

# Agenda



NF Wire Forum

1. Copper Wire Rod – Cu-ETP1
2. Copper Wire Rod – Cu-OFE

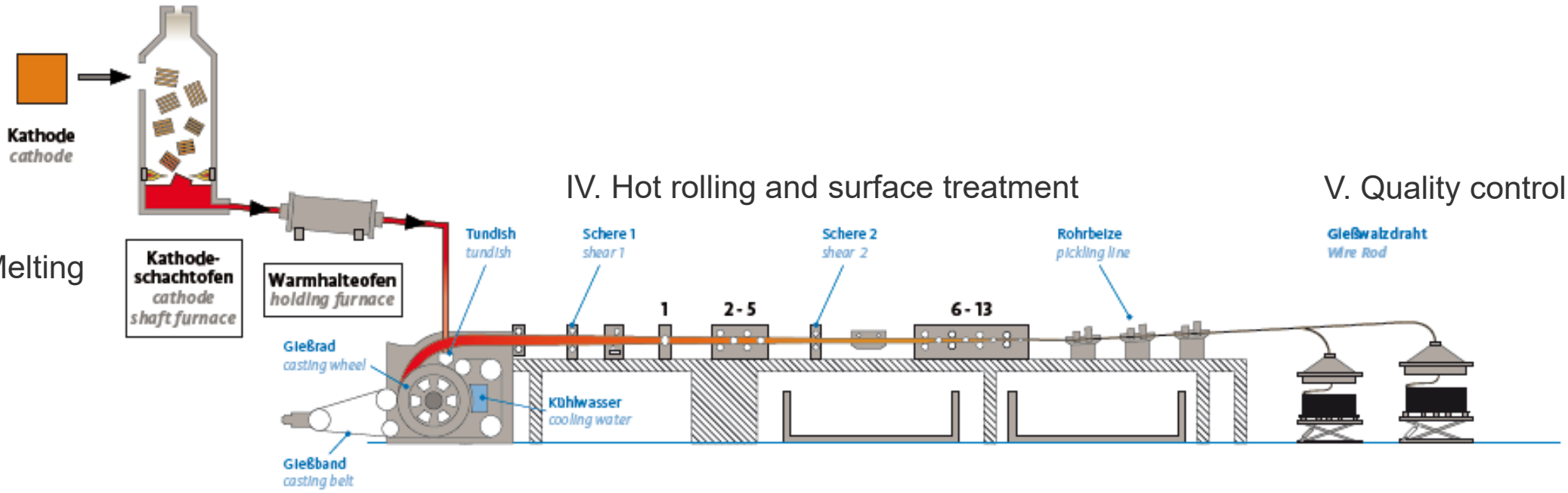


Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# Influencing factors on good drawability of Copper Wire Rod

NF Wire Forum

I. Feed mix




II. Melting

IV. Hot rolling and surface treatment

V. Quality control

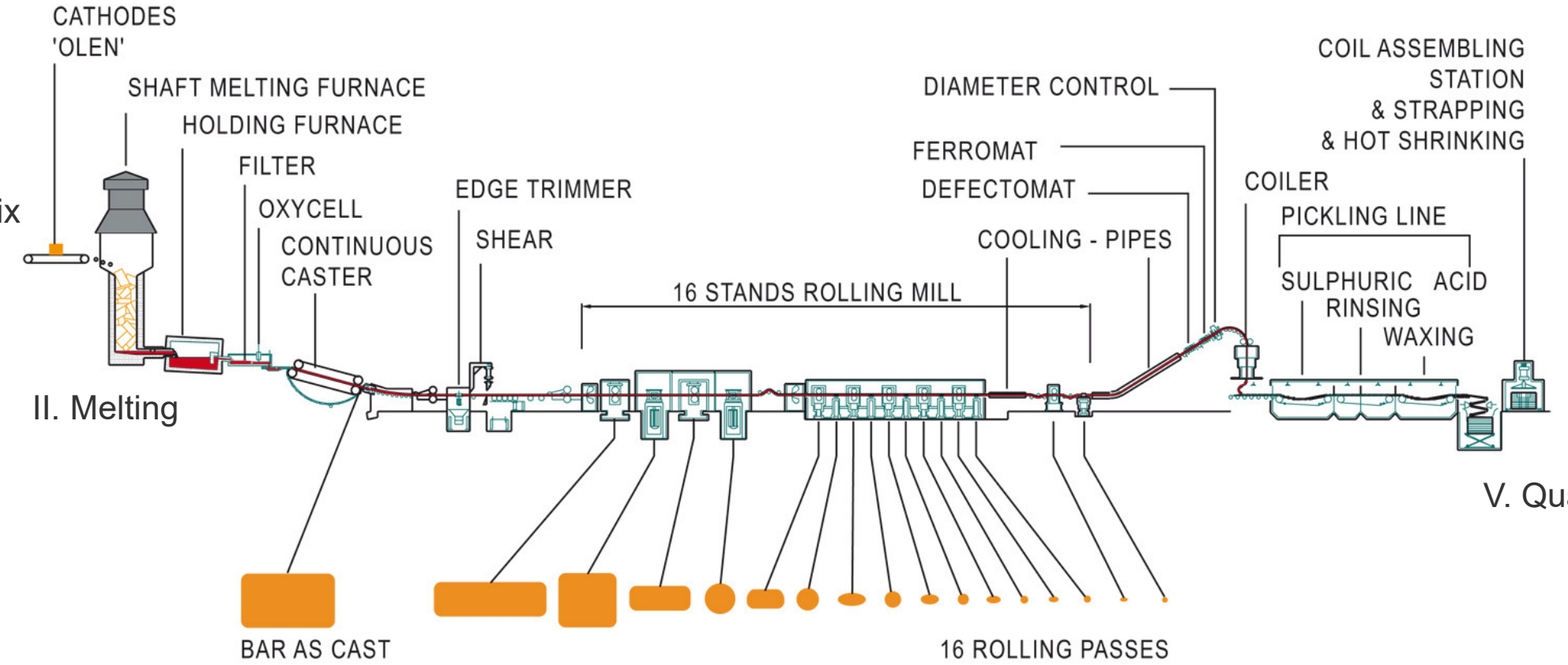
III. Casting and Solidification



Aurubis Metals for Progress · BALLOFFET · BECHEM LUBRICATION TECHNOLOGY · Deutsches Kupferinstitut · NIEHOFF GRUPPE

# Influencing factors on good drawability of Copper Wire Rod

NF Wire Forum




I. Feedmix

II. Melting

III. Casting and Solidification

IV. Hot rolling and surface treatment

V. Quality Control



Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# I. Feedmix: Copper Cathodes

NF Wire Forum

- **Grade A cathodes** from 4 Aurubis tankhouses out of different production campaigns
- Purchase of grade A cathodes
- Cathode classification for internal and external cathodes in the Aurubis group is basis for production planning (grade A is not like grade A)
- **„correct“ cathode mix** is essential for
  - **fine wire** output of a rod line
  - compliance with **chemical purity**
  - homogeneous forming and softening behaviour
  - **high conducivity** and **SEN values**

| Ag | As | Bi | Fe | Ni | Pb | S | Sb | Se | Sn | Te | max. impurities |
|---|---|---|---|---|---|---|---|---|---|---|---|
| <15 | <1 | <1 | <2 | <2 | <1 | <3 | <1 | <1 | <1 | <1 | 30 |



Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

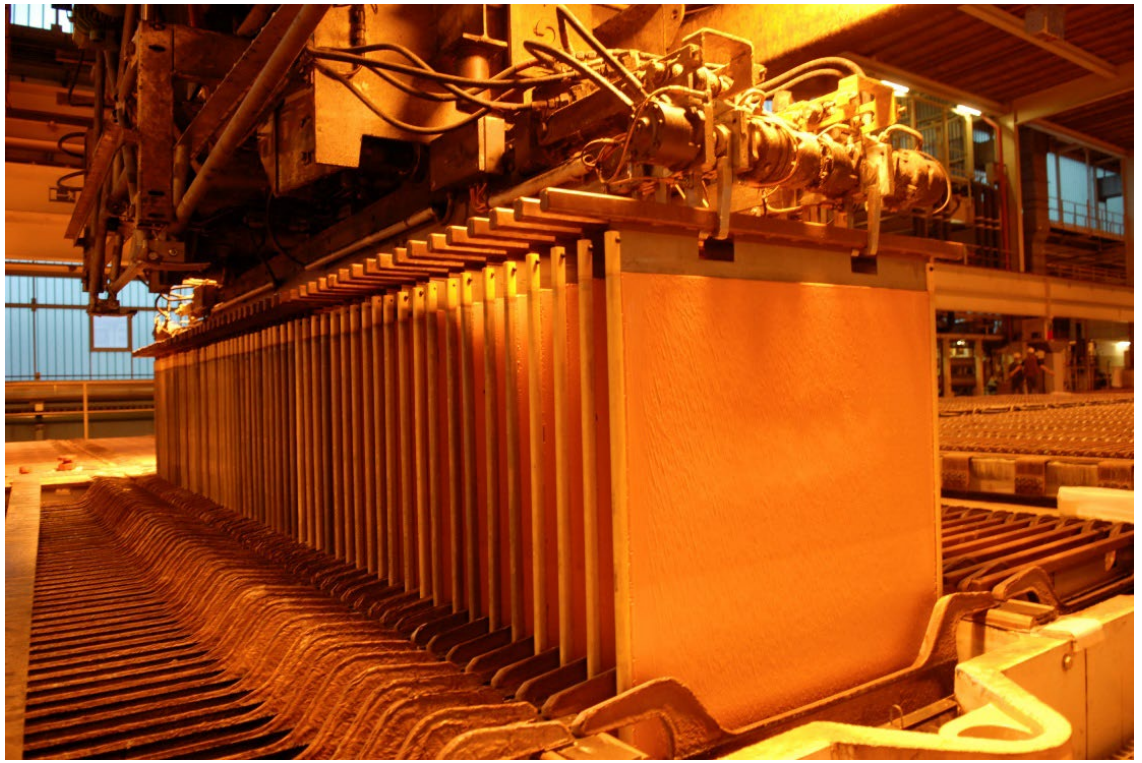
# I. Feedmix: cathode capacity at Aurubis group

NF Wire Forum

Hamburg Tankhouse: 400.000t/a

Olen Tankhouse: 350.000t/a





Lünen Tankhouse: 160.000t/a

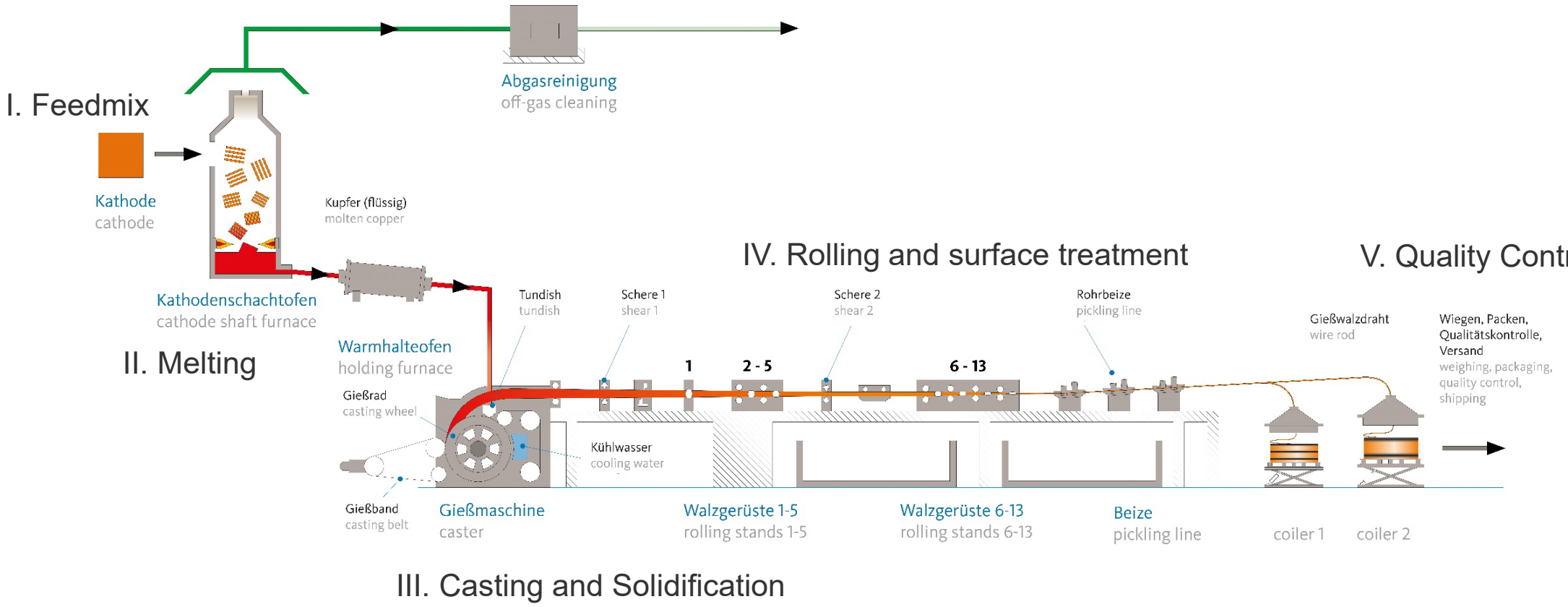
Pirdop Tankhouse: 220.000t/a



Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# Influencing factors on good drawability of Copper Wire Rod

NF Wire Forum

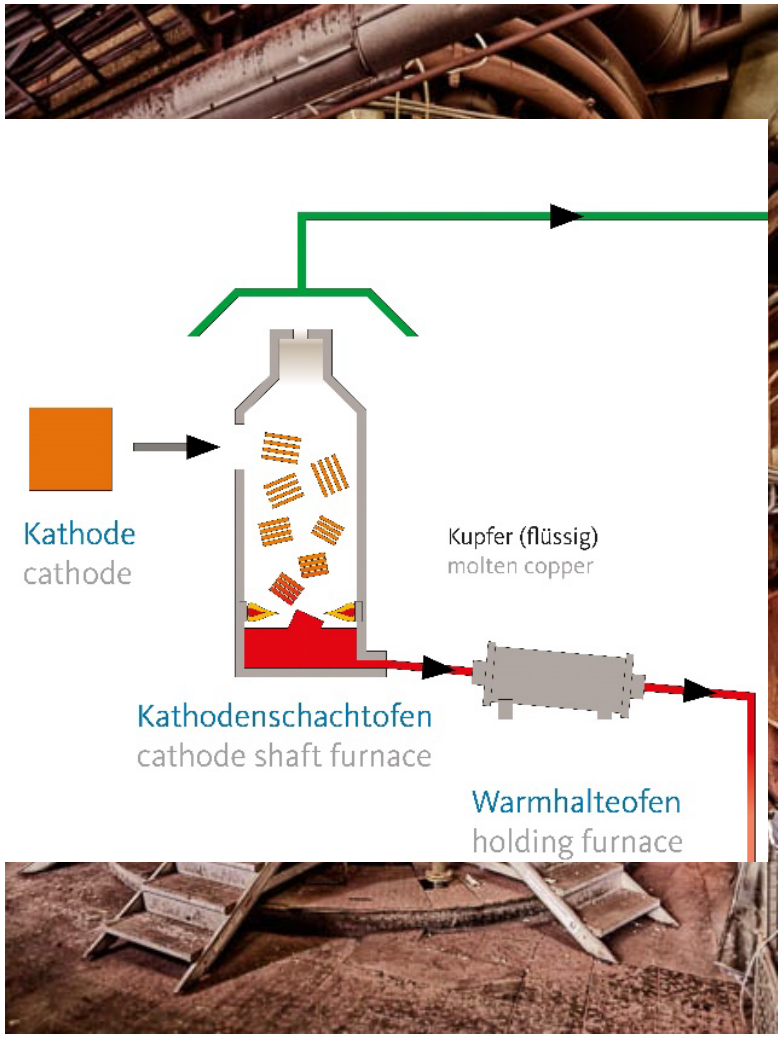






Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# II. Melting



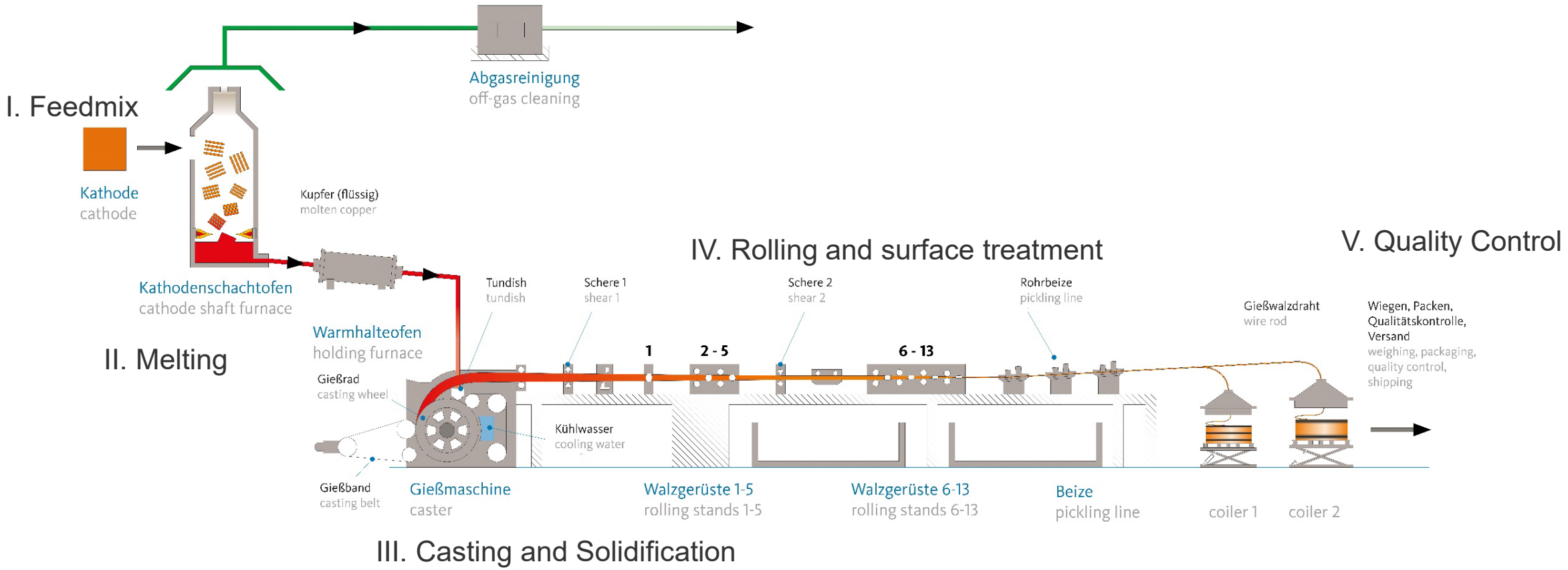

- Burner parameters in the shaft furnace, launders, holding furnace and tundish
- Temperature of the copper melt (shaft furnace, launders, holding furnace and tundish)
- Oxygen content of the copper melt
- Refractory material in shaft furnace, launders, holding furnace and tundish

Aim:

- Copper melt with oxygen content below 200ppm
- Gas in the melt
- Avoidance of anorganic refractory inclusions

# Influencing factors on good drawability of Copper Wire Rod

NF Wire Forum

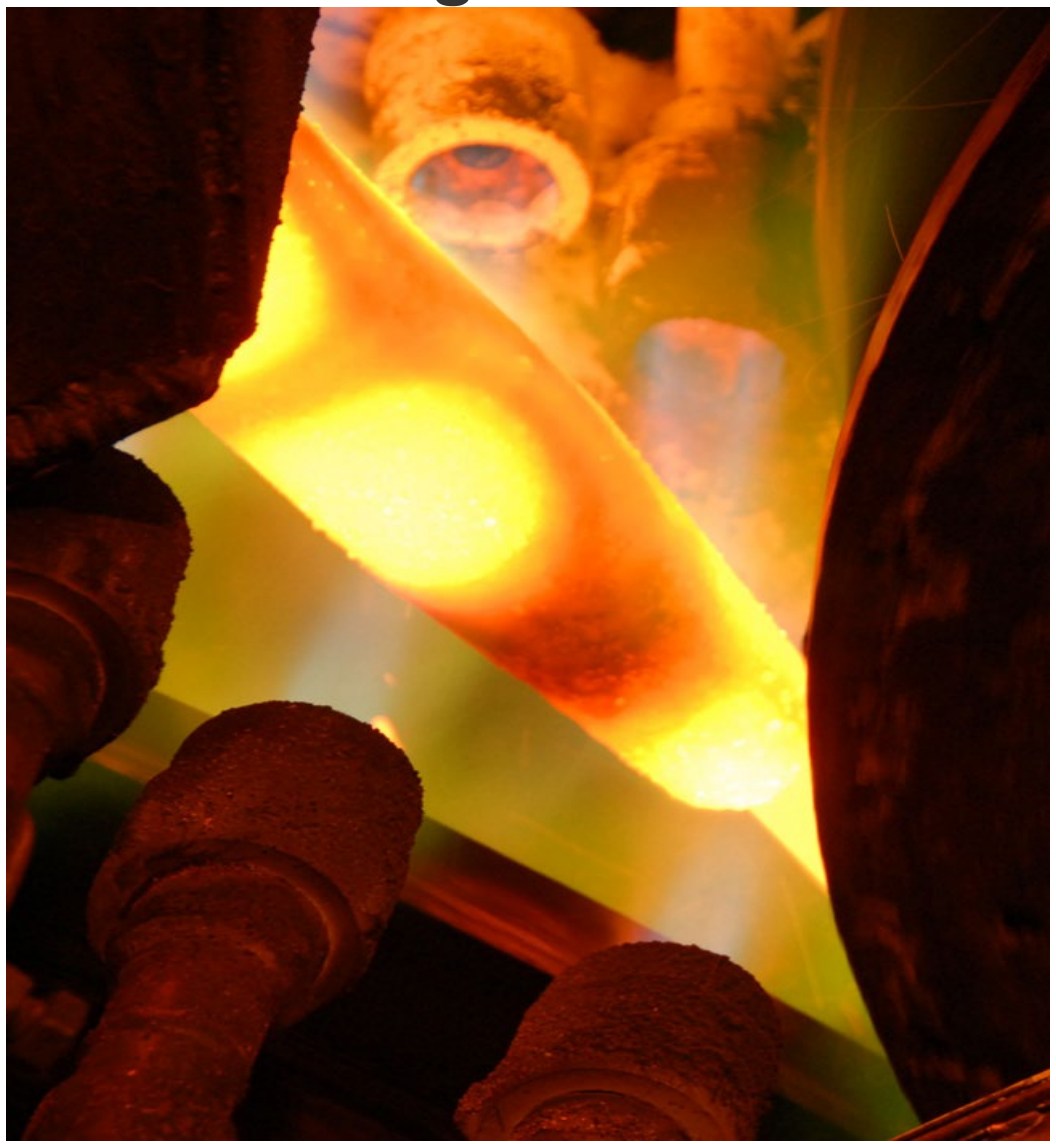


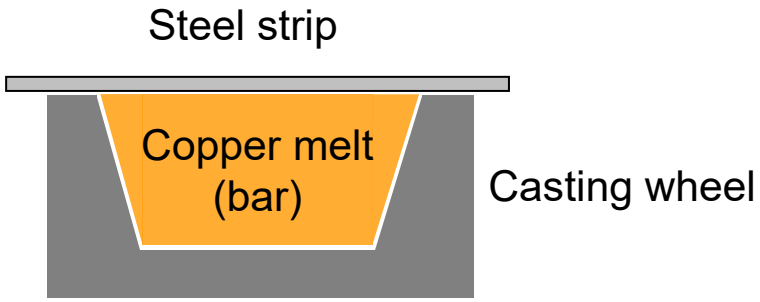




Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# III. Casting and Solidification SCR Principal





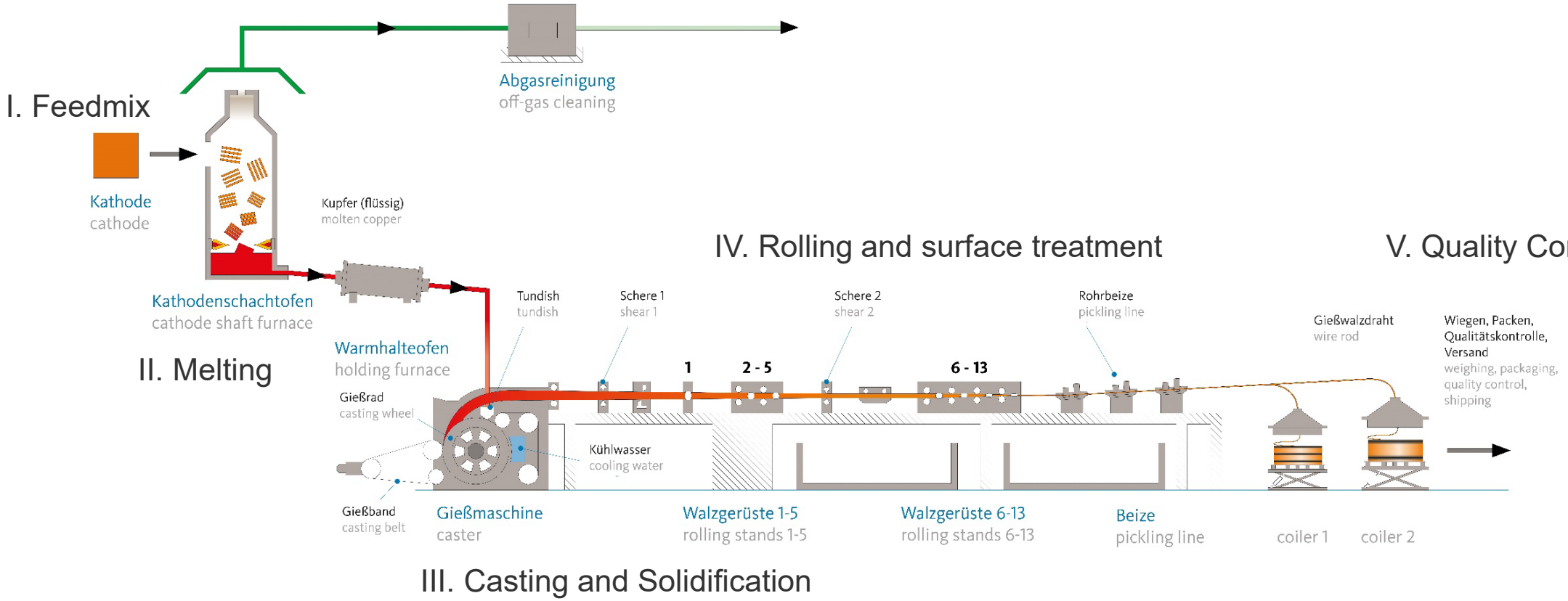

- copper melt temperature in tundish area
  $T_{Melt} > T_{Solidus}$
- homogeneous heat transfer in the casting wheel or Hazelett-Caster (soot layer / oil with graphite)
- homogeneous solidification and degassing of the remaining melt
- direct cooling water volume

Aim:

- Minimising of gas pores and blowholes

# Influencing factors on good drawability of Copper Wire Rod

NF Wire Forum







Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# IV. Rolling and surface treatment

NF Wire Forum

- Bar and wire rod temperature
- Rolling current in the pre rolling mills
- Surveillance of cooling and rolling lubricant
- Separated cooling lubricant systems for pre and finishing rolling mill
- Roll material, roll change frequency and preparation
- Inline control with eddy current and magnetising of the wire rod

Aim

- Homogeneous, fine grain microstructure without inclusions

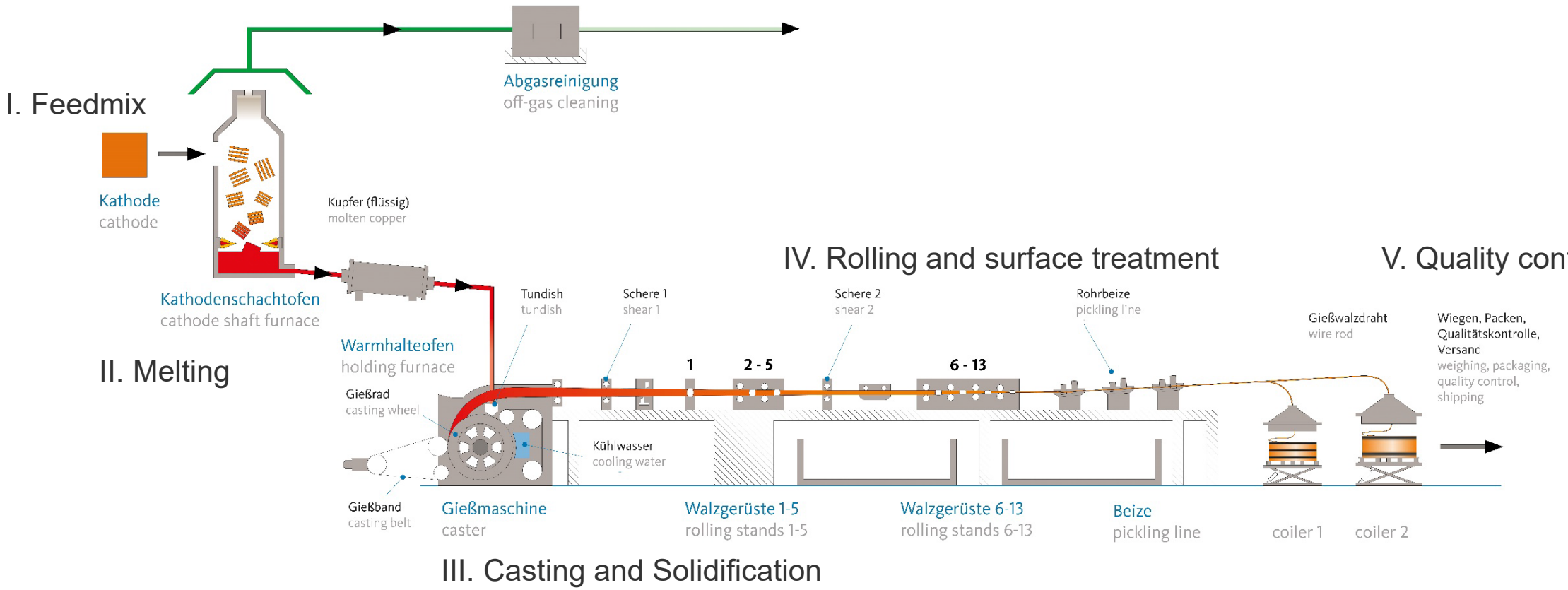




Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# Influencing factors on good drawability of Copper Wire Rod

NF Wire Forum







Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# V. Quality control: tests on wire rod

NF Wire Forum

- Twist test
- Oxygen level
- Diameter (in-line, off-line)
- Optical surface assessment
- Residual oxide layer
- Optical check of each coil



- Resistivity measurement
- Spiral Elongation Number (SEN)
- Chemical Analysis
- Tensile test for mechanical technological values (tensile strength, elongation at break)

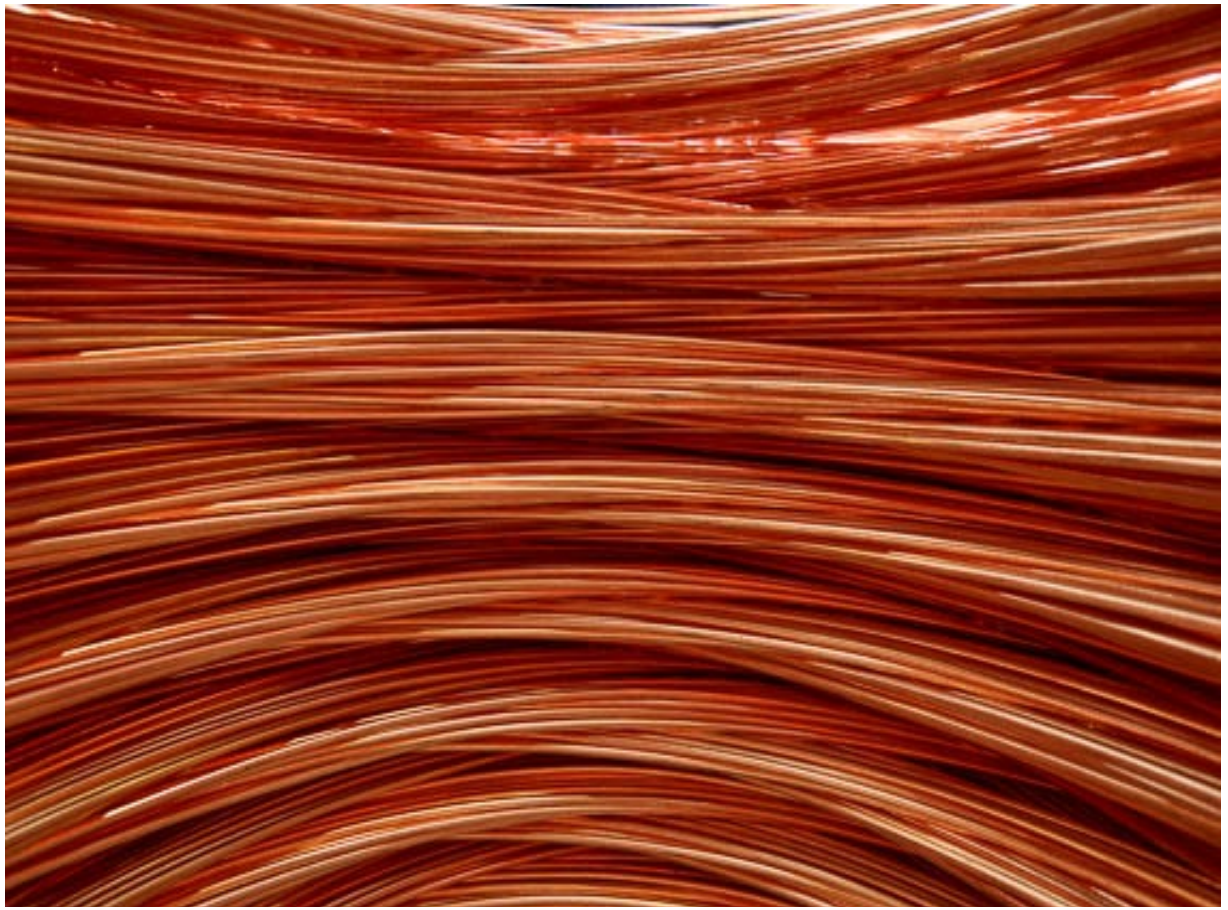


Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# Selection criteria for good drawability copper wire rod

NF Wire Forum

- “best” feed mix with grade A cathodes
- Oxygen content < 250 ppm
- Δ temperature $T_{Copper\ melt} > T_{Copper\ solidus}$
- Cooling water
- Rolling current at rolling stands
- Low defectomat and ferromat signals
- Good twist test result
- Low residual oxide layer





Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# Aurubis ROD | RheinROD Cu-ETP1 – 8mm – Qualities

NF Wire Forum

**FINE-MAGNET**

*- Best drawability down to 50µm and excellent surface -*

**FINE**

*- Best drawability down to 50µm -*

**MULTI-MAGNET**

*- homogeneous drawability and excellent surface -*

**MULTI**

*- homogeneous drawability and recrystallisation behavior -*

**ENERGY**

*- good drawability -*

**NOSV Special**

*- Excellent RRR values for Superconductors -*

- ✓ Excellent conductivity
- ✓ Application in cables and magnet wires with minimal conductor diameters
- ✓ Based on excellent Aurubis Grade A++ cathode



Aurubis Metals for Progress · BALLOFFET · BECHEM LUBRICATION TECHNOLOGY · Deutsches Kupferinstitut · NIEHOFF GRUPPE

# Join in:
# Live Panel on May 11th at 14h CET

NF Wire Forum

Please send **your questions** until May 10th to nf-wire-forum@aurubis.com

We look forward to seeing you again virtually!

www.nf-wireforum.com






Aurubis Metals for Progress · BALLOFFET · BECHEM LUBRICATION TECHNOLOGY · Deutsches Kupferinstitut · NIEHOFF GRUPPE



# NF Wire Forum

---

Aurubis
Metals for Progress

BALLOFFET

BECHEM
LUBRICATION
TECHNOLOGY

Deutsches
Kupferinstitut

NIEHOFF
GRUPPE

NF Wire Forum

# Copper Wire Rod

## NF WIRE FORUM ONLINE EVENT

**May, 2021**

Aurubis AG, Dr. Cornel Abratis



Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# Agenda



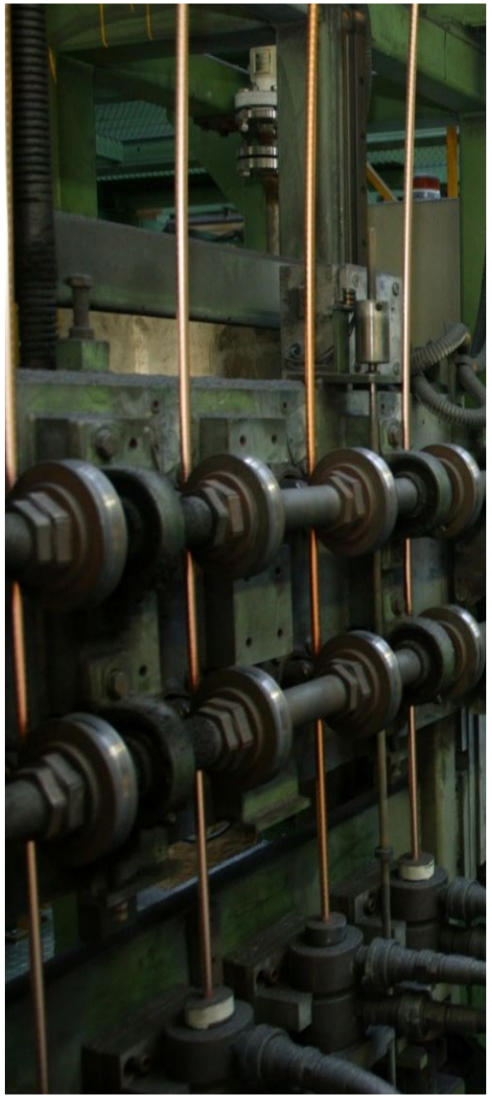
NF Wire Forum

1. Copper Wire Rod – Cu-ETP1
2. Copper Wire Rod – Cu-OFE

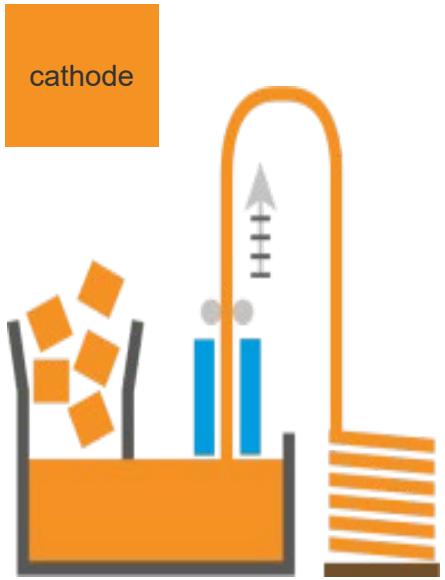


Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# Copper rod Cu-OFE – Aurubis FOXROD



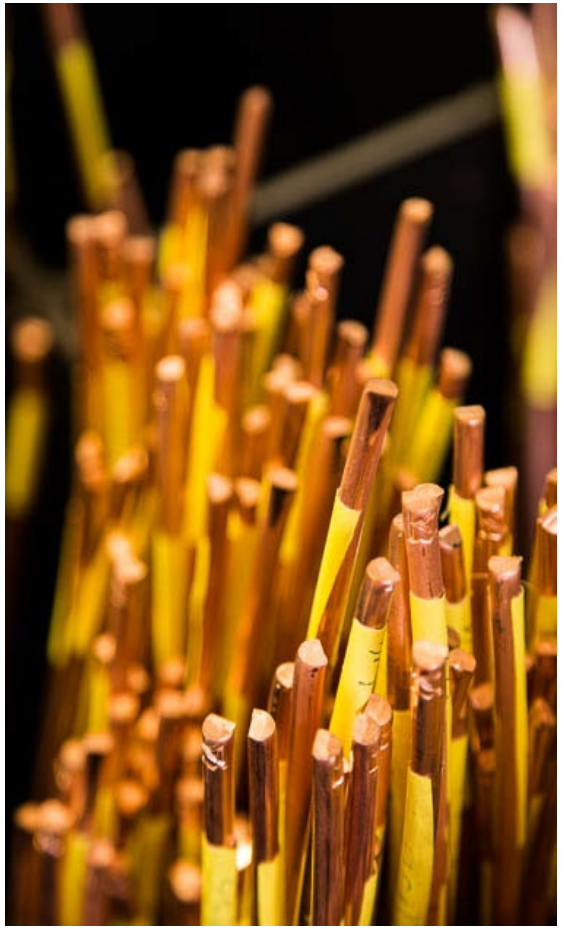
- Aurubis is an essential producer of oxygen free rod with a capacity of 40.000t/a
- Feedmix: grade A++ cathode from Olen tankhouse
- Graphite furnace and cover layer for oxygen free conditions
  - ➢ Oxygen will be erased from the melt by the reaction of carbon and oxygen and protects the melt of reoxydisation
- 6 Cu-OFE production lines (2 Upcast and 4 Rautomead)
- Efficient production method for OF and copper alloys



# Aurubis FOXROD for FINE wire

NF Wire Forum

- Oxygen level lower than 4ppm
- Porosity test
- Diameter and ovality check
- Process parameter surveillance
- Special solidification equipment for 8mm production Aurubis FOXROD Cu-OFE
- Graphite furnace to avoid anorganic inclusions

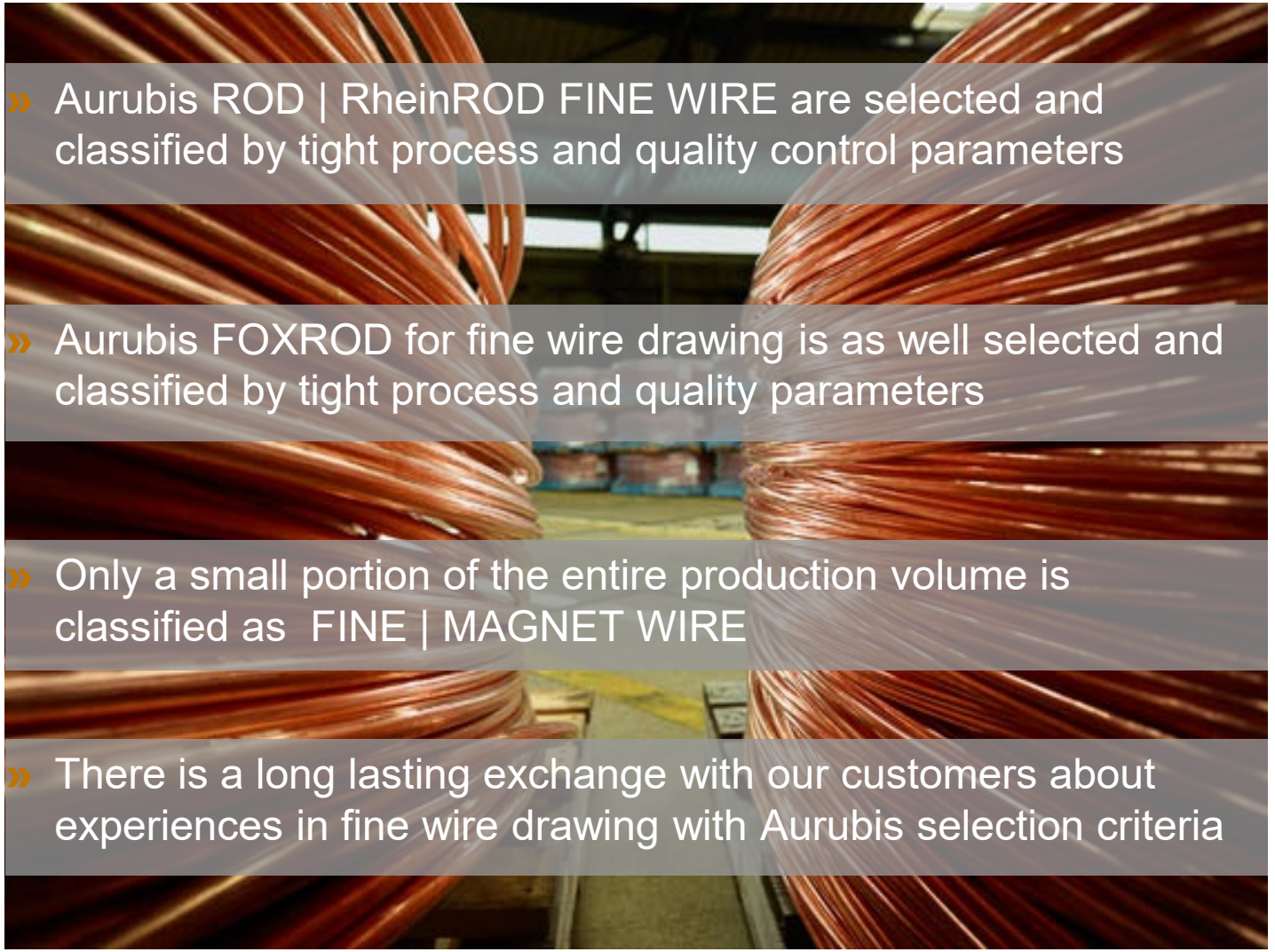




Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# Summary

NF Wire Forum



- Aurubis ROD | RheinROD FINE WIRE are selected and classified by tight process and quality control parameters
- Aurubis FOXROD for fine wire drawing is as well selected and classified by tight process and quality parameters
- Only a small portion of the entire production volume is classified as  FINE | MAGNET WIRE
- There is a long lasting exchange with our customers about experiences in fine wire drawing with Aurubis selection criteria



Aurubis Metals for Progress · BALLOFFET · BECHEM LUBRICATION TECHNOLOGY · Deutsches Kupferinstitut · NIEHOFF GRUPPE

NF Wire Forum

# Wire breaks

*Features – damage mechanism – possible root causes*

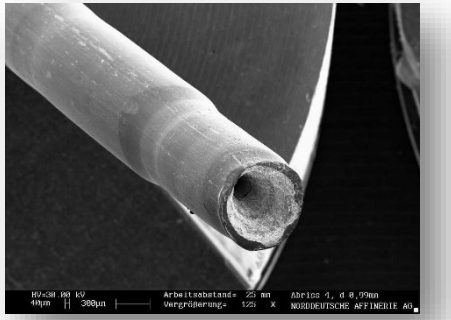
NE Drahtforum GbR

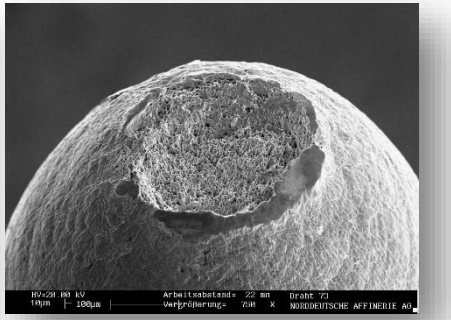


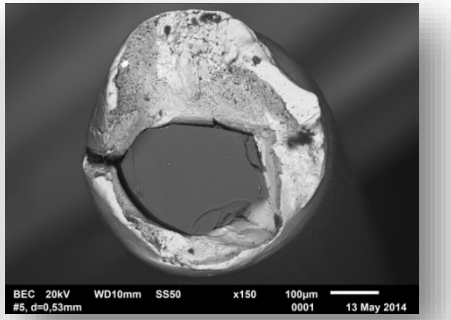
Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

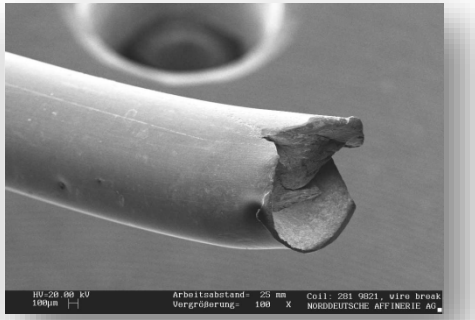
# Introduction

NF Wire Forum



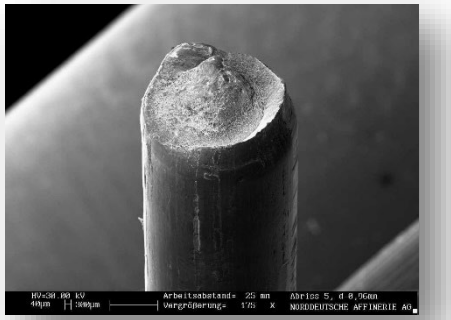



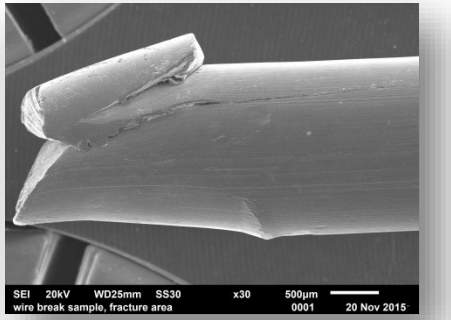



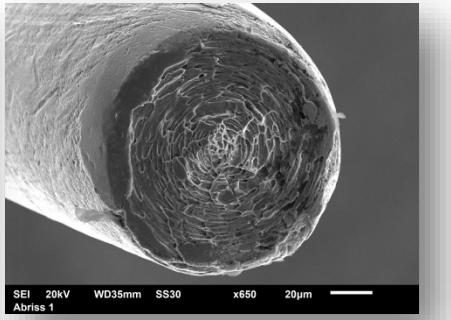



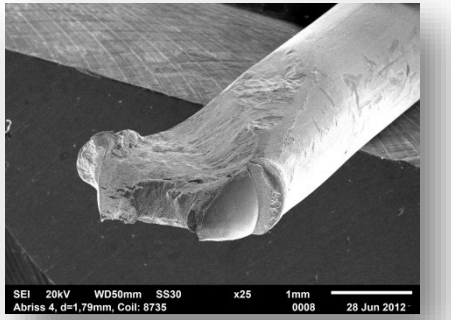

## Wire Breaks

… are the undesired result of unfavorable interactions of adjacent forces, tensions and metallic/physical processes in the material exceeding beyond the material's stress limit.



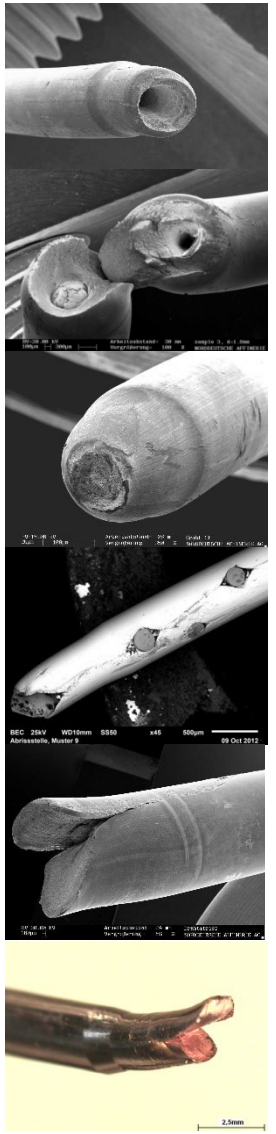






Aurubis Metals for Progress · BALLOFFET · BECHEM LUBRICATION TECHNOLOGY · Deutsches Kupferinstitut · NIEHOFF GRUPPE

# Typical Wire Breaks

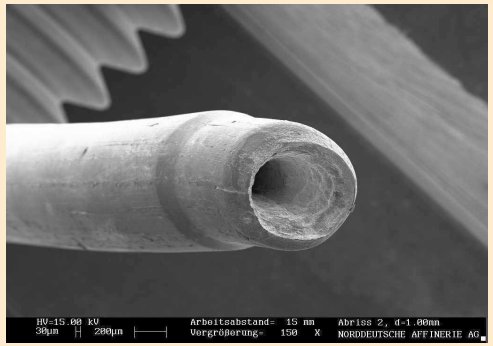
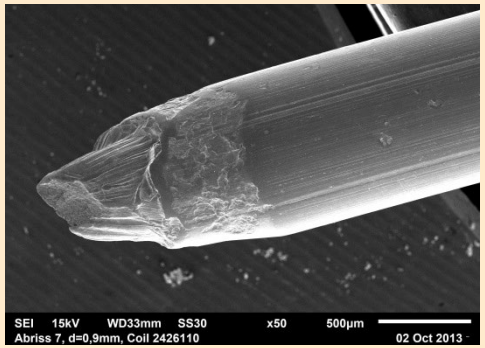
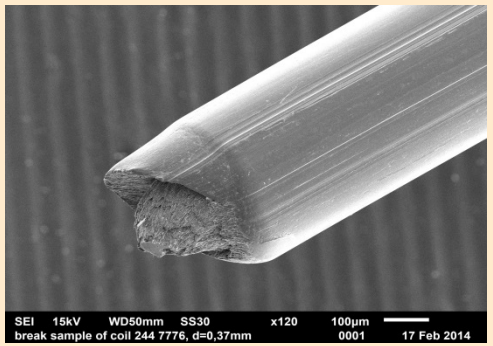
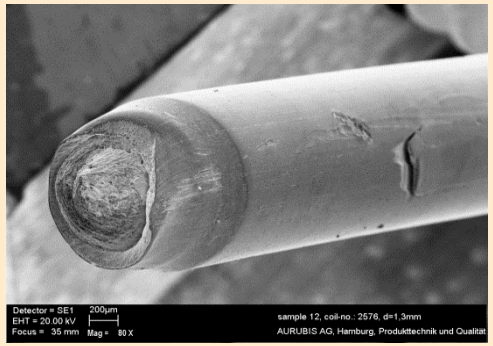
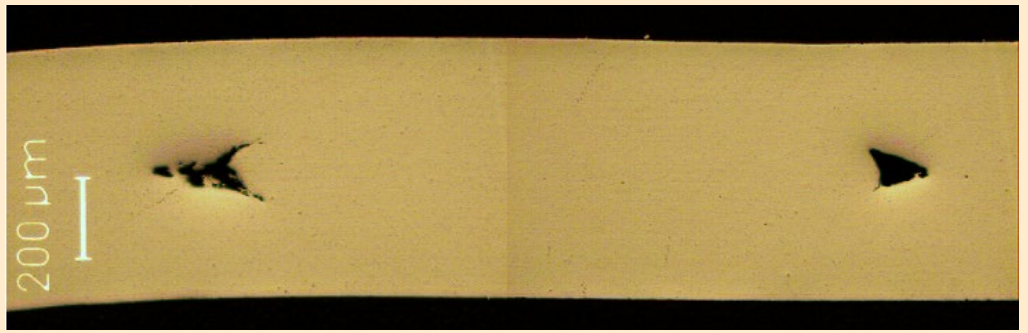
- Cup- and Cone break  I (drawing conditions)
- Cup- and Cone break II (Cuprous enrichments)
- Ductile force break / strain break
- Inclusion break
- Force break by rolled-in or pressed-in chip / mech. surface damage (surface break)
- Weld break
- Annealing break

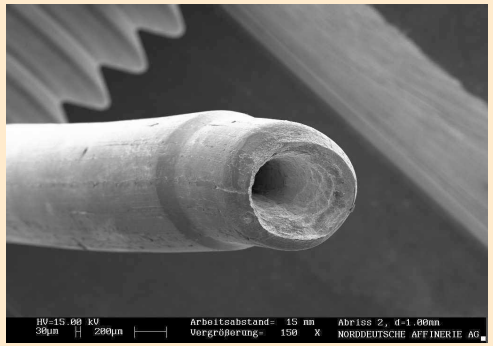
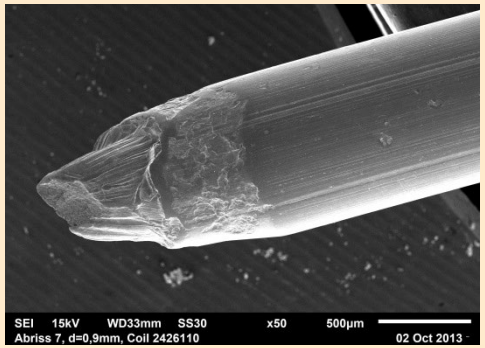
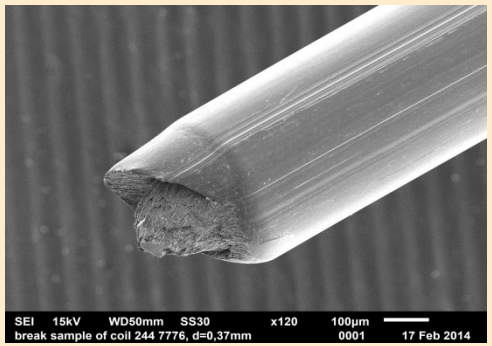
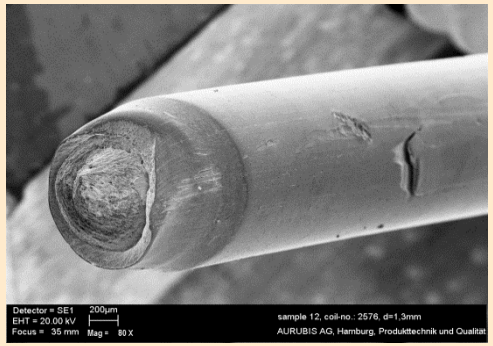
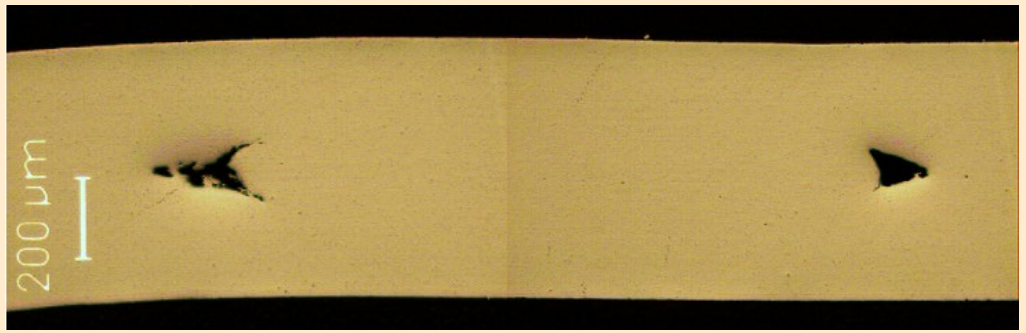


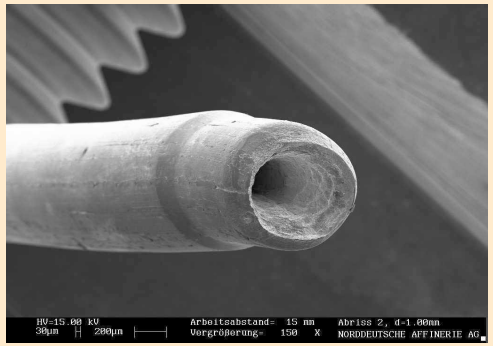
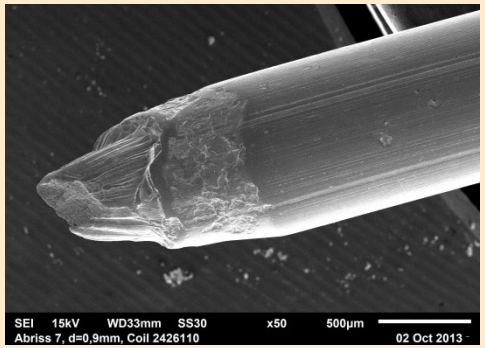
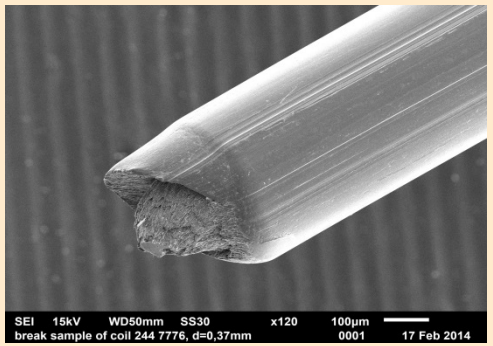
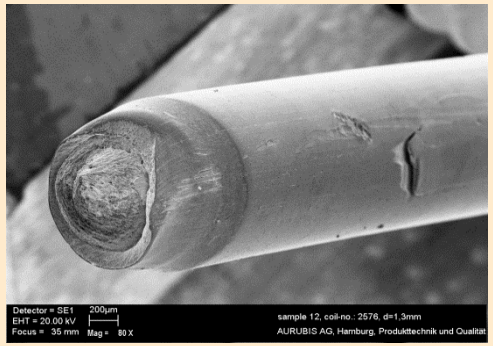
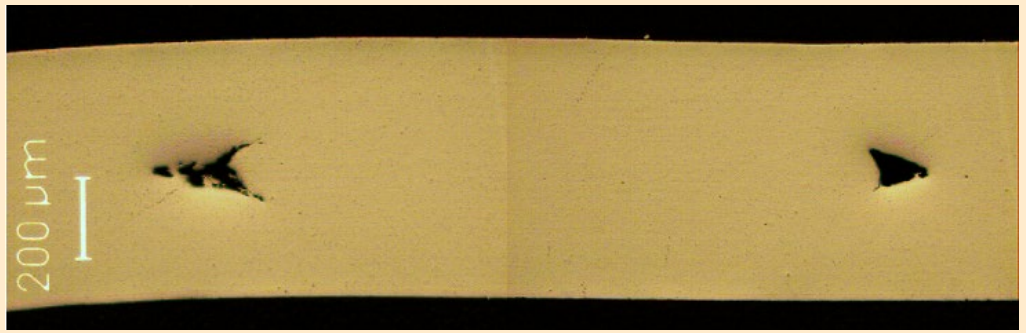
NF Wire Forum

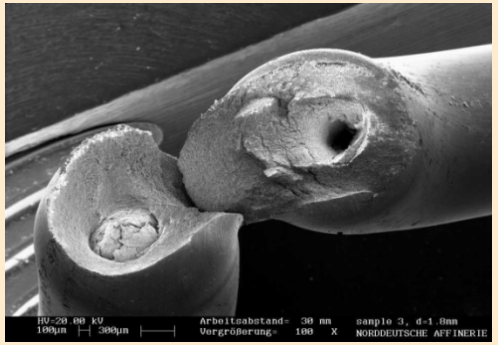
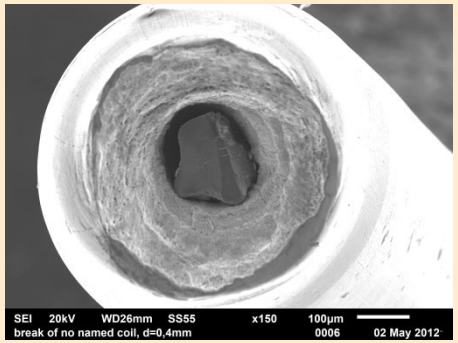
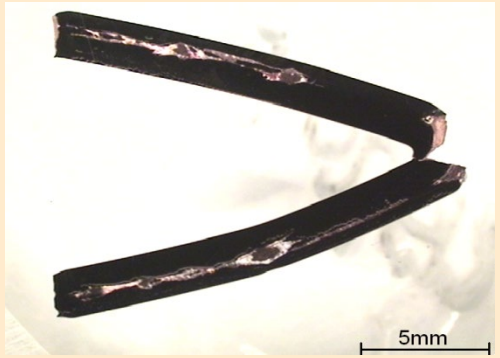
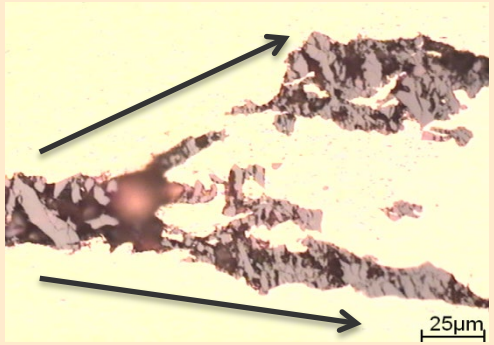


Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

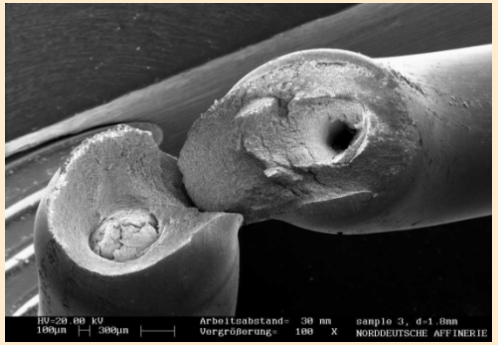
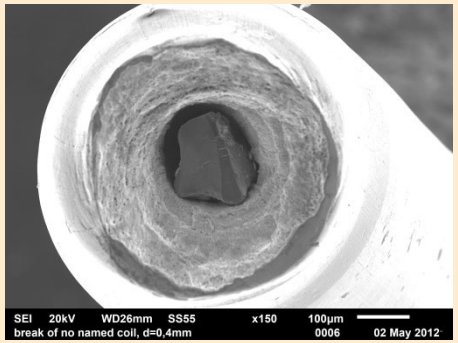
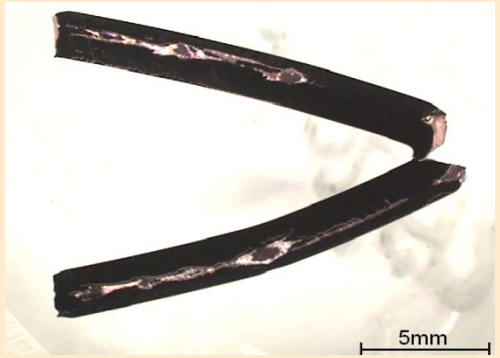
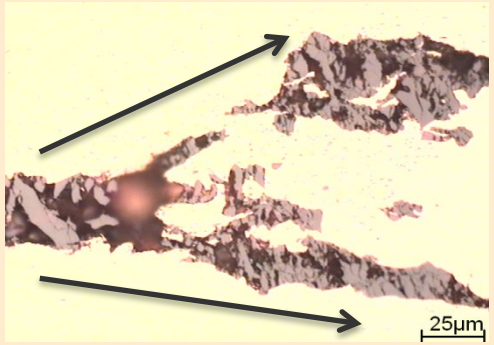
| Break type | Cup- and Cone-break I (drawing conditions) |
|---|---|
| Examples |      |
| Features | - cup side with a deep whole in the middle of the wire or<br>- cone side with a symmetrical necking and a tip<br>- surface defects (draw marks, etc.) aside of the breakage area<br>- inner cracks so called “craw feet” in longitudinal cross sections<br>- no impurity phase agglomeration in the copper wire matrix |

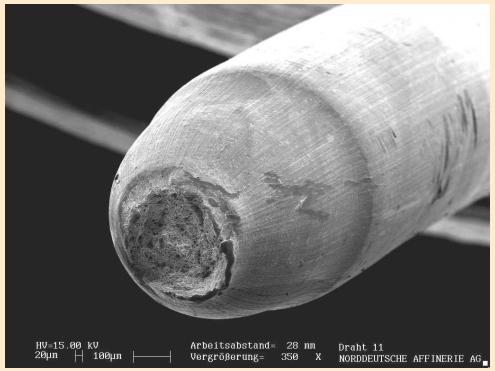
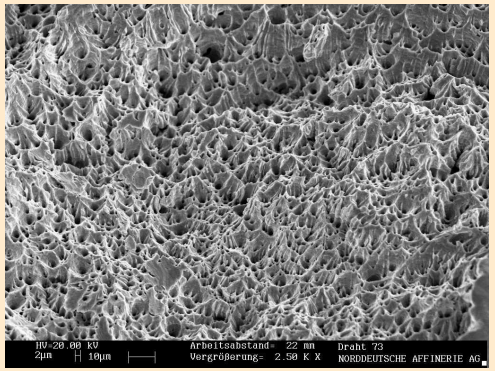
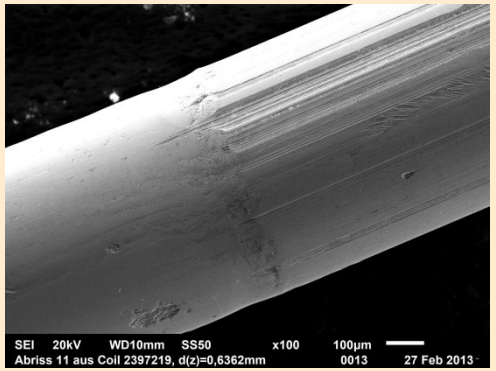
| Break type | Cup- and Cone-break I (drawing conditions) |
|---|---|
| Examples |      |
| Damage mechanism | - high shear stresses between wire surface and neutral line induce local material failures where the max. material stress level is exceeded (inner cracks “craw feet”)<br>- the tip of the “craw feet” is orientated in drawing direction<br>- with additional strain, these cracks grow and reduce the load-bearing cross-section of the wire until the material fails or breaks |

| Break type | Cup- and Cone-break I (drawing conditions) |
|---|---|
| Examples |      |
| Possible root causes | - insufficient lubrication / shot instant of lubrication film in the drawing die<br>- drawing die wear<br>- drawing die clogged/ blocked<br>- small drawing die angle with low diameter reduction and therefore inhomogeneous forming of the wire cross section |

| Break type | Cup- and Cone- Break II (wire rod) |
|---|---|
| Example |         |
| Features | - whole and conus at both break ends<br>- necking at break area<br>- second phase enrichment locally in the microstructure |

NF Wire Forum

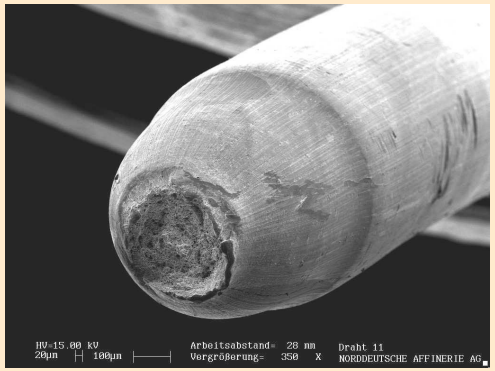
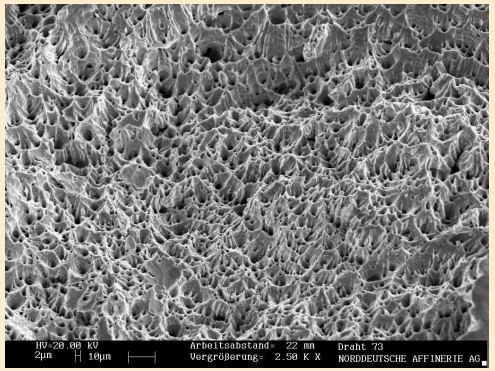
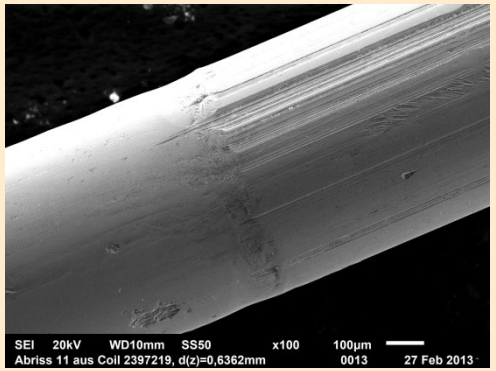
| Break type | Cup- and Cone- Break II (wire rod) |
|---|---|
| Example |         |
| Damage mechanism and root cause | - second phase enrichments cause tensions in the microstructure depending on size and distribution and the different forming behaviour<br>- development of cracks, increasing of material separation, ductile breaking of the remaining cross section<br>- Cuprous enrichments of a copper wire rod line |

| Break type | Force break/ strain induced break |
|---|---|
| Examples |       |
| Features | - local symmetrical necking<br>- ductile break area with funnel / honeycomb structure<br>- drawing marks and other surface failures in drawing direction next to the break area |

NF Wire Forum



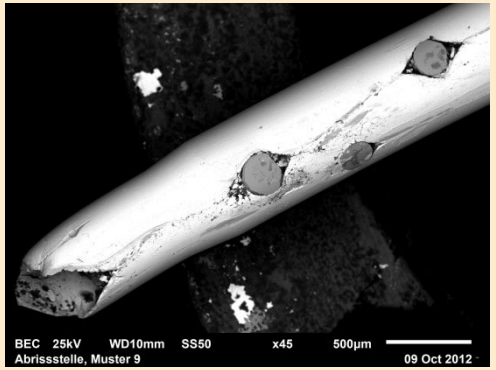
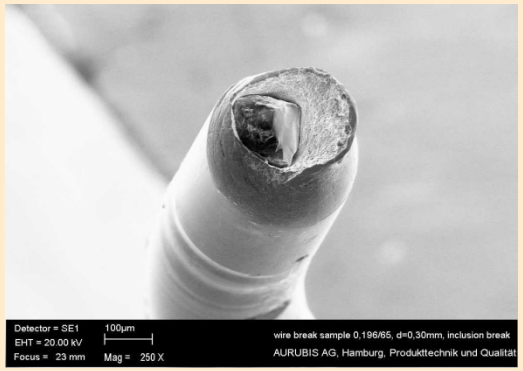
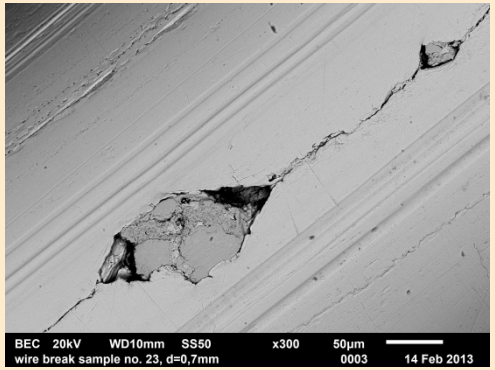
Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

| Break type | Force break/ strain induced break |
|---|---|
| Examples |       |
| damage mechanism and root cause | - geometrical softening / necking of the wire **>** physical hardening of the copper wire<br>- uncontrolled local plastic deformation by tensile stress<br><br>- blocked wires on the capstan<br>- unfavourable conditions of wire, dies and process parameters |

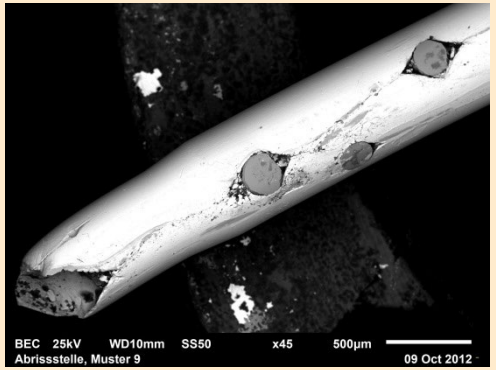
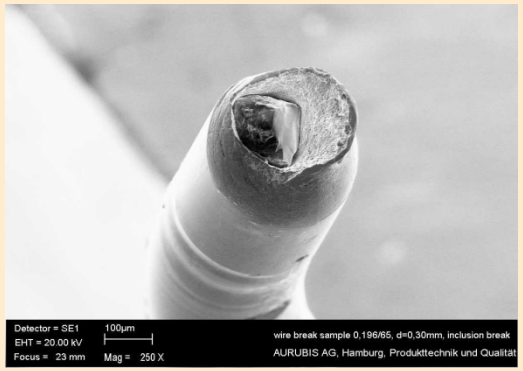
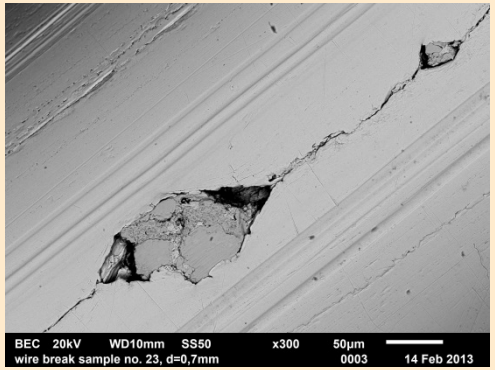
NF Wire Forum

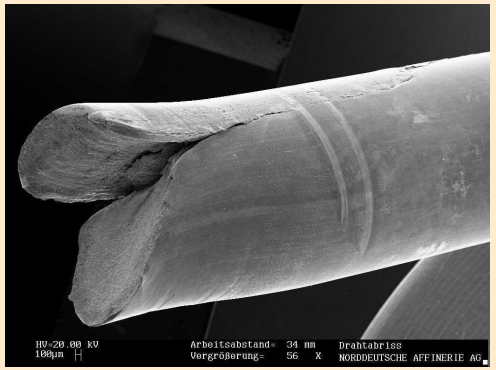
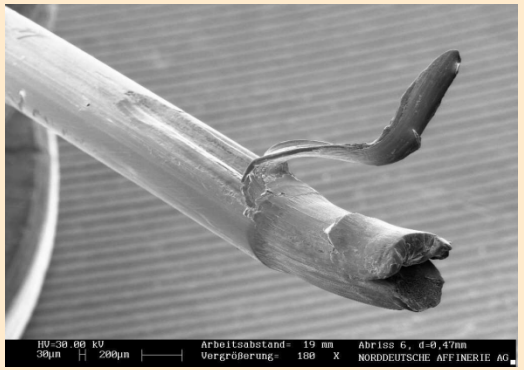
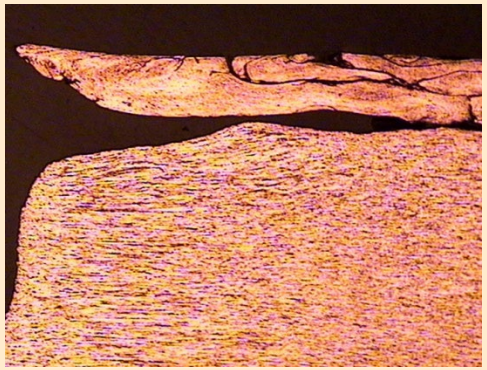


Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

| Break type | Inclusion break |
|---|---|
| Examples |    |
| Features | - V-shapes break area with or without pressed-in or inner particles<br>- surface crack in drawing direction as the case may be with further inclusion or particles rests |

NF Wire Forum

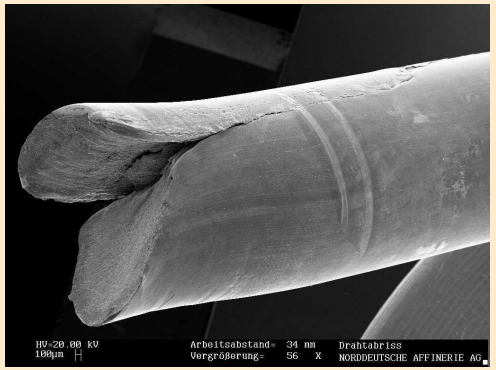
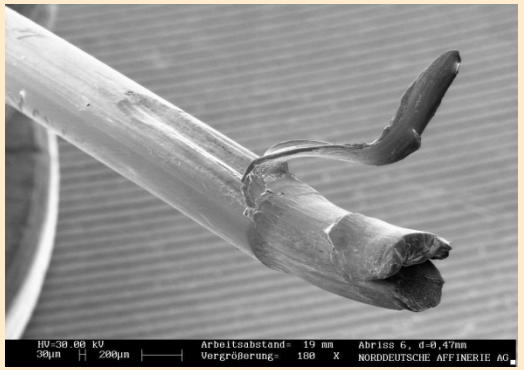
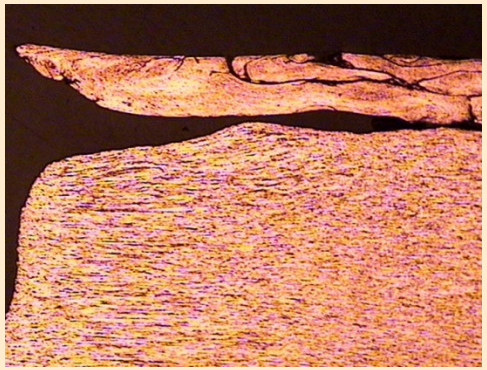
| Break type | Inclusion break |
|---|---|
| Examples |    |
| Damage mechanism and root cause | - reduction of the load bearing cross section by particles or inclusion incorporating with wire diameter reduction<br>- notch effect and exceeding failure stress<br>- copper wire surface in contact loose particles of the entire process chain incl. transport and stocking<br>- particles of the casting, rolling and drawing areas |

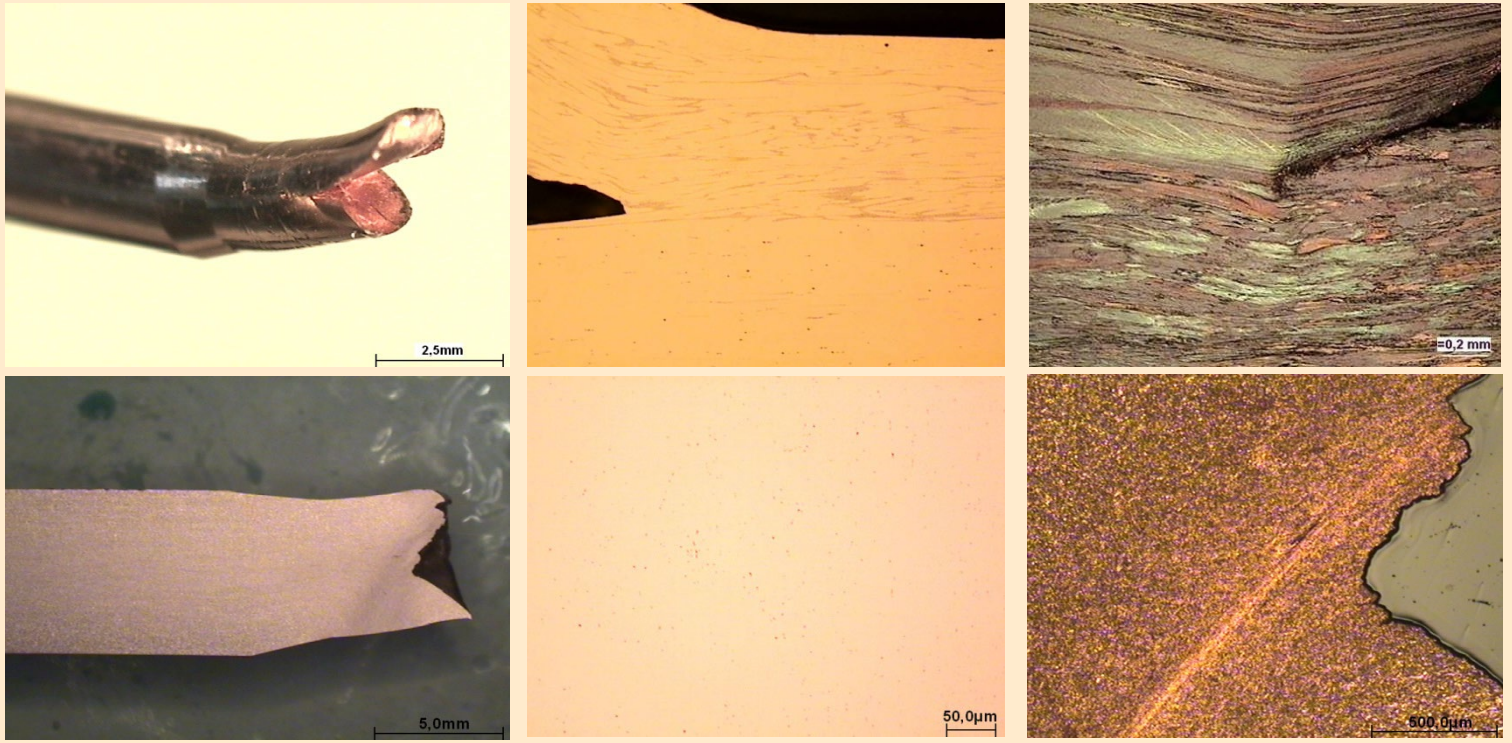
| Break type | Force break by rolled-in/ pressed-in particle |
|---|---|
| Examples |      |
| Features | - necking wire cross section<br>- material takes off the surface in the break area e.g. a flake |

NF Wire Forum



Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

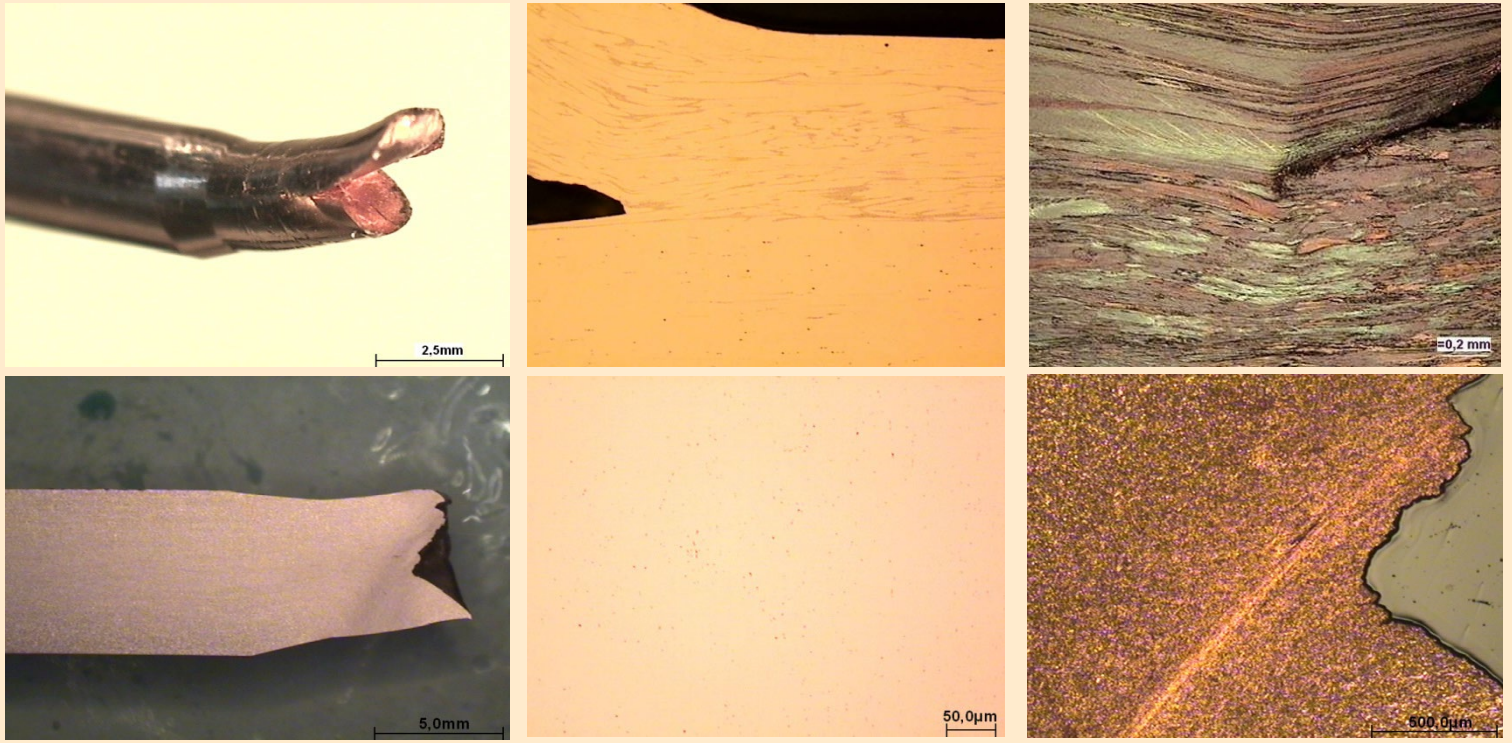
| Break type | Force break by rolled-in/ pressed-in particle |
|---|---|
| Examples |    |
| Damage mechanism and root cause | - particles/flakes from mechanical surface damages are pressed/ rolled in the surface<br>- particles/flakes can negatively influence lubrication and cooling → increase of drawing force → exceeding of forming ability of the material<br>- copper particles, flakes, flitters, etc. from different production steps |

| Break type | Weld break |
| --- | --- |
| Examples |   |
| Features | - hot weld break: „fish mouth“ and cuprous network in the weld areas<br>- cold weld: uniform microstructure on both sides of the joint |

NF Wire Forum



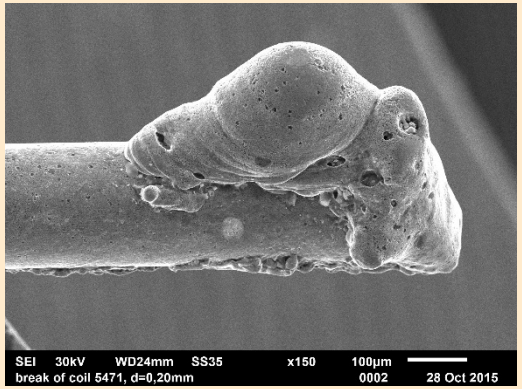
Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

| Break type | Weld break |
| --- | --- |
| Examples |  |
| Damage mechanism and root cause | - different microstuctures with different mechnical properties / oxide enrichments<br><br>- unsuitable welding process or process parameters |

NF Wire Forum



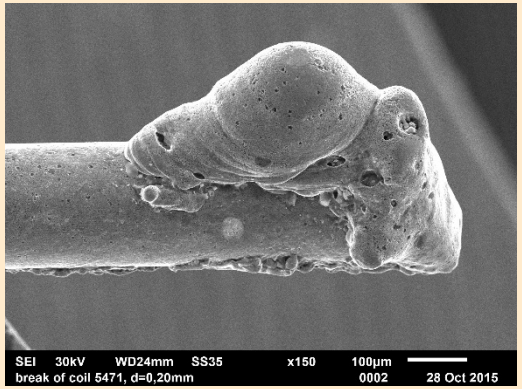
Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

| Break type | Annealing break |
| --- | --- |
| Examples |   |
| Features | - smooth break area<br>- molten material at the tip<br>- further burnt spots on the break sample |

NF Wire Forum



Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

| Break type | Annealing break |
|---|---|
| Examples |   |
| Damage mechanism and root cause | - melting of the wire by an eletric arc<br><br>- badly guided wire on the contact roll<br>- grooves on the contract roll |

NF Wire Forum



Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# Conclusion for wire breaks at fine wire drawing

NF Wire Forum

- ✓ **Break type** at **fine wire drawing** can be detected with **appr. equipment „on macroscopic level“** and is important to determine the root cause and implement **elimination measures**
- ✓ Scanning Electron Microscopy (SEM) is suitable for further investigations (e.g. inclusion material analysis)
- ✓ Preparation of cross sections of fine wire diameters are very complex and reveal no further information of the root cause
- ✓ Big portion of the **fine wire** breaks are **inclusion**, **strain induced and cup&cone break**



Aurubis Metals for Progress
BALLOFFET
BECHEM LUBRICATION TECHNOLOGY
Deutsches Kupferinstitut
NIEHOFF GRUPPE

# Join in:
# Live Panel on May 11th at 14h CET

NF Wire Forum

Please send **your questions** until May 10th to nf-wire-forum@aurubis.com

We look forward to seeing you again virtually!

www.nf-wireforum.com






Aurubis Metals for Progress · BALLOFFET · BECHEM LUBRICATION TECHNOLOGY · Deutsches Kupferinstitut · NIEHOFF GRUPPE