Development of CuCrZr for applications in Neutral Beams

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Outline

On CuCrZr Material

Materials specs, Product and Processes

The Development Program

Problems & Solutions in Pre-series Phase

Main series-All melts data

High Heat Flux testing

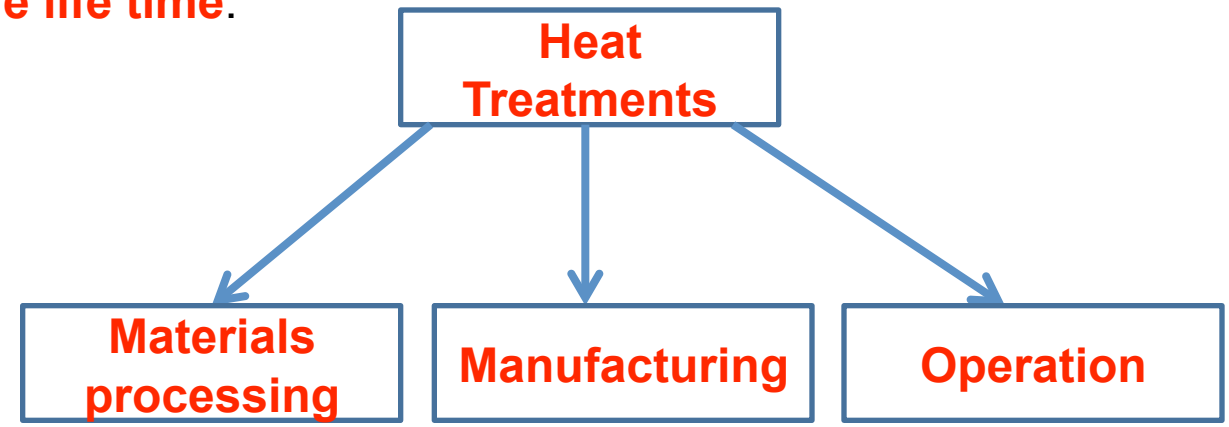
Summary

On CuCrZr material

CuCrZr is **precipitation hardened alloy** and used as **heat sink material in Fusion applications**

Present development is for Indian Neutral Beam Program.

Properties are function of **heat treatment** that the component undergoes in it's **entire life time**.



Thermo-mechanical treatments for getting desired material properties

High temperature Joining processes => Degradation of strength => regaining is necessary

Thermal cycles
-Ageing effects
-Creep effects
-Fatigue effects

On CuCrZr material

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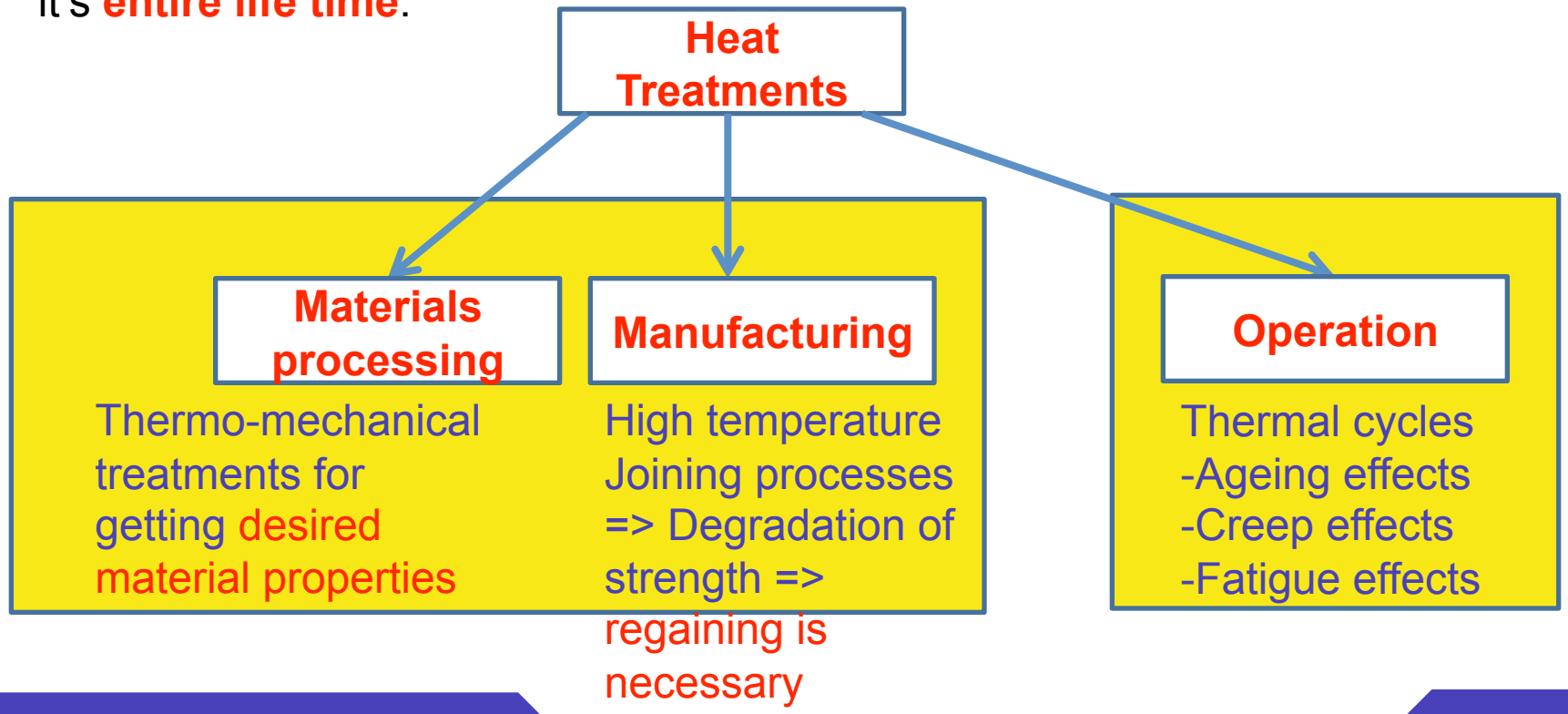
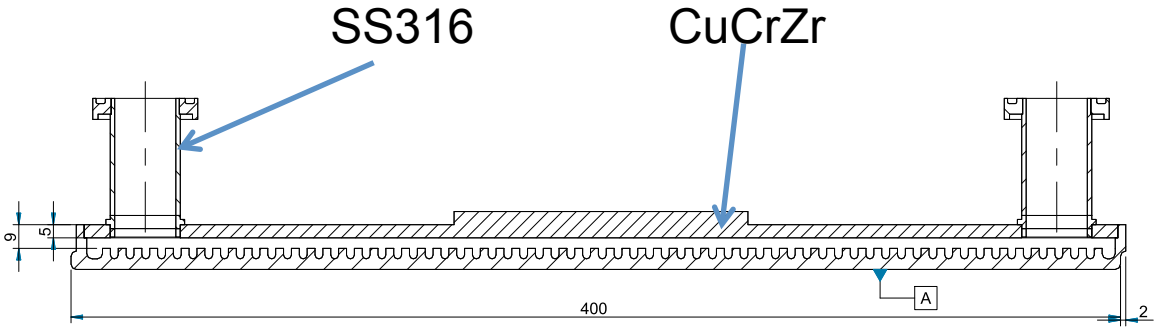


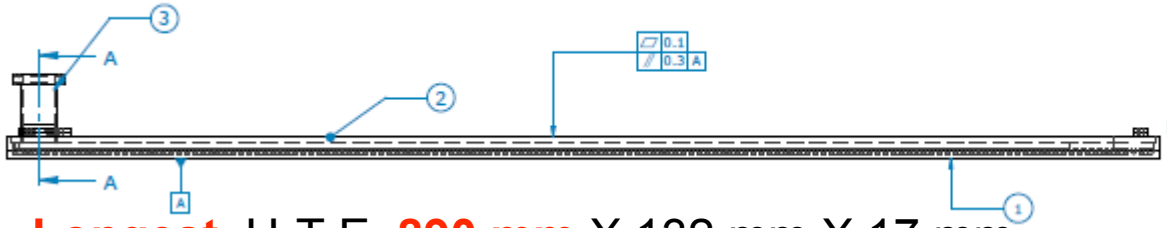
Material specs, Products and Processes

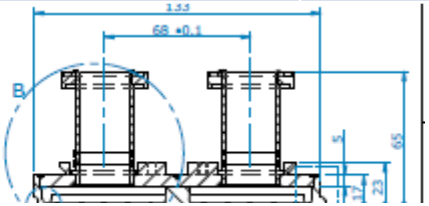


Shortest H-T-E **350 mm** X 67 mm X 17 mm

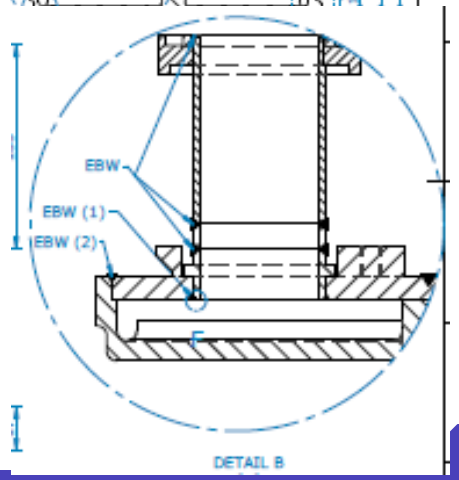
Desired properties of CuCrZr

Property	Value
UTS, Mpa	~400MPa
YS, Mpa	~300MPa
% El	>15
Therm. Cond, W/m C	>325
Grain size	<100µm





Longest H-T-E **890 mm** X 132 mm X 17 mm



*** Machining of long plates**

*** Electron Beam Welding**

1. **CuCrZr-Ni-SS316L** (**pipe to Pipe**)
2. **CuCrZr-CuCrZr**(**Pipe to Plate**)
3. **CuCrZr-CuCrZr**(**Plate to Plate**)

The Development Program

To develop the capability to produce CuCrZr material indigenously to cater the requirement

Forming + EBW qualification phase

establish all process parameters including acceptance tests related to fabrication

To Validate the design concept

Development of Indian CuCrZr

Pre-series

4 Single types + 2 Double types

High Heat Flux testing

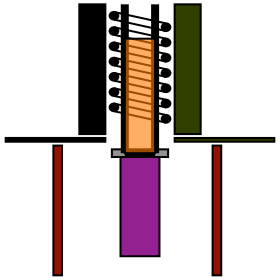
Passing all acceptance criteria

Main series

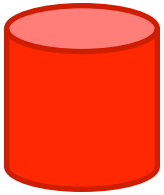
234 Nos

Material Processing Steps

Vacuum Induction Melting



Master alloys OFHC copper + CuCr +CuZr

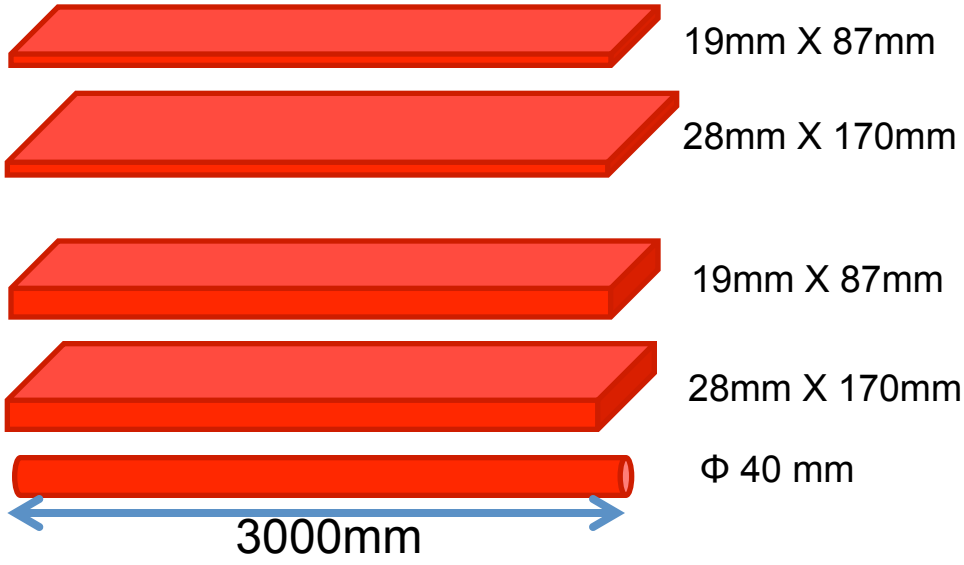


Billet size: Φ 225 mm X 350 mm

Hot Work- Extrusion

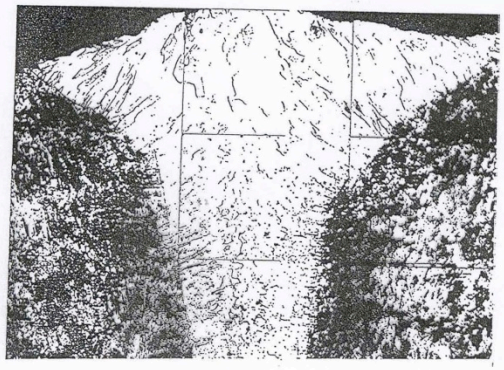
Solution annealing + Quenching

Cold Work

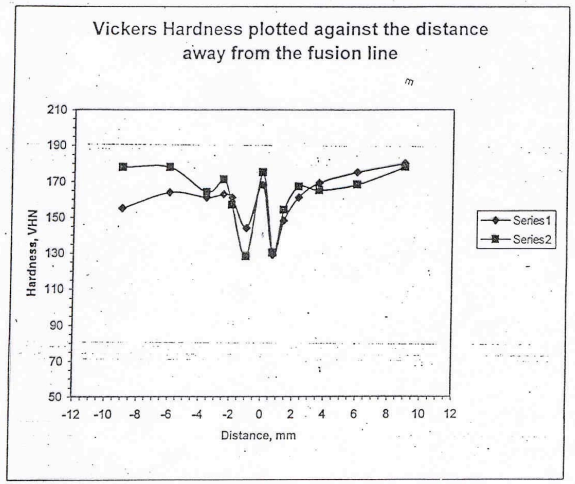


Pre-series phase: EBW characterization 1 of 2

Exhaustive coupon welding program : similar and dissimilar joints



Electron Beam weld cross section of Cu-1.0%Cr-0.1%Zr Alloy

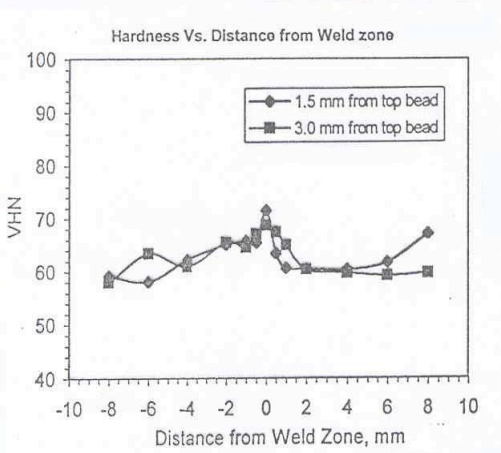


Sample : STCWEBA

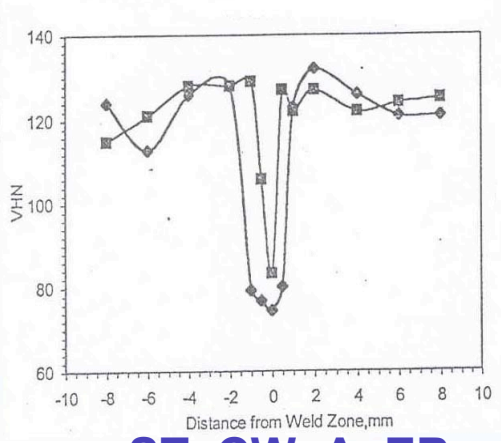
Series 1 : 1.0 mm away from the top bead

Series 2 : 2.5 mm away from the top bead

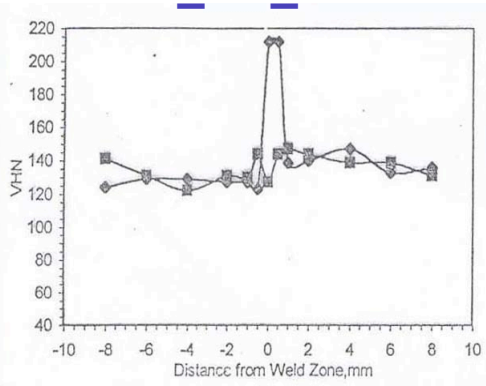
ST_EB



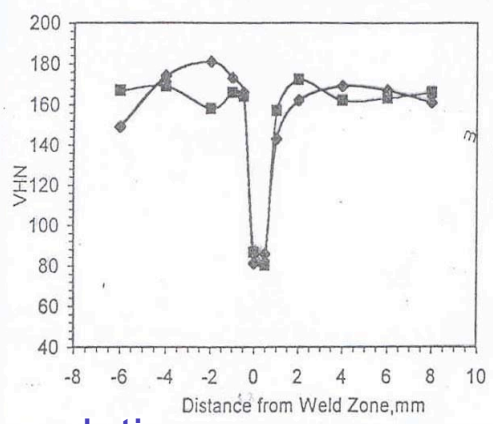
ST_A_EB



ST_EB_A

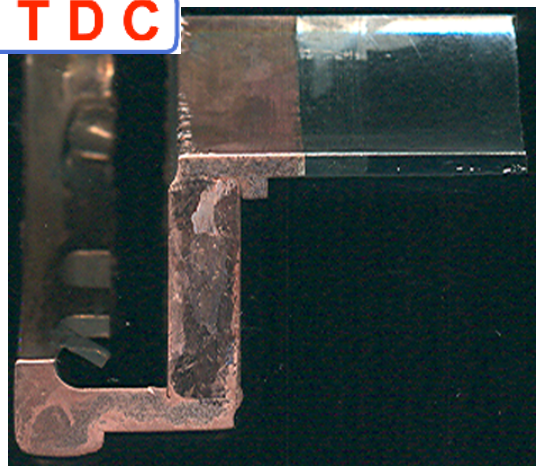


ST_CW_A_EB

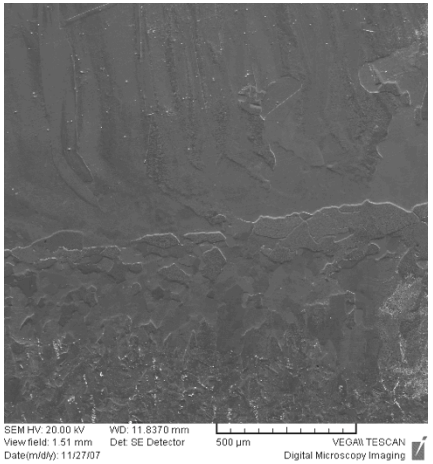


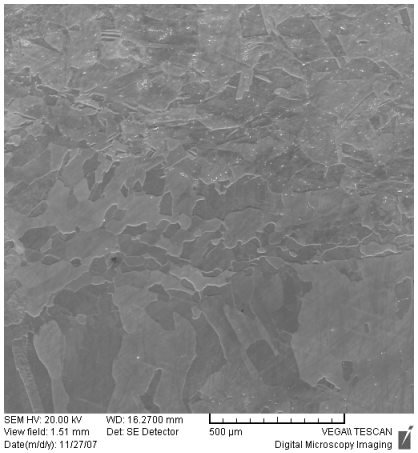
HAZ material is equivalent to solution Annealed state and strength regaining Post EBW Ageing treatment is necessary.

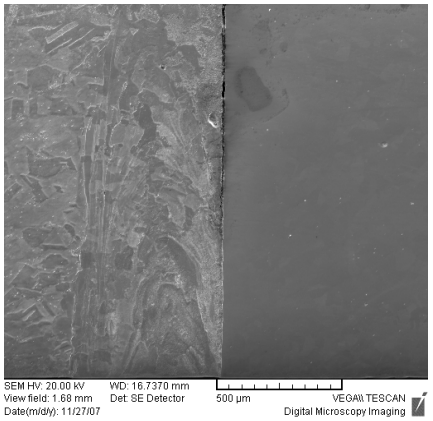
Pre-series phase: EBW characterization 2 of 2

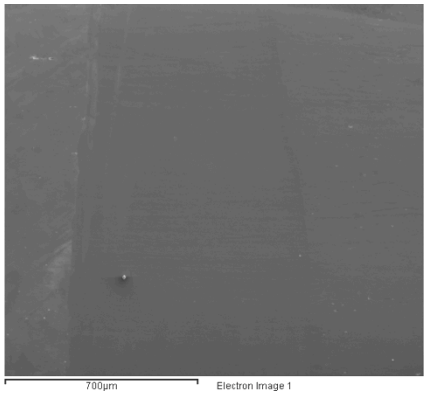


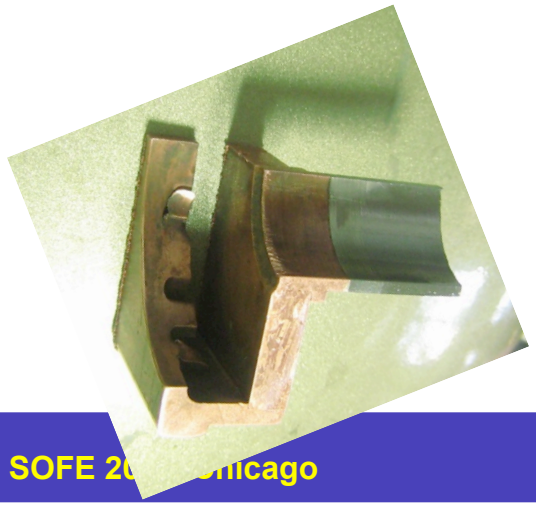
Location	Weld Joint
1	CRZ/CRZ
2	CRZ/CRZ
3	CRZ/Ni
4	Ni/SS









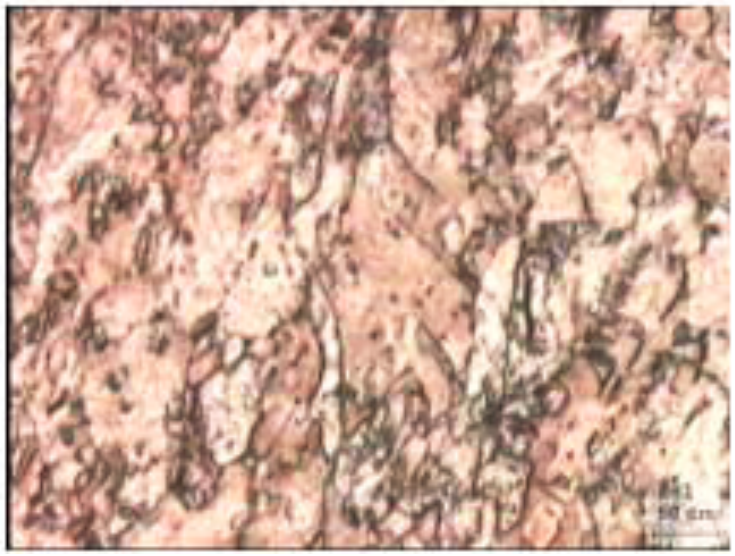


Problems & Solutions -Pre series Phase 1 of 3

1. Cracks and fissures in weld joints

One batch had grains of the order of **3 mm !** when during the time of welding.
Cracks were found in the welding
Hence the batch was taken out from further processes

Batch with larger grains



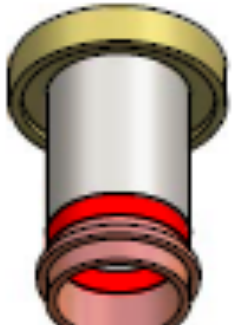
Batch with grain size =**65**µm

Strict quality control procedures employed in the Main series and the grain size always remained < 90 µm

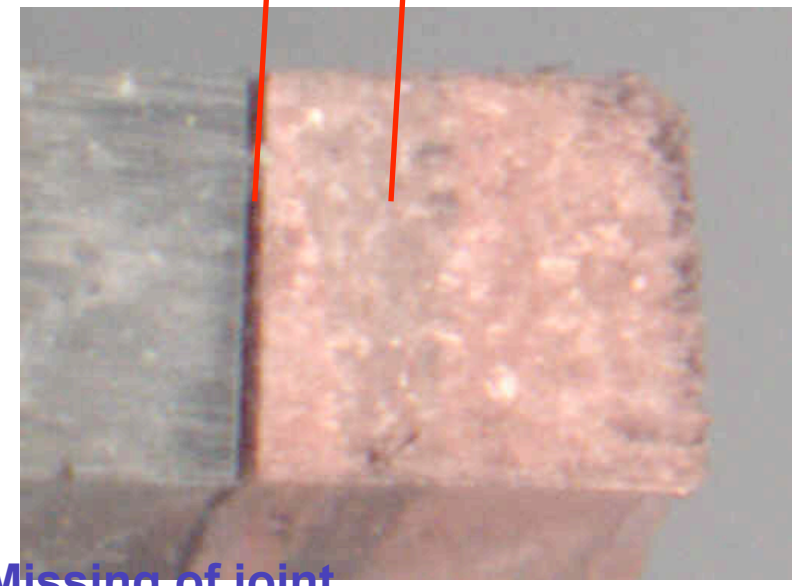
Problems & Solutions -Pre series Phase 2 of 3

2. He leak failure in dissimilar joint

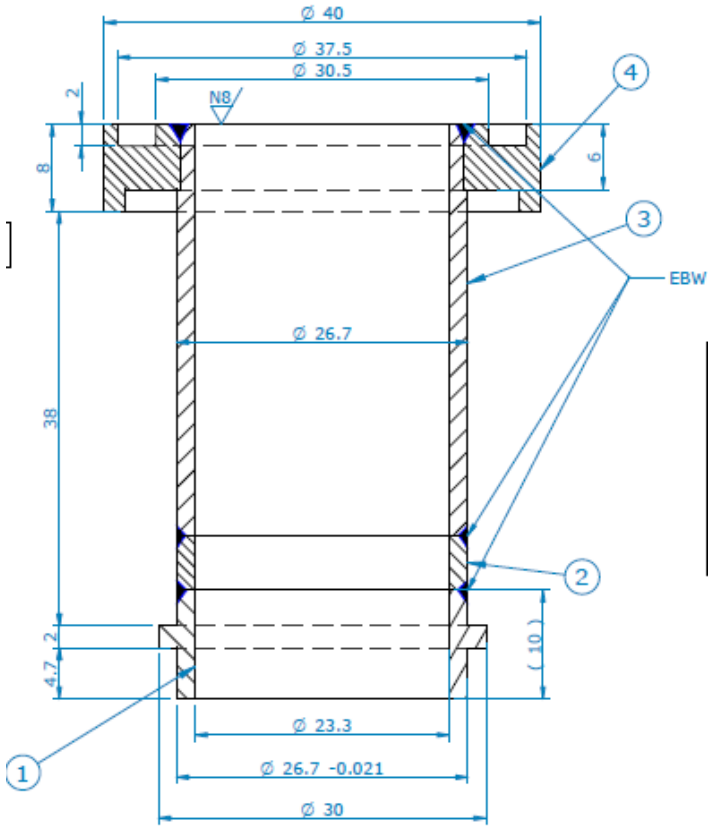
(Ni and CuCrZr)



~400µm



Missing of joint



Magnetic field due to Thermoelectric Eddy Currents generated during EBW, deflects the beam.

Solution : Reducing the pipe thickness by 50 %
-> Reduces thermoelectric eddy current density
→ hence beam deflection.

Problems & Solutions -Pre series Phase 3 of 3

Machining of Long Thin Plates with very low Longitudinal Stiffness

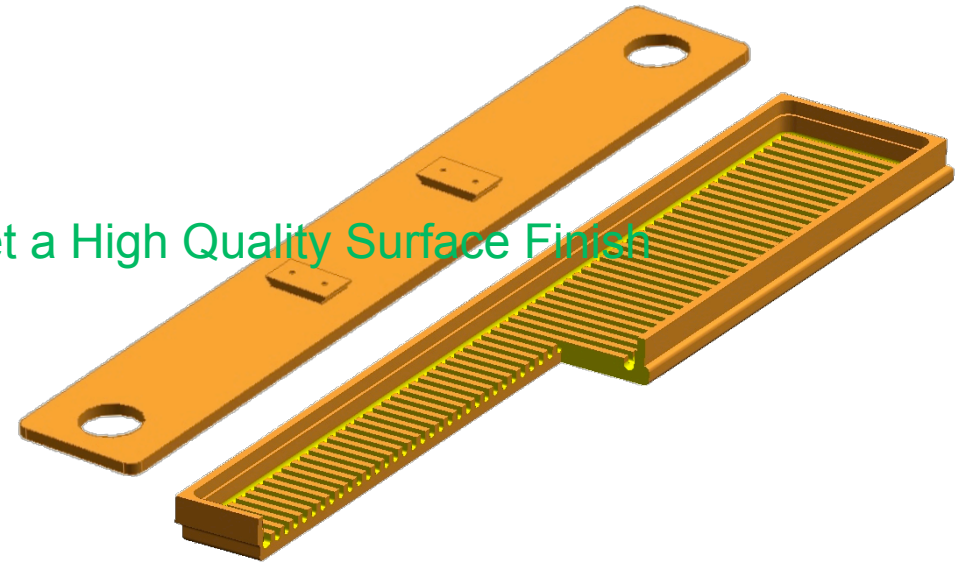
Extensive Bend & Twist – (Relaxation of internal stresses)

Method of Intermittent Bend Removal & Machining – Material Seasoning

Material softens while machining

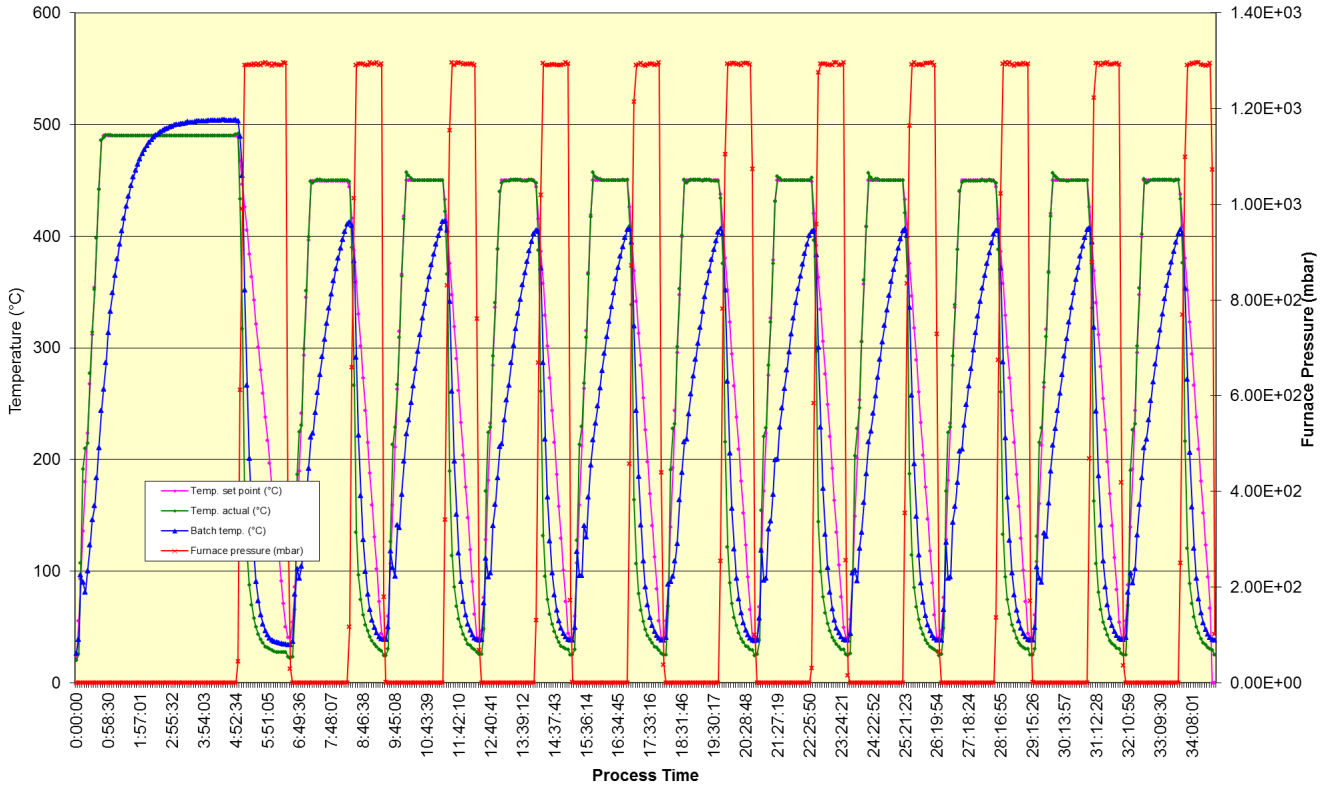
Tool/Feed Rate Optimization to get a High Quality Surface Finish

For UHV Applications

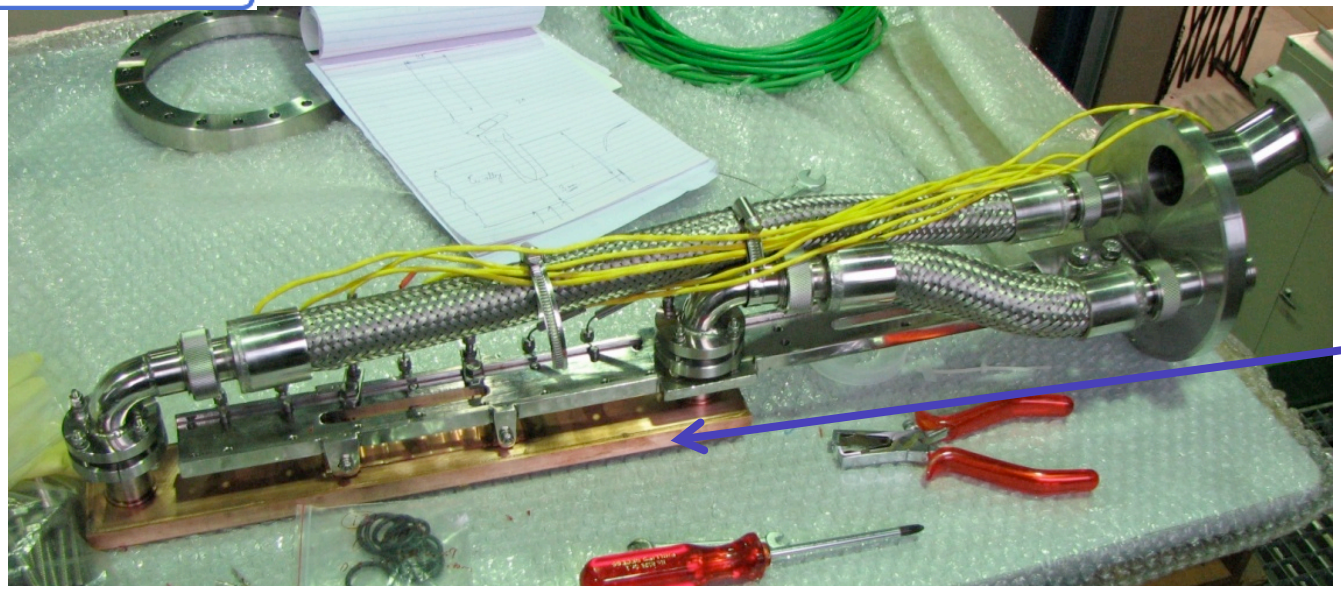


Acceptance tests

Helium Leak Test – 10^{-9} torr-lit /s
Pressure test ~ 15 bar
Thermal cycling after ageing treatment + Leak test



Deliverables of Pre-series

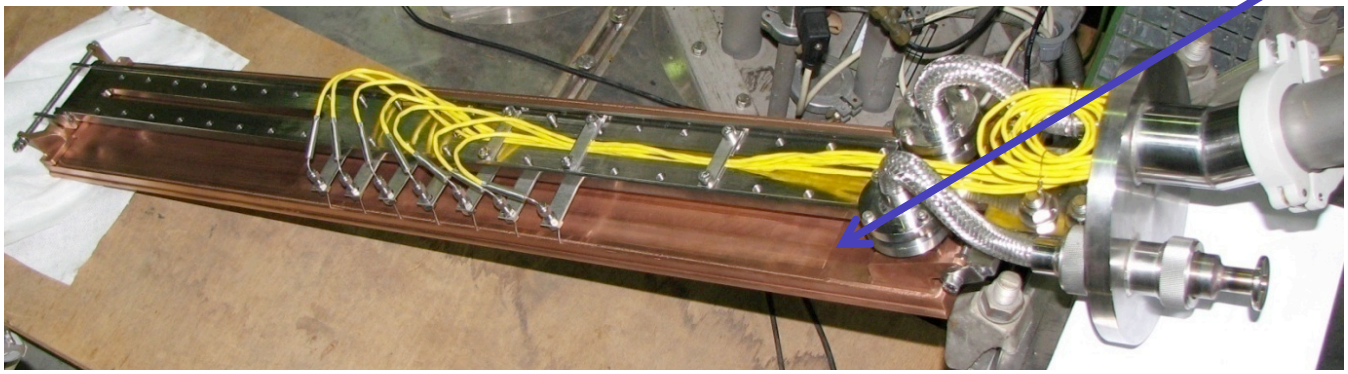


400 mm long H-T-E

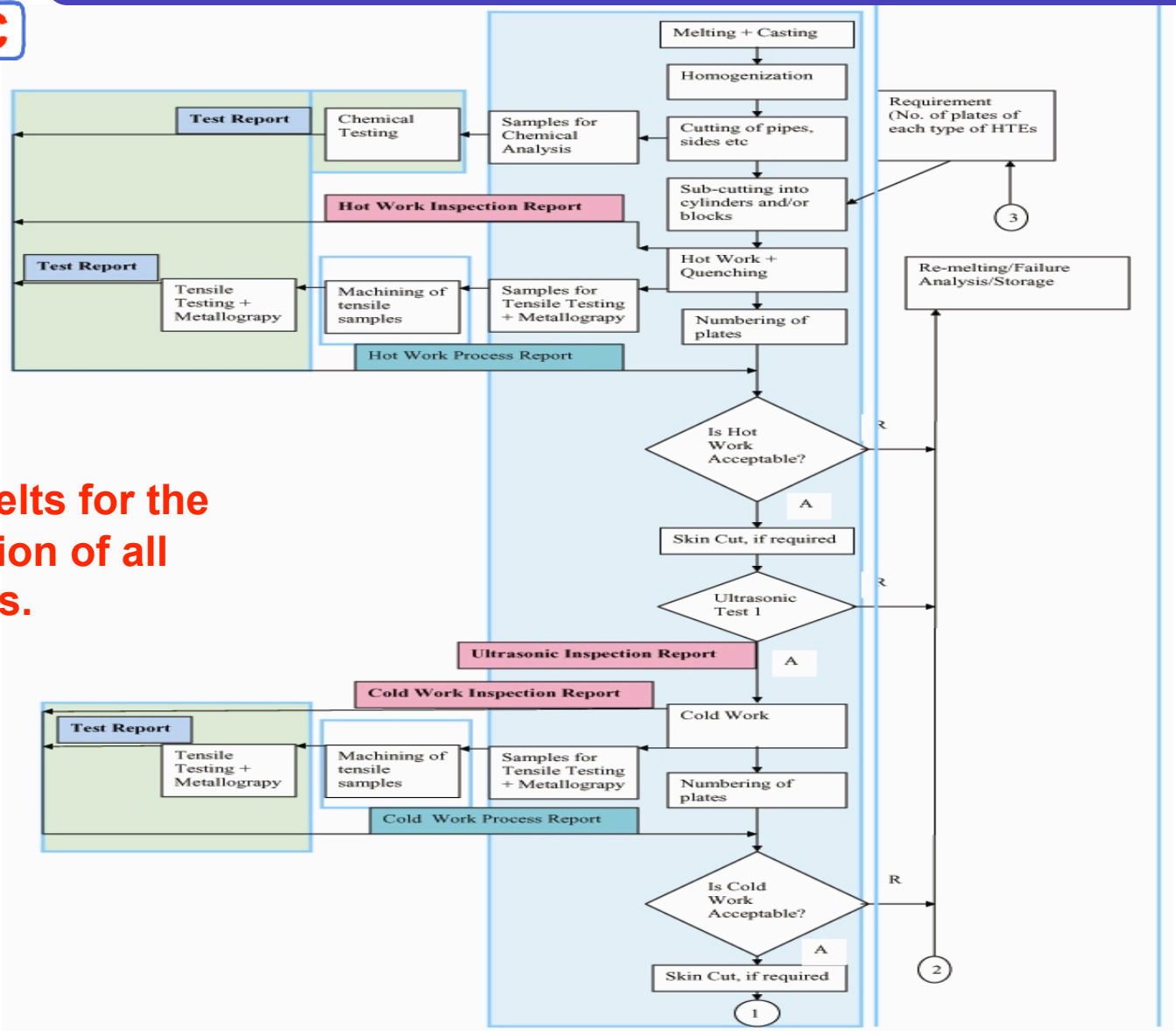
4 in no.s

890 mm long H-T-E

2 in no.s

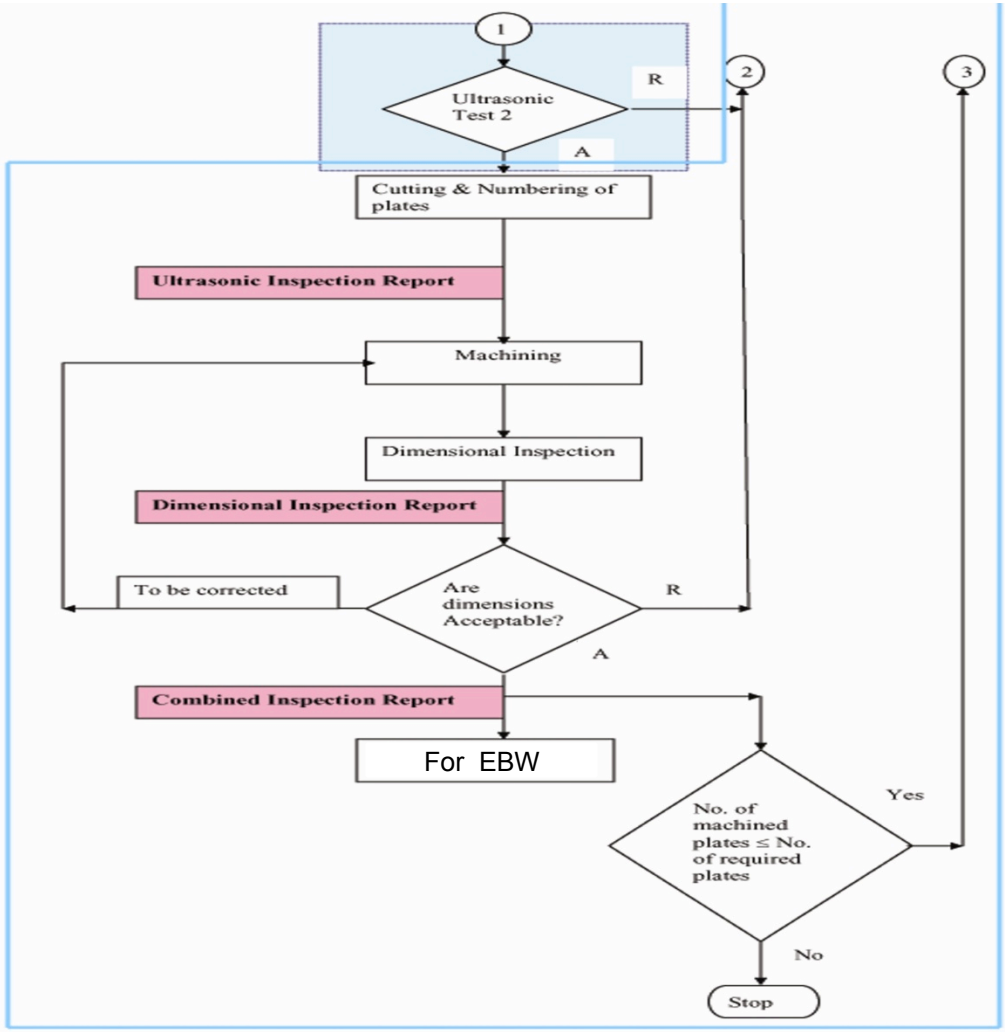


Quality Control Chart for Main Series



~ 150 melts for the production of all elements.

Quality Control Chart for Main series

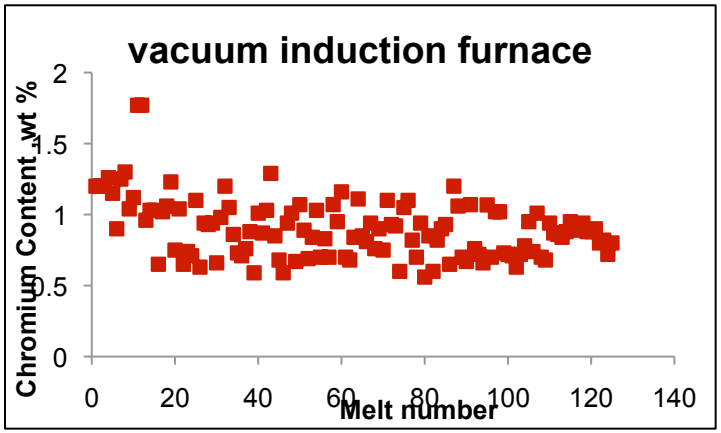


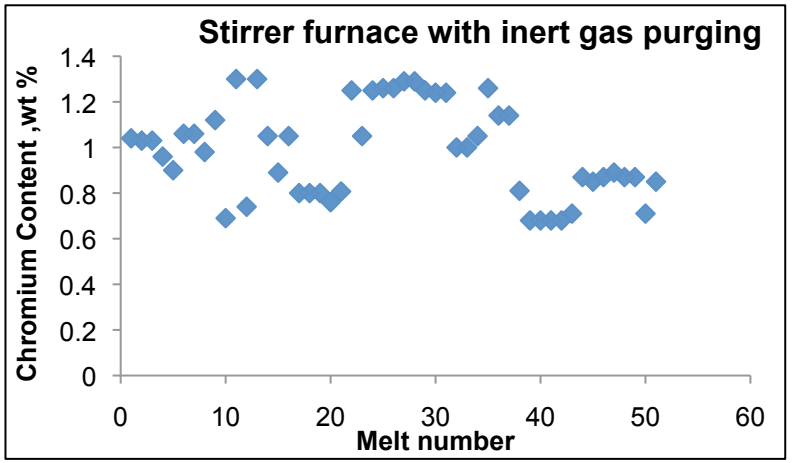
Solidification & Casting Applications Lab

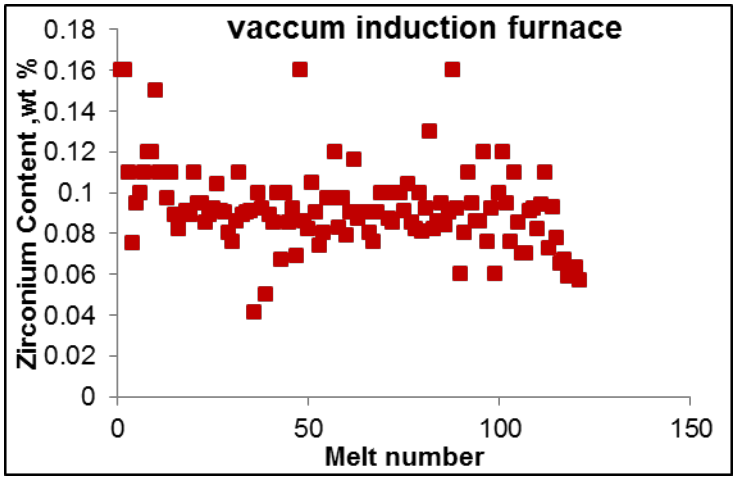
Materials Testing Lab

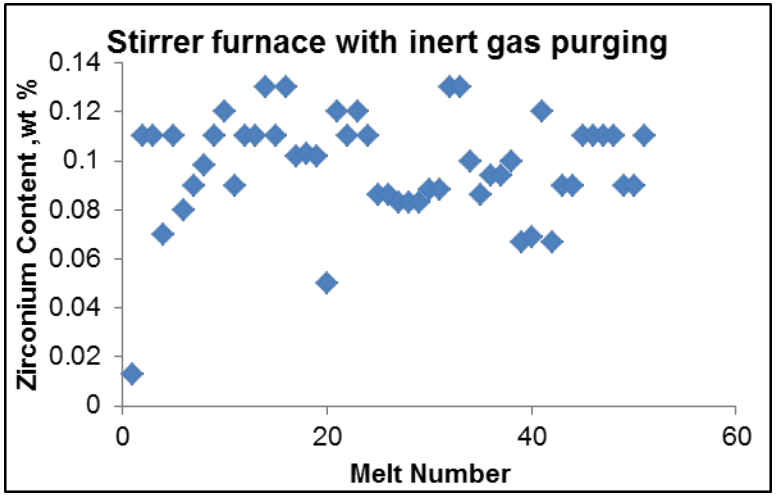
Design & Precision + Metal working & Applications Lab

Chemical composition for all melts









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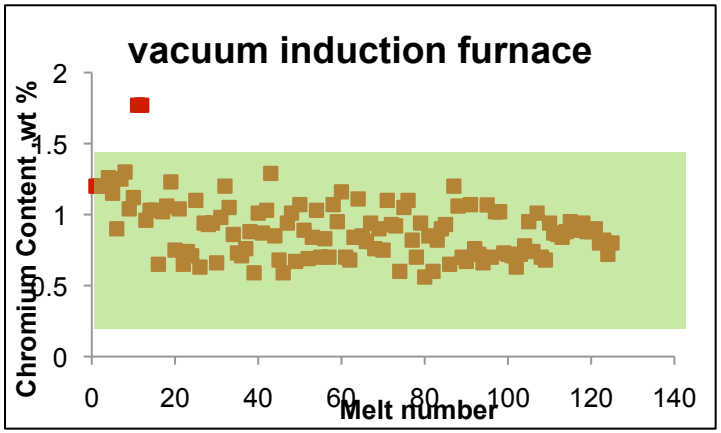
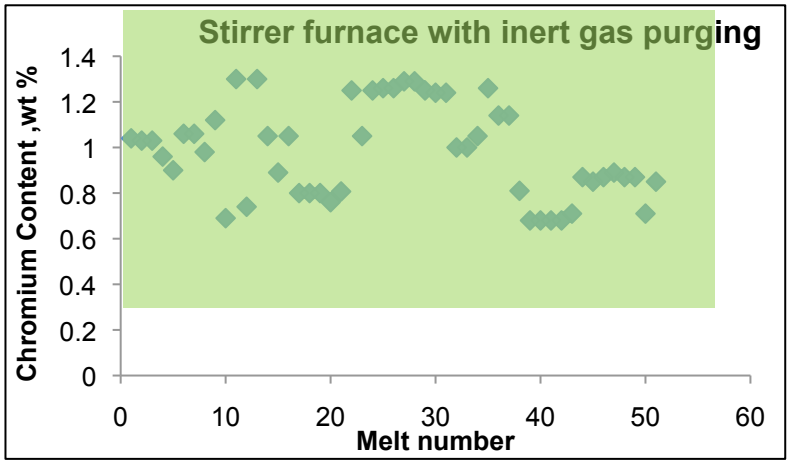
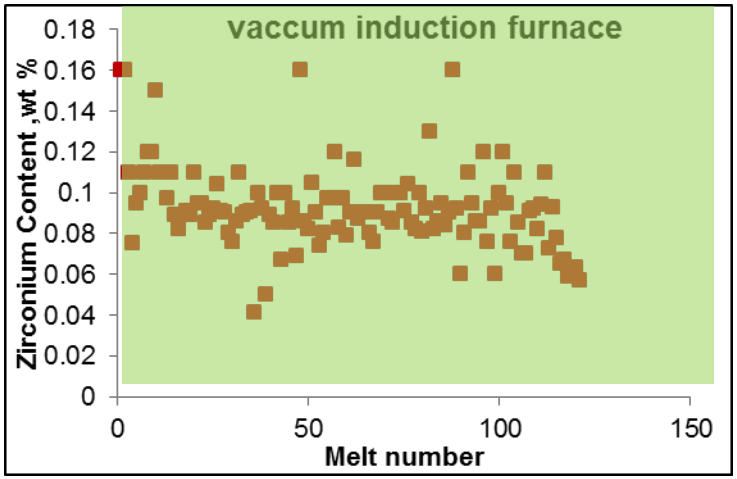
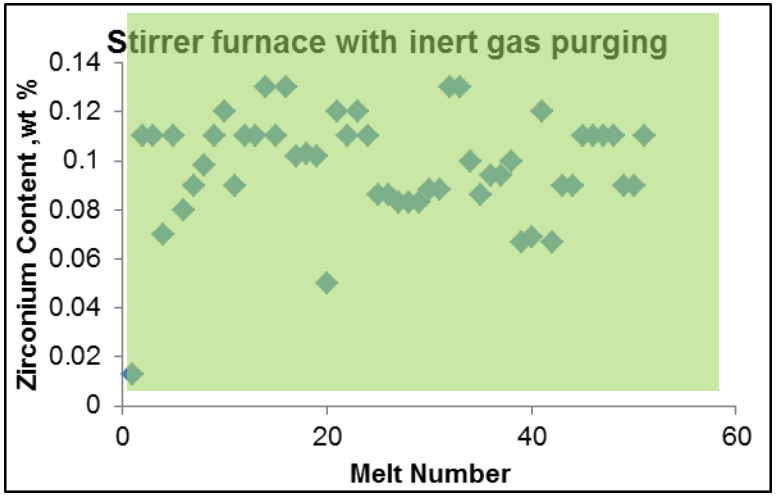


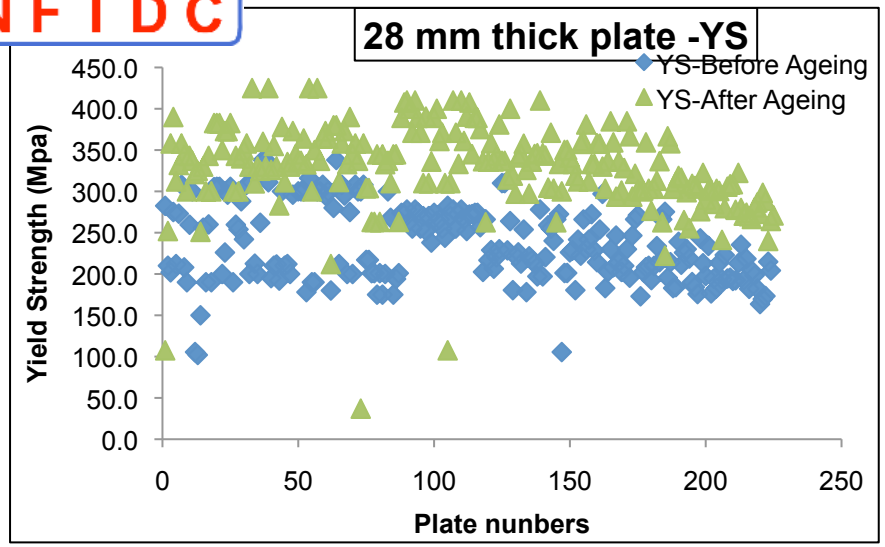


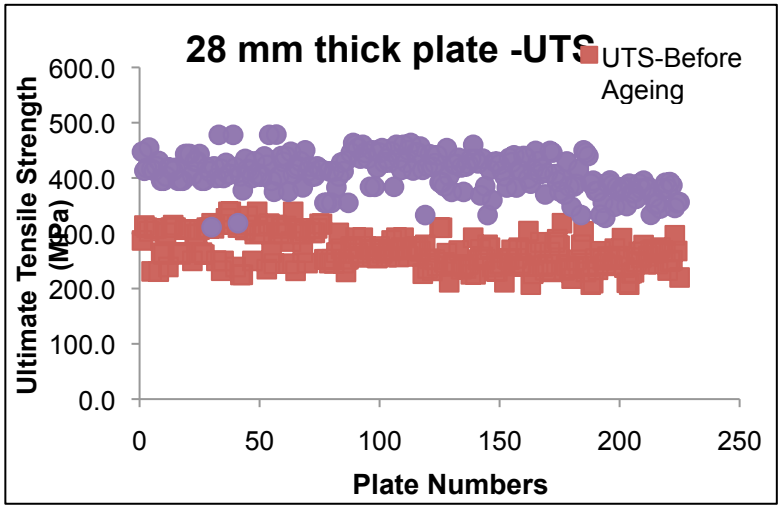


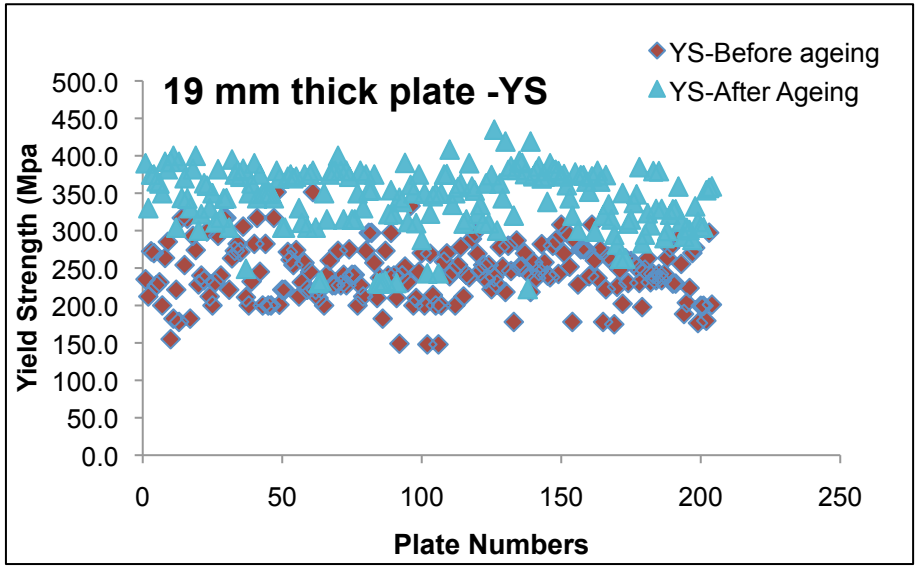


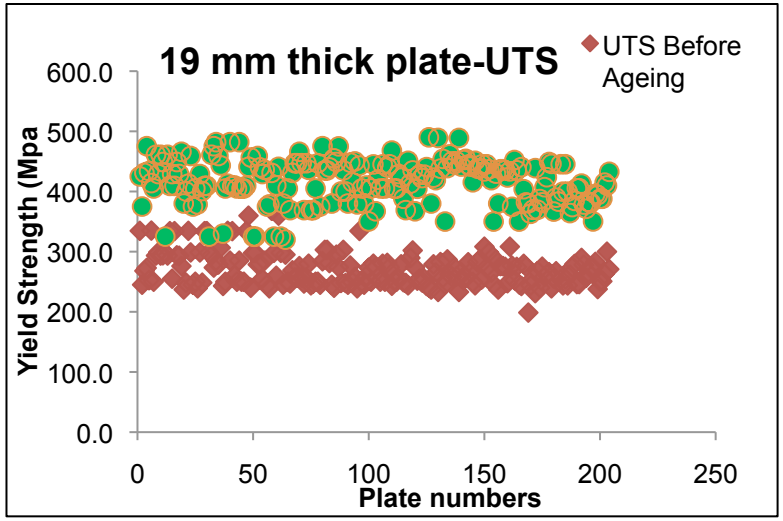
UNS material -C 18150 composition spread

Strength data for all plates(For extrusion route)









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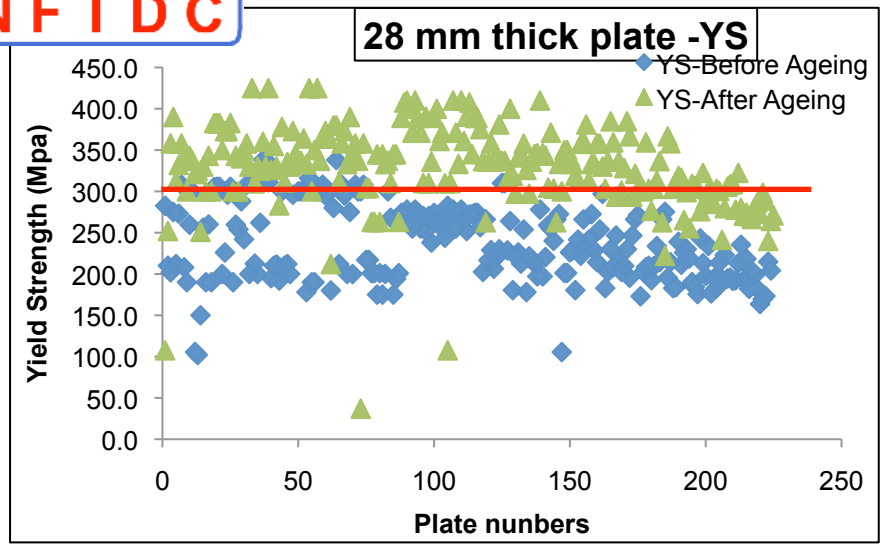
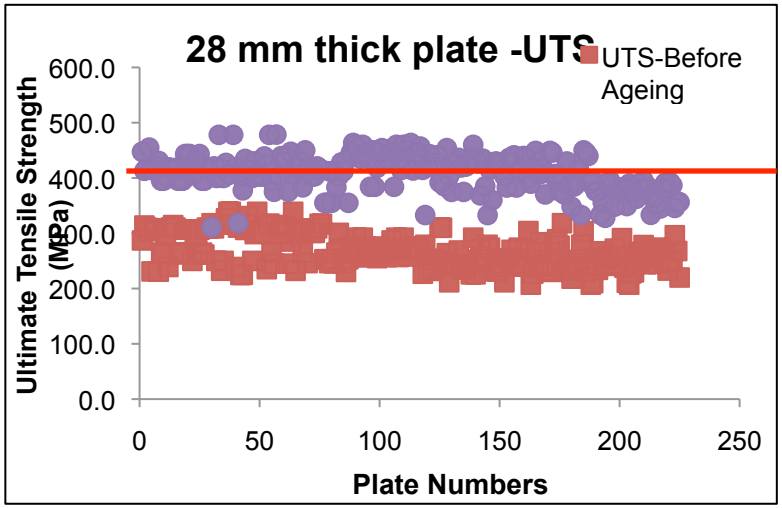
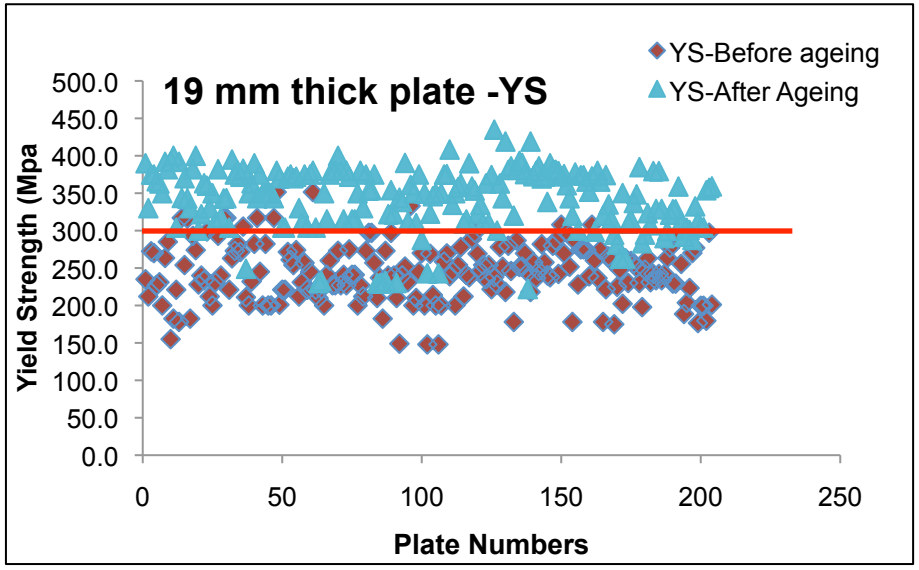
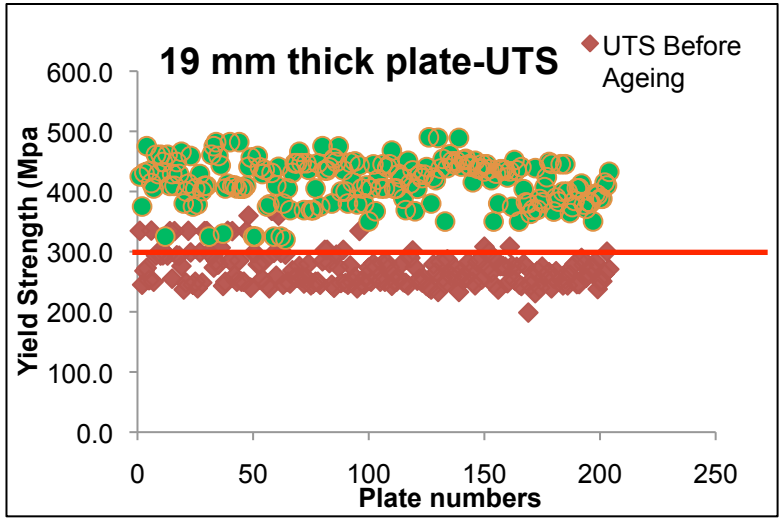


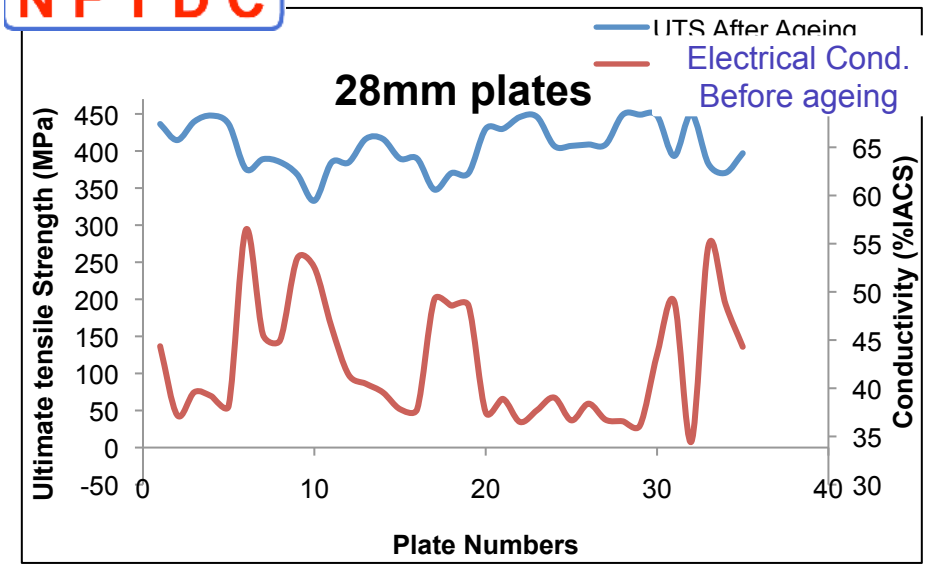


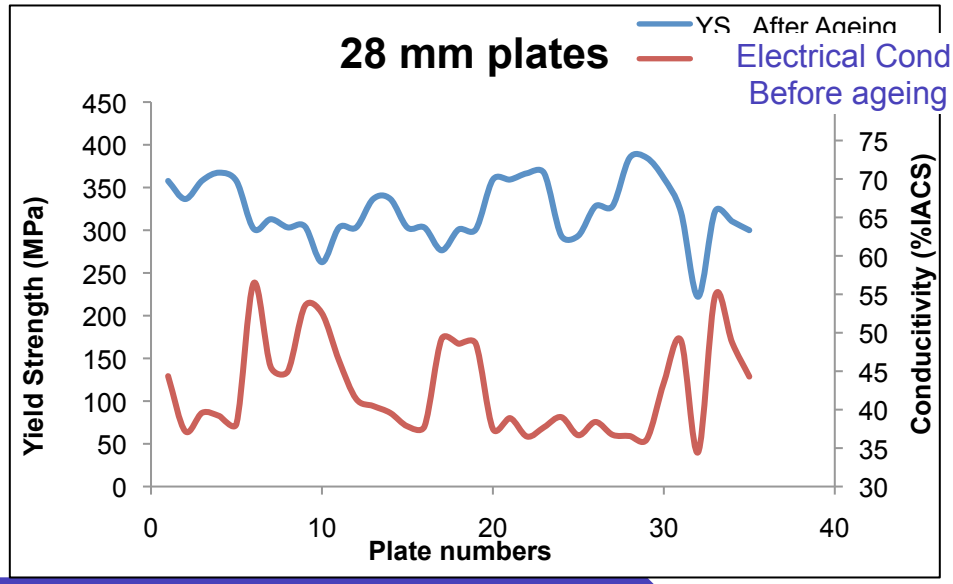




Specification central value line -

Strength and electrical conductivity





Low electrical conductivity in solution annealed state gives good strength in Aged condition.

As cast 40-50 % IACS

As hot forged +A/c : 50-70% IACS

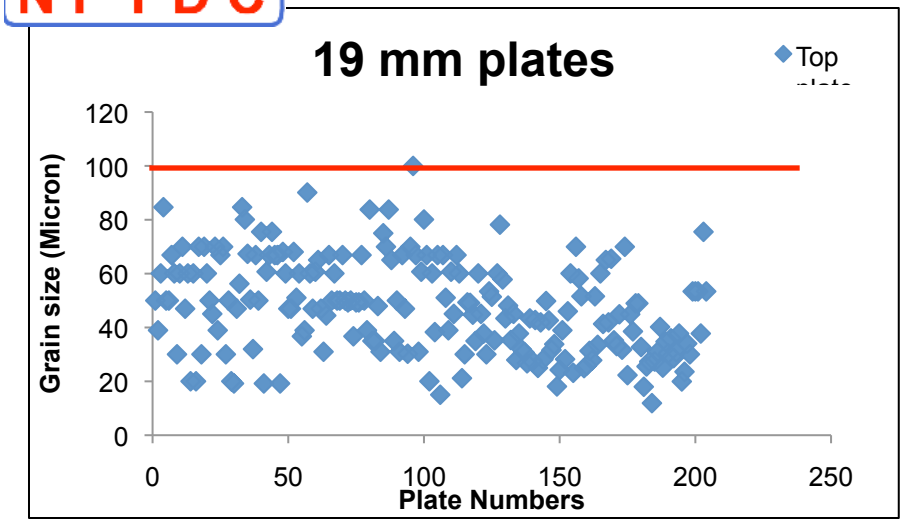
hot forged+ WQ : 40-50% IACS

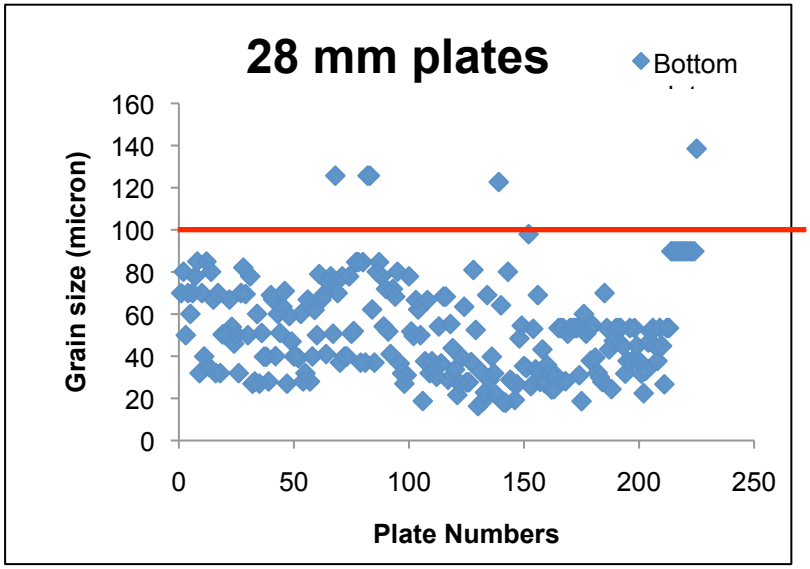
s hot extruded+ WQ: 35-45% IACS

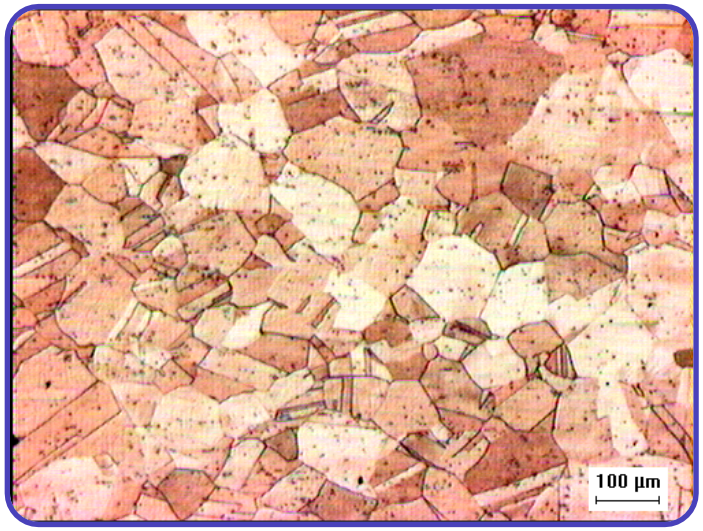
As hot forged + Extruded + Cold Drawn + Aged : 80-85% IACS

With **Wiedemann-Franz Law,** The thermal conductivity is **325 W/m K**

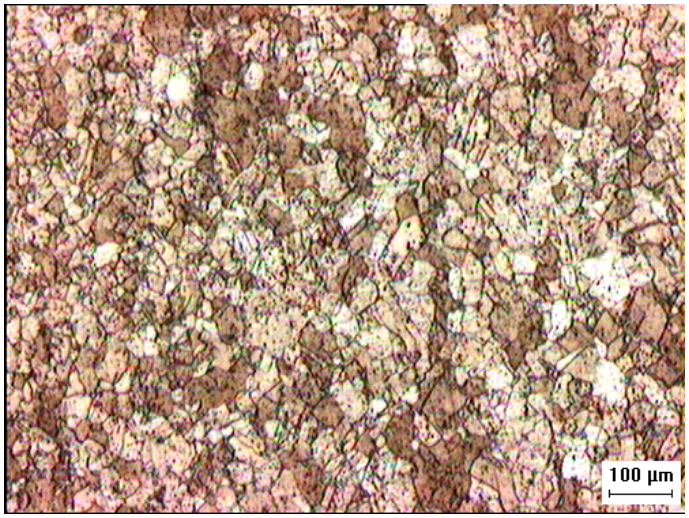
Grain sizes







ASTM Grain size No. 4-5 (64–90 µm)



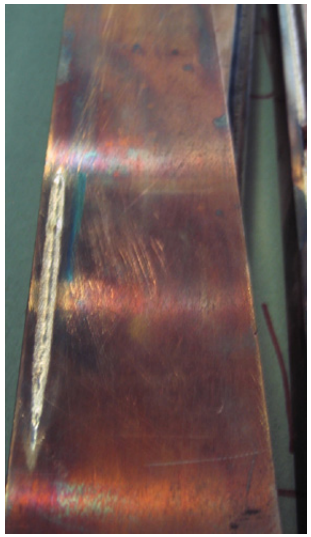
ASTM Grain size No. 6-7 (32–45 µm)

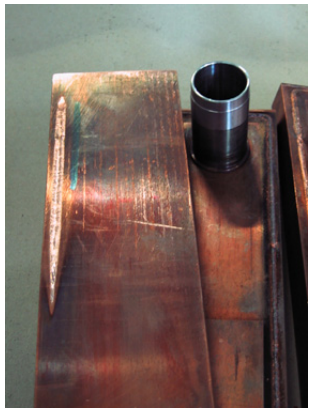
Acceptance criteria -- Grain size ≥ ASTM grain size no. 4

Specification upper limit value line -

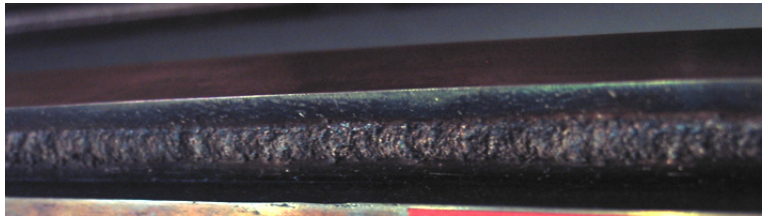
Problems encountered in Main series

Five components, beam welded through the component
→ failure in EB control system

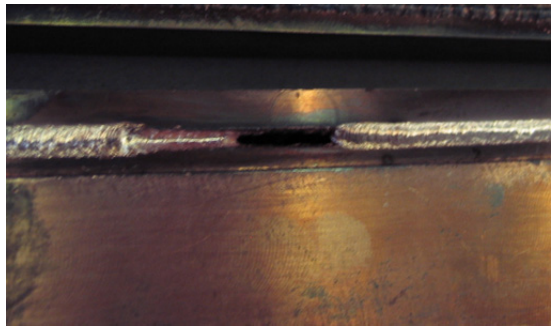




One H-T-E- weld seam quality was poor



One H-T-E - Burn through the weld line



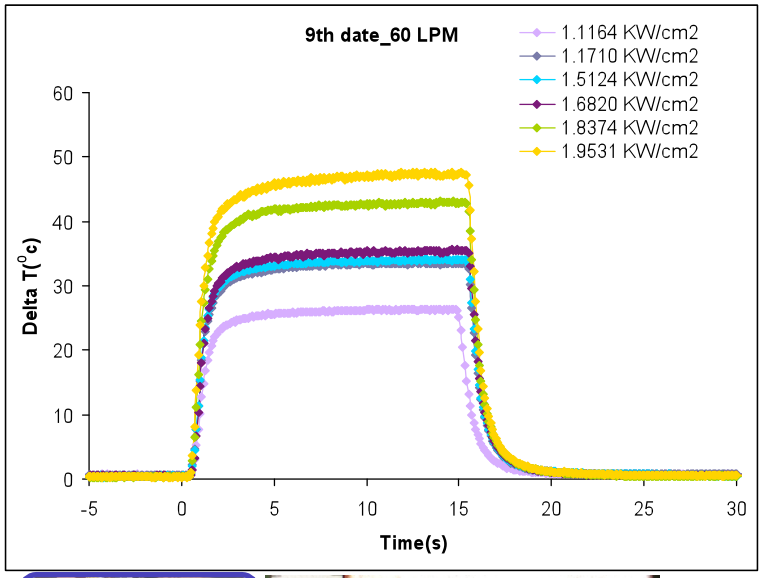
One H-T-E- leak in the water stub part.

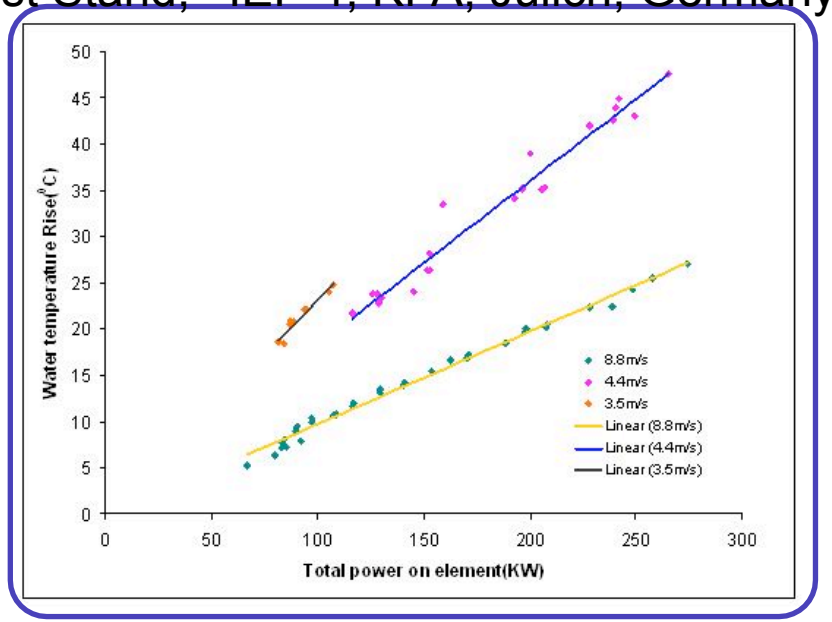
All 8 eight H-T-Es have been rejected and new ones were welded.

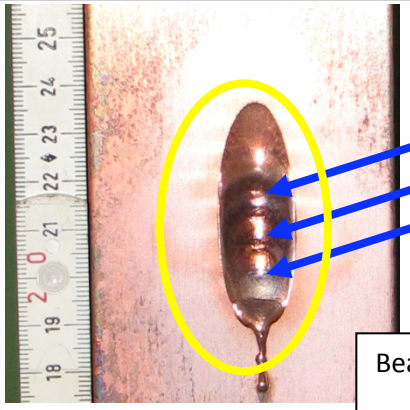
Out of 210 H-T-Es so far manufactured, 8 have been rejected.
~ 4 % rejection

High Heat Flux Testing

Tests carried out on MARION Test Stand, IEF-4, KFA, Julich, Germany







Periodicity of f

Burn out occurred at @ PD ~ 20 MW/m2

Safe operation limit -10MW/m^2

Performance is well at 15MW/m^2

No permanent deflection seen.

No leak problems

Burn out occurred ~ 20 MW/m^2

Summary

- The Indian CuCrZr material for usage in High Heat Flux elements of NB has been developed.
- The material is successfully used for Heat Transfer Elements for Indian NB program.
- The prescription of fabrication of Heat Transfer Elements is available and shall be used in manufacturing of Elements for

  1. ITER Diagnostic Neutral Beam Calorimeter
  2. SPIDER Beam Dump