

# Material procurement of seamless cavities and characterization of spun half-cells

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ENGINEERING  
DEPARTMENT


*Manufacturing of Seamless cavities - CERN-LNL meeting 07-11-2018*

# 1. LNL – Material requirements

Manufacturing of 400 MHz seamless cavities



Large size copper discs  
Ø1500mm



ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLEAIRE  
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Materials Technical Specification  
GS-IS & EN-MNE

### Technical Specification

N° 2000 - Ed. B  
EDMS No: 790780

Oxygen-Free Electronic copper sheets

Cu-OFE

This document specifies the CERN technical requirements for Cu-OFe equivalent to UNS C10100 Grade 1, according to ASTM B224 maximum oxygen content of 5 ppm.

CERN - CH211 Geneva 23 - Switzerland EDMS No: 790780

**1. NORMATIVE REFERENCES**

Unless stated in the present CERN specification or agreed by a written mention in the order, the material shall be in accordance with the following referenced documents. The latest edition applies.

ASTM B224	Standard Classification of Coppers
ASTM B170	Standard Specification for Oxygen-Free Electrolytic Copper-Rolled Forms for Electron Devices
ASTM F68	Standard Specification for Oxygen-Free Copper in Wrought-Forms for Electron Devices
ASTM B152	Standard Specification for Copper Sheet, Strip, Plate, and Rolled Bar
ASTM B577	Standard Test Methods for Detection of Cuprous Oxide (Hydrogen Embrittlement Susceptibility) in Copper
ASTM E112	Standard test methods for determining average grain size
ISO 6892-1	Metallic materials - Tensile testing - Part 1: Method of test at room temperature
EN 10307	Non-destructive testing - Ultrasonic testing of austenitic and austenitic-ferritic stainless steels flat products of thickness equal to or greater than 6 mm (reflection method)
EN 4050-1	Aerospace series - Test method for metallic materials - Ultrasonic inspection of bars, plates, forging stock and forgings - Part 1: General requirements
EN 4050-4	Aerospace series - Test method for metallic materials - Ultrasonic inspection of bars, plates, forging stock and forgings - Part 4: Acceptance criteria
EN 10204	Metallic products: Types of inspection documents

2. REQUIREMENTS

2.1. CHEMICAL COMPOSITION

The composition shall conform to the requirements of the UNS C10100 Grade 1 according to the standard ASTM B170:

Cu	0.0005% in mass max.
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2.2. HYDROGEN EMBRITTLMENT

According to ASTM B170 and F68, the material shall be free from hydrogen embrittlement.

2.3. STRUCTURE

The grain size number, according to ASTM E112, shall be 4 or greater.

2.4. INCLUSIONS CONTENT

In accordance with ASTM F68, only classes 1 and 2 shall be accepted.

2.5. MECHANICAL PROPERTIES

Hot or cold-rolled in accordance with the thickness, the sheets shall be given the necessary treatment to allow delivery as close as possible to the quarter-hard state, according to ASTM B152 and the required mechanical properties given in the following table.

Tensile testing shall be carried in accordance with ISO 6892-1. Tensile testing must be performed both longitudinal and transverse to the rolling direction.

At room temperature:

Tensile strength	$R_m$	240-250 <sup>a</sup> N/mm <sup>2</sup>
Yield stress	$R_{0.2}$	200-240 <sup>a</sup> N/mm <sup>2</sup>
Elongation at break	$A_5$	min. 25%
Brinell hardness 20 kgf (2 mm ball)	HBS	min. 60 <sup>a</sup>

<sup>a</sup>Any value out of these ranges shall be discussed between CERN and manufacturer prior to delivery. The transverse elongation must not differ from the longitudinal elongation by more than 5 % strain.

2.6. ELECTRICAL PROPERTIES

According to ASTM B170 and F68, the conductivity in annealed conditions should be at least 101% IACS.

2.7. THERMAL CONDUCTIVITY

At 4.2 K, a thermal conductivity of 400 W.m<sup>-1</sup>.K<sup>-1</sup> shall be guaranteed.

Tech. Spec. N°2000 - Cu-OFe - Sheets 3/4

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2.6. INTERNAL SOUNDNESS

The homogeneity of the copper shall be ultrasonically inspected. In the absence of an app ultrasonic standard for flat copper products, EN 10307 adapted to copper shall be used. Criteria of acceptance are given in the following table.

Number and extent of the tests	- Each copper piece (sheet/plate) - 100% of the piece
Method	- Frequency: the highest possible to join the acceptance level. The frequency has to be indicated in the procedure Written procedure based on EN 10307 (or equivalent)
Acceptance criteria based on EN 4050-4, Table 1	- The highest possible class - To be agreed with CERN and indicated in the procedure - Ultrasonic indications greater than the class value - Heterogeneous attenuation leading to variations of at least 20% of the first back wall echo
Cases of rejection	- In the event of faults, the results shall be discussed between CERN and the manufacturer/deliverer.

2.6. SURFACE QUALITY

Sheets shall be produced without brushing. Surface shall be clean and free from scale, pe any other foreign matter which could adversely affect the ultrasonic test sensitivity or cause in interpretation.

For each sheet, shall be prohibited:

- Defects, scratches or discontinuities (oxide impregnation) deeper than 130 µm or 5% thickness, whichever is the smaller.
- Folding of laminates under the surface.
- Protection film containing glue or any kind of protection which could leave traces on the surface of the sheet.

In specific cases, dye penetrant tests might be requested.

3. INSPECTION AND TESTING

3.1. GENERAL

Quality control shall be carried out in accordance with an Inspection and Test Plan (ITP) agreed between the manufacturer and CERN. CERN (or its representative) reserves the right to be during the different stages of fabrication.

In any case ultrasonic testing, and when requested dye penetrant testing, shall be performed according to a written procedure that shall be submitted to CERN for approval prior to the start of production.

Tech. Spec. N°2000 - Cu-OFe - Sheets 4/6

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3.2. TEST METHOD

Test	Applicable standard	Test unit
Chemical analysis	Using appropriate Standards*	On final product
Hydrogen embrittlement	ASTM B577, Method D (or equivalent)	For each batch and each size within the batch By sampling on the sheets
Structural analysis (structure/inclusions)	Grain size ASTM E112 Inclusions: ASTM F68	For each batch and each size within the batch By sampling on the sheets
Mechanical properties	ISO 6892-1	For each batch and each size within the batch By sampling on the sheets
Electrical properties	Using appropriate Standards*	For each batch and each size within the batch By sampling on the sheets
Ultrasonic testing	Written procedure based on: - EN 10307 for the method - EN 4050-4 for acceptance criteria	For each sheet 100% of the sheet
Dimensions	Using appropriate Standards*	Each sheet

\* The choice of a suitable method is at the discretion of the manufacturer. The manufacturer shall declare the method used if required.

3.3. IDENTIFICATION

Each sheet shall be marked with:

- Cast №
- Manufacturer's name
- Type of material
- Traceability number between delivered lot and inspection documents

The markings shall be shown on one side only every 20 cm. It shall be possible to erase them easily using solvents.

3.4. INSPECTION CERTIFICATE

The certificate shall be based on specific inspection 3.1. according to EN 10204. All the inspection documents shall be drawn up in accordance with the prevailing standards and shall be submitted to CERN for approval prior to delivery.

4. PACKING

The packaging of the sheets shall be strong enough to preserve the surface condition during transport.

Tech. Spec. N°2000 - Cu-OFe - Sheets 6/6

## 2. CERN strategy & suppliers

### Cu OFE

- CERN specs
- Ø1500mm

Firm	Cu OFE	Comments
Schmelzmetall	No offer	No Dimensions
ILF products	No offer	
Goodfellow	No offer	
Prometall	No offer	
SISO	No offer	
Tresoldi metalli	No offer	
Hauselmann	No offer	
Luvata	No offer	max rolling width 1020mm
Aurubis	No offer	max rolling width 1100mm
Metal sheets	No offer	max thickness 3mm
Metelec	No offer	max thickness 3mm
Matthey	No offer	
Wieland	No offer	
Columbia metals	No offer	
Aviva	No offer	(3x) 3060.7x1231.9x4.7mm
Eisenmetall	No offer	1000x2000mm
Ametra metall	No offer	
Amco metall	No offer	
Swissmetal	No offer	

## 2. CERN strategy & suppliers

### Cu OFE

- CERN specs
- Ø1500mm



### Cu OFE Alternatives

- Ø1500 mm

Cu	Cu %	Other elements	Rp0.2	Rm	Elongation min A <sub>50</sub>		cold forming properties
<b>OFE</b>	99.99		220-260	<140	33	40-65	Excellent
<b>OF</b>	99.95	Pb 0.005	220-260	<140	33	40-65	Excellent
<b>HCP</b>	99.95	P(0.002-0.007)Pb0.005	220-260	<140	33	40-65	Excellent
<b>DHP</b>	99.99	P (0.015-0.04)	220-260	<140	33	40-65	/

## 2. CERN strategy & suppliers

### Cu OFE

- CERN specs
- Ø1500mm



### Cu OFE Alternatives

- Ø1500 mm

Firm	Cu OFE	Comments	Alternative
Schmelzmetall	No offer	No Dimensions	No offer
ILF products	No offer		DHP BSEN1652
Goodfellow	No offer		Cu 99,9% CW024 C106H H (DHP)
Prometall	No offer		CW0211A R240 Demi dur
SISO	No offer		Cu DHP demi dur R240
Tresoldi metalli	No offer		No offer
Hauselmann	No offer		Cu DHP R240 Demi dur
Luvata	No offer	max rolling width 1020mm	No offer
Aurubis	No offer	max rolling width 1100mm	No offer
Metal sheets	No offer	max thickness 3mm	No offer
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## 2. CERN strategy & suppliers

### Cu OFE

- CERN specs
- Ø1500mm



### Cu OFE Alternatives

- Ø1500 mm



### Cu OFE

- CERN specs
- Ø1200-1150mm

Firm	Cu OFE	Comments	Alternative
Schmelzmetall	No offer	No Dimensions	No offer
ILF products	No offer		DHP BSEN1652
Goodfellow	No offer		Cu 99,9% CW024 C106H H (DHP)
Prometall	No offer		CW0211A R240 Demi dur
SISO	No offer		Cu DHP demi dur R240
Tresoldi metalli	No offer		No offer
Hauselmann	No offer		Cu DHP R240 Demi dur
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Columbia metals	No offer		No offer
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Eisenmetall	No offer	1000x2000mm	No offer
Ametra metall	No offer		No offer
Amco metall	No offer		No offer
Swissmetal	No offer		No offer
<b>KME</b>	OFFER	<b>6000Kg min</b>	
<b>MKM</b>	OFFER	out of specs. surface	
<b>Bikkar</b>	OFFER	<b>unreacheable firm</b>	
<b>Carl Shreiber</b>	OFFER	<b>closed</b>	

## 2. CERN strategy & suppliers

### Cu OFE

- CERN specs
- Ø1500mm



### Cu OFE Alternatives

- Ø1500 mm



### Cu OFE

- CERN specs
- Ø1200-1150mm

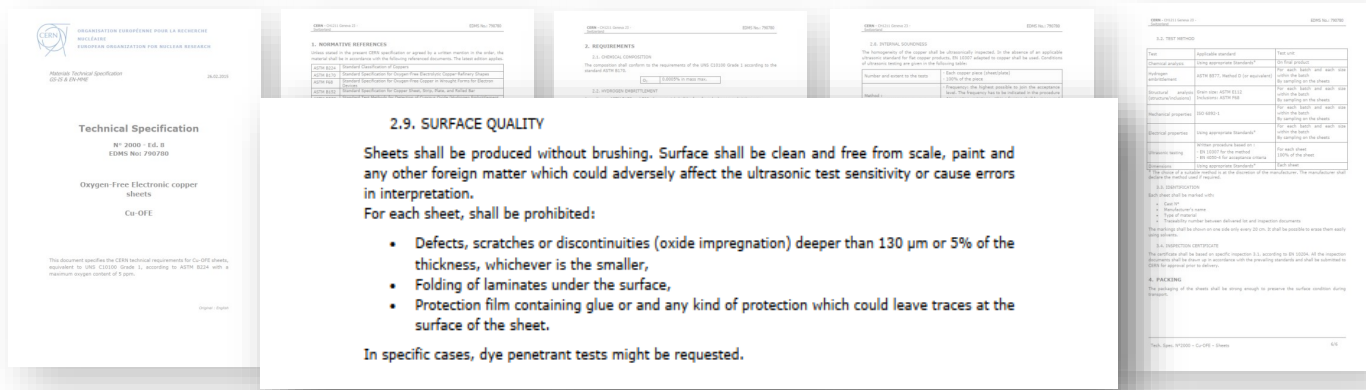


### Cu OFE

- ~~CERN specs~~
- Ø1200-1150mm

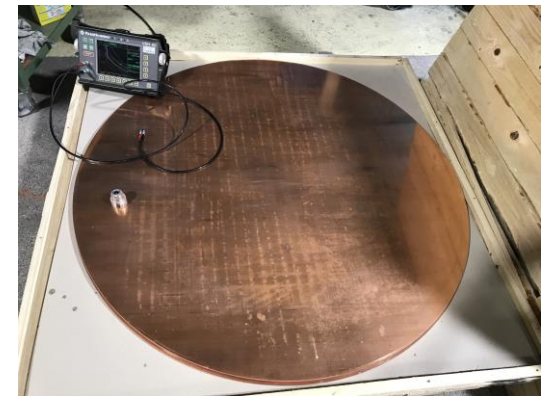
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Ametra metall	No offer		No offer
Amco metall	No offer		No offer
Swissmetal	No offer		No offer
KME	OFFER	6000kg/min	
<b>MKM</b>	<b>OFFER</b>	<b>out of specs. surface</b>	
Bikkar	OFFER	unreachable firm	
Carl Shreiber	OFFER	closed	

# 2. CERN strategy & suppliers



**Before forming**

- ✓ Inspection certificate 3.1, EN 10204
- ✓ Ultrasonic testing
- ✓ No possibility to characterise the material



**After forming**

- ✓ Material characterisation in terms of composition and surface state after Electropolishing



## 2. CERN strategy & suppliers

- **New dimensions → new supplier?**

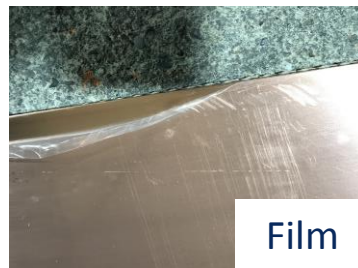
Aurubis: maximum width is 1100 mm and MOQ is 2000 kg.

- **Material preparation procedure at CERN**



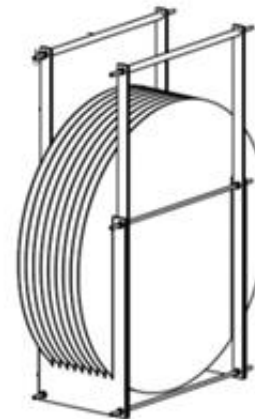
Reception

Material certificate  
3.1 EN 10204



Protection layer  
(Pavatex)  
Between the sheet  
and the equipment

Teflon holder

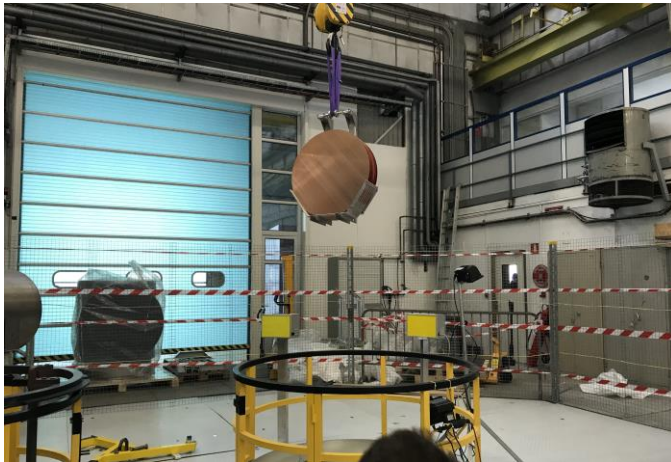


SS holder



## 2. CERN strategy & suppliers

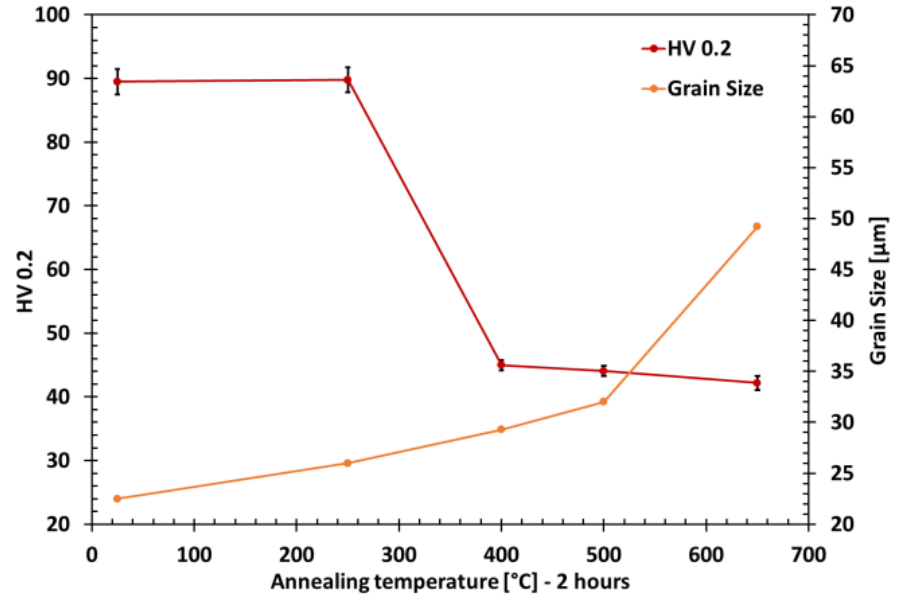
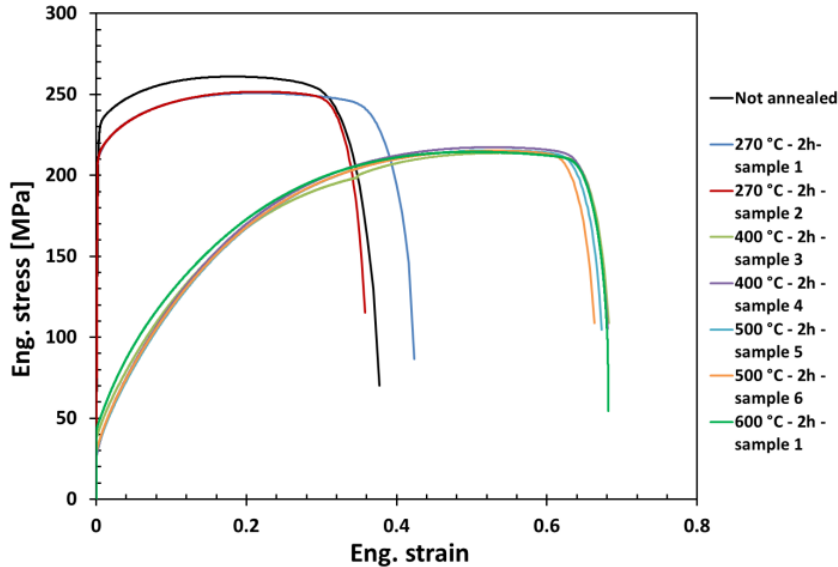
- Up to 20 discs in one cycle
- $\varnothing 940\text{mm}$



# 3. Annealing of Cu OFE in CERN

## Base material OFE Cu th.3mm

E. Cantergiani EDMS 1711461

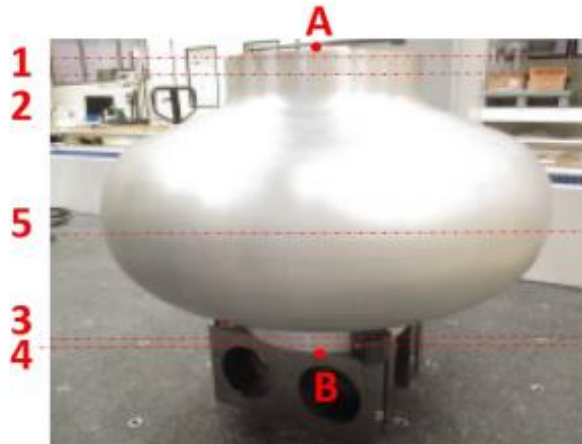


Heat Treatment/sample	Yield stress [MPa]	Ultimate Tensile strength [MPa]	Strain at Fracture	Strain hardening exponent (n)
Not annealed	227	261	0.38	0.078
270 °C - 2h - sample 1	212	251	0.42	0.092
270 °C - 2h - sample 2	213	252	0.36	0.094
400 °C - 2h - sample 3	41	214	0.68	0.516
400 °C - 2h - sample 4	30.7	217	0.68	0.523
500 °C - 2h - sample 5	32	215	0.67	0.52
500 °C - 2h - sample 6	33	215	0.66	0.51
600 °C - 2h	46	215	0.65	0.50

600°C – 2h in vacuum  $10^{-6}$ - $10^{-7}$ mbar

# 4. Control of cavities at CERN

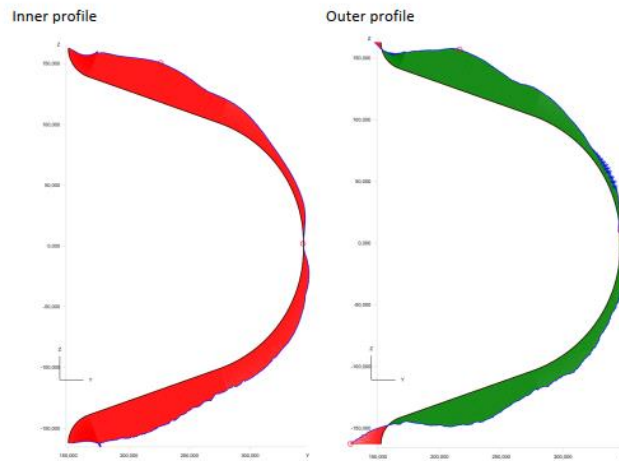
## Metrology



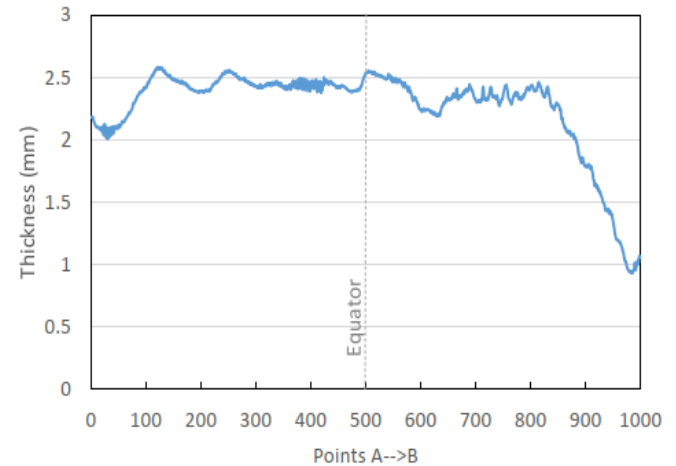
DIAMETER AND CIRCULARITY

Nominal values	'IRIS' [ $\phi 304.6$ ]				'EQUATOR' [ $\phi 692.6$ ]
	1	2	3	4	5
Section	1	2	3	4	5
Diameter	304.663	-	-	-	692.991
Circularity [0.2]	0.556	0.222	1.071	0.397	0.397

SHAPE PROFILE



THICKNESS PROFILE

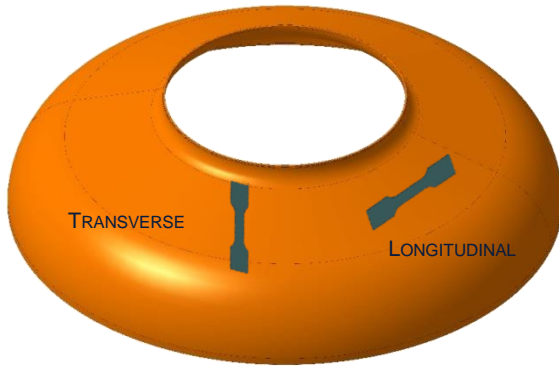




# 4. Control of cavities at CERN

## Half cells characterisation

Mechanical properties



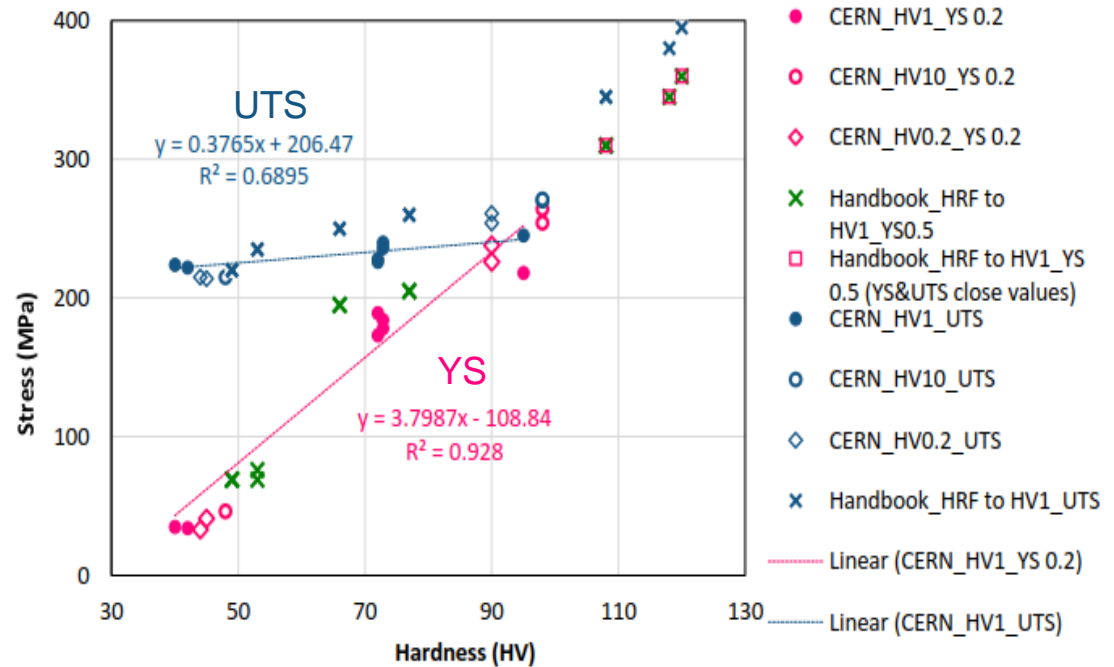
Hardness Profile

Equator



Iris

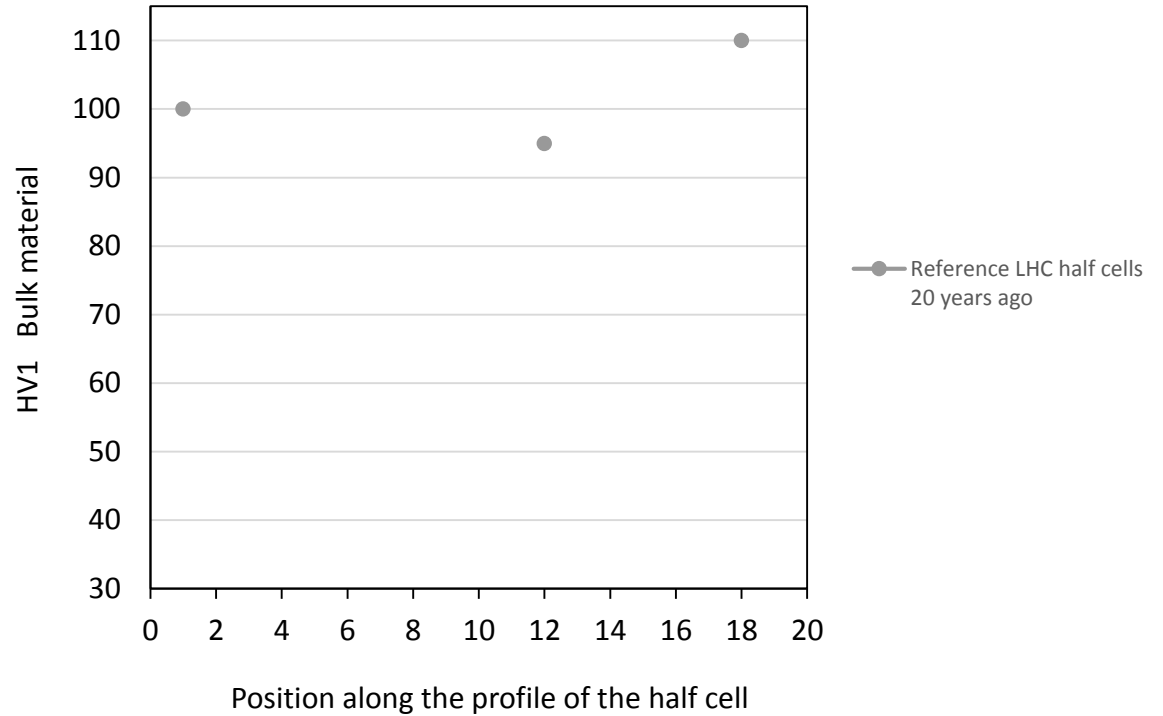
## STRESS AND HARDNESS RELATION



# 5. Manufacturing procedure of half cells

**No annealing**  
*20 years ago*

Hardness Profile



# 5. Manufacturing procedure of half cells

**No annealing**  
*20 years ago*



**Intermediate annealing**  
*Fully annealed iris*

Hardness Profile



↑ %Cold Work  
↓ Recrystallization temperature



# 5. Manufacturing procedure of half cells

## Intermediate annealing during spinning of half-cells

EDMS 1986651 P.Pastuszak

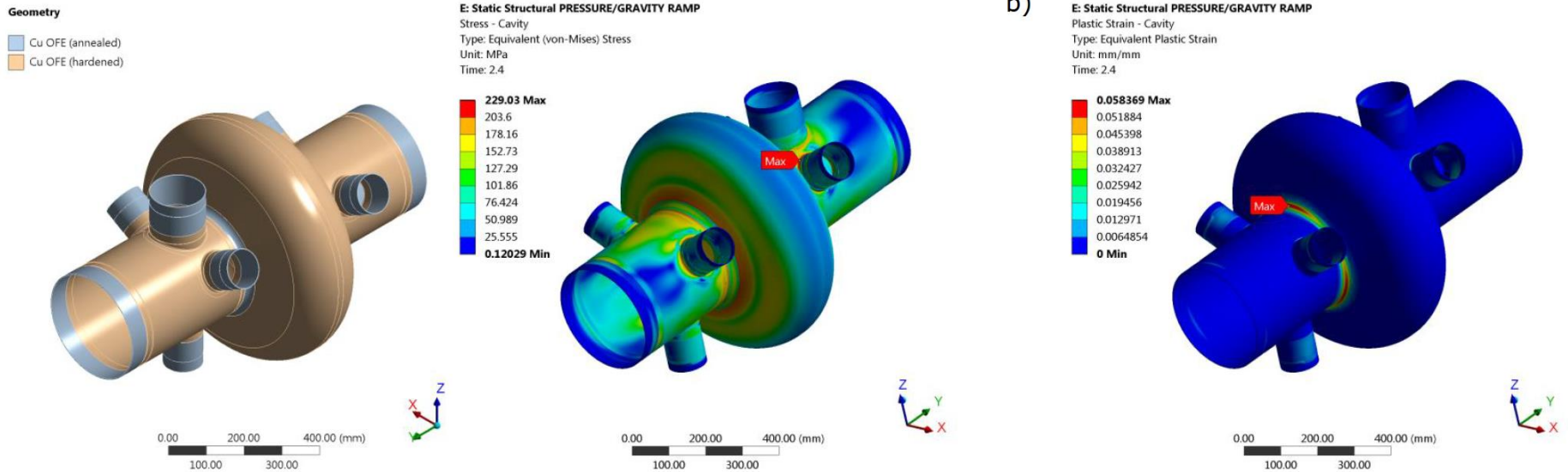


Figure 6: a) Stress distribution and b) plastic strain distribution at 2.4 load multiplier.

*“The cavity succeeds on all criteria established in this report (Global failure 1, Local failure, Non-linear buckling), which are in accordance with ASME code. The cavity is judged safe by authors and suitable for use in the LHC RF cryomodule.”*



# 5. Manufacturing procedure of half cells

**No annealing**  
*20 years ago*



**Intermediate annealing**  
*Fully annealed iris*

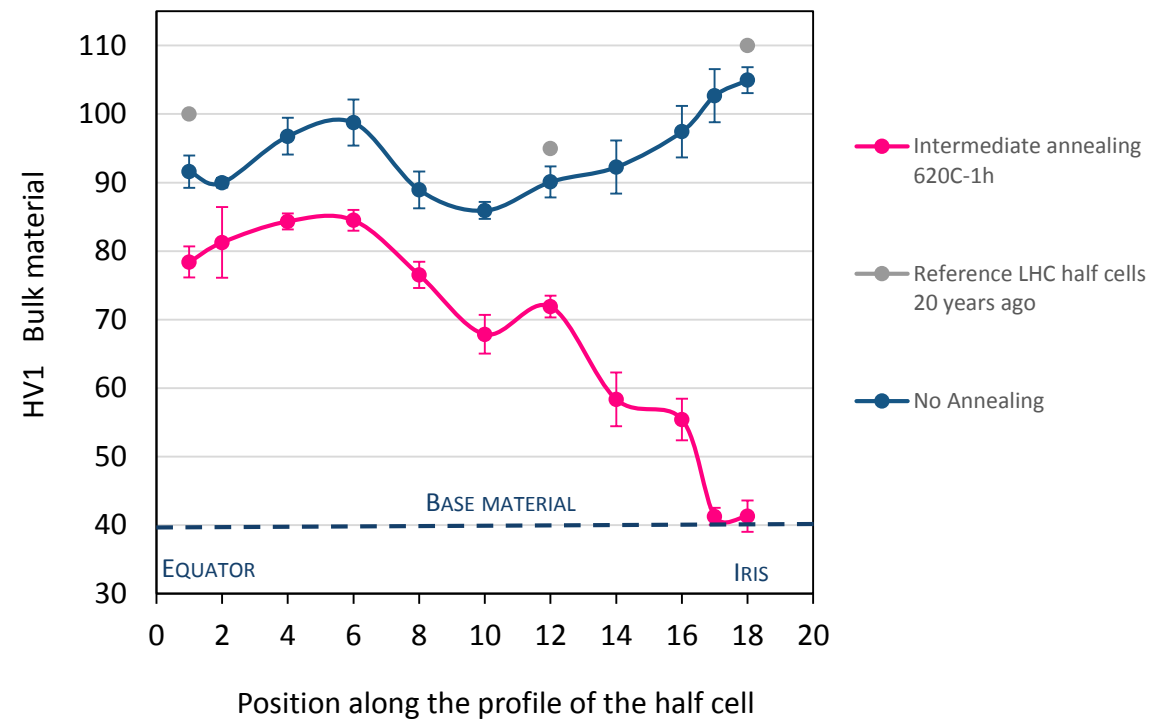


**Influence of annealing temperature**

Hardness Profile



↑ %Cold Work  
↓ Recrystallization temperature



# 5. Manufacturing procedure of half cells

**No annealing**  
*20 years ago*



**Intermediate annealing**  
*Fully annealed iris*



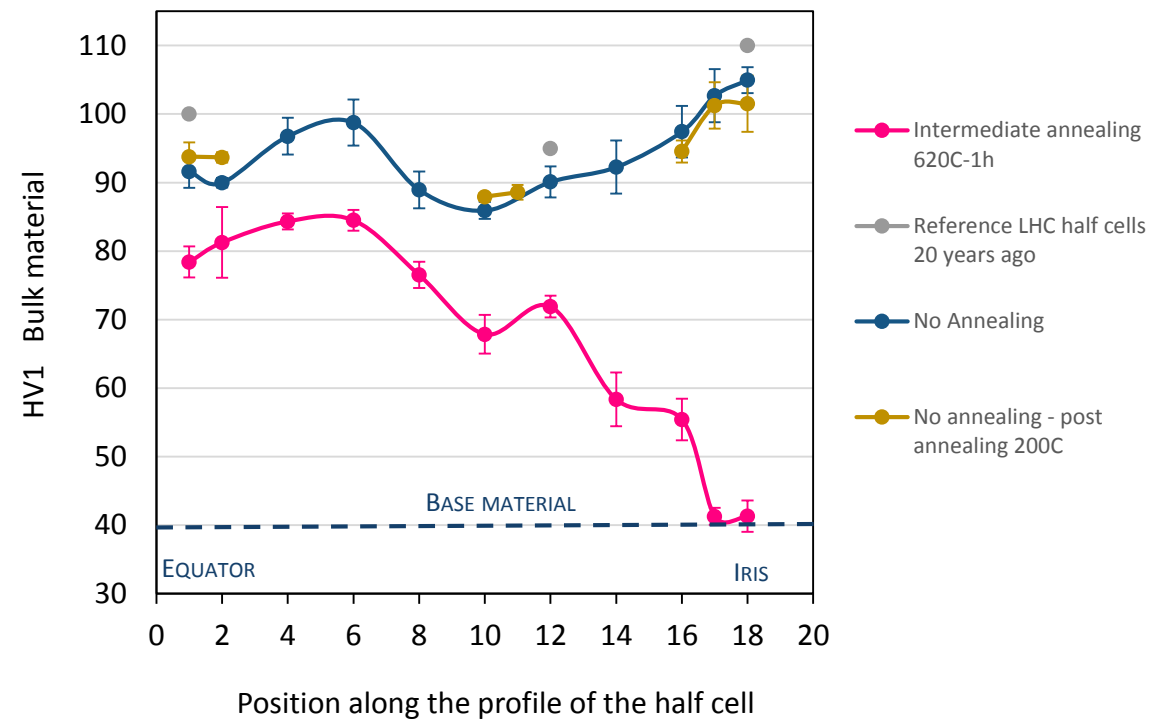
**Influence of annealing temperature**

200°C

Hardness Profile



↑ %Cold Work  
↓ Recrystallization temperature



# 5. Manufacturing procedure of half cells

**No annealing**  
*20 years ago*



**Intermediate annealing**  
*Fully annealed iris*



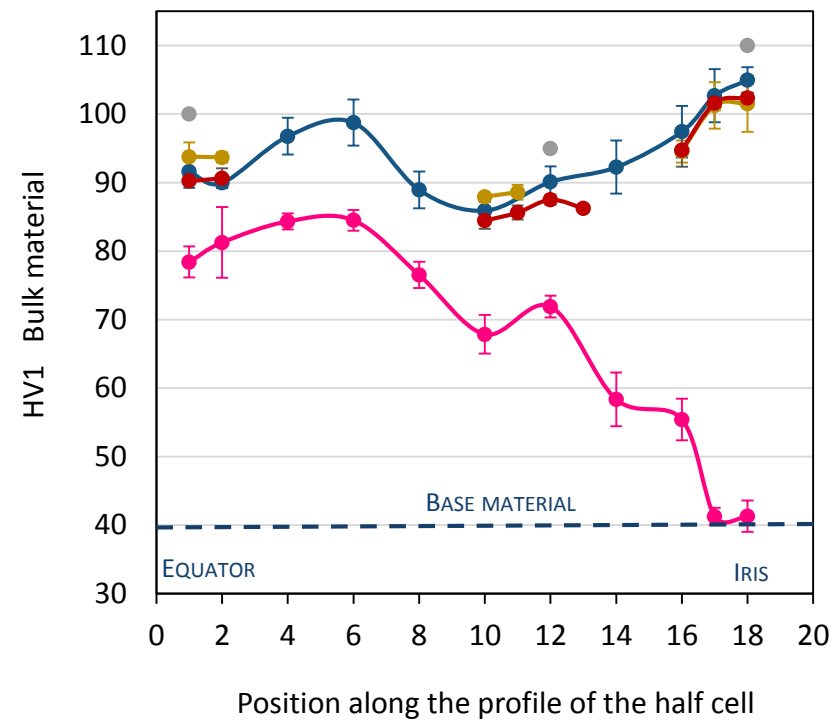
**Influence of annealing temperature**

200°C 250°C

Hardness Profile



↑ %Cold Work  
↓ Recrystallization temperature



# 5. Manufacturing procedure of half cells

**No annealing**  
*20 years ago*



**Intermediate annealing**  
*Fully annealed iris*



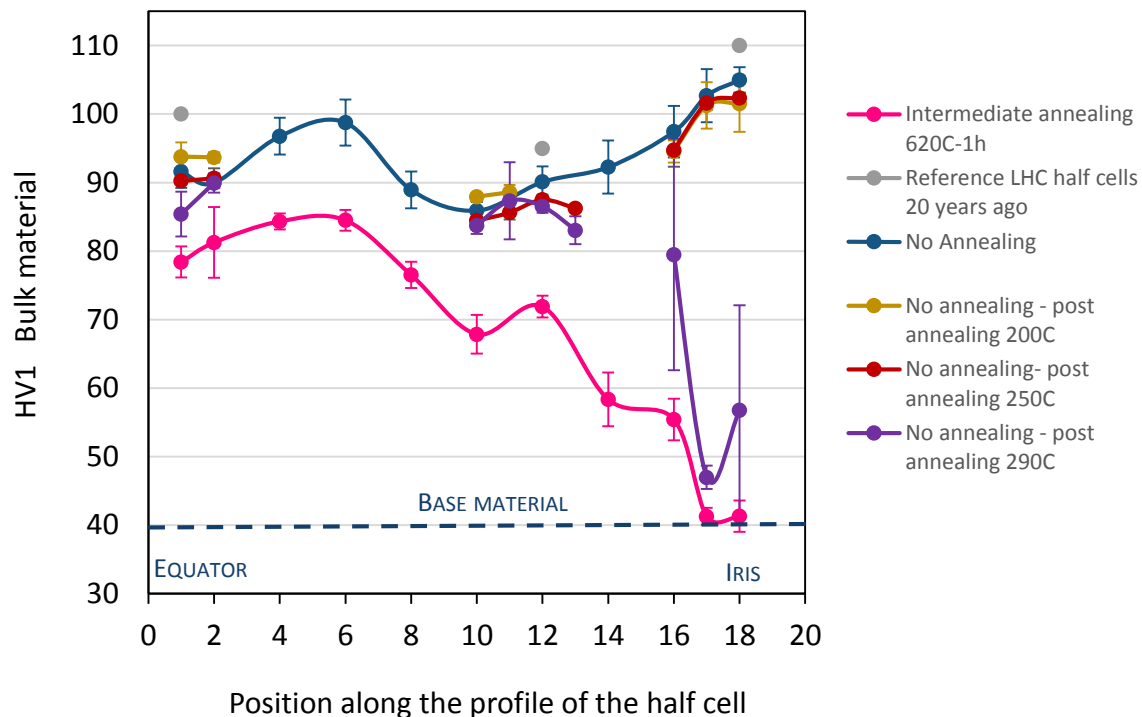
**Influence of annealing temperature**

200°C 250°C 290°C

Hardness Profile



↑ %Cold Work  
↓ Recrystallization temperature



# 5. Manufacturing procedure of half cells

**No annealing**  
*20 years ago*



**Intermediate annealing**  
*Fully annealed iris*



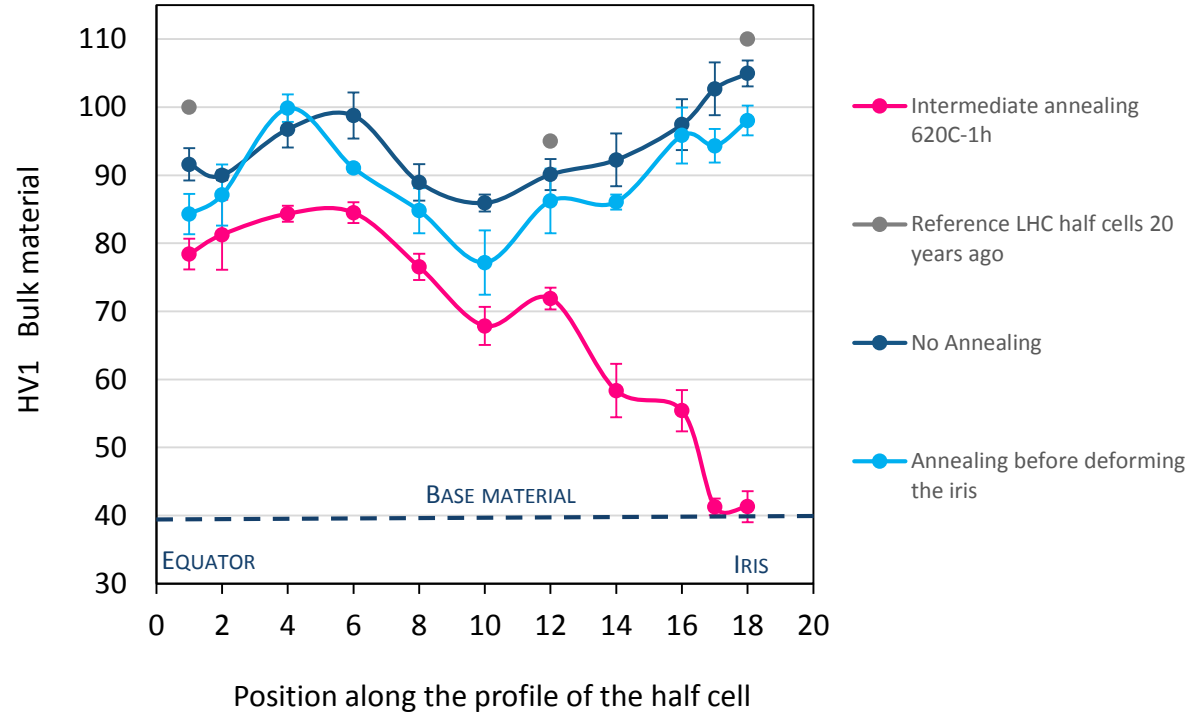
**Influence of annealing temperature**

200°C 250°C 290°C



**New forming procedure**

Hardness Profile



## 6. Final remarks

### To take into account...

- **New suppliers/new dimensions**

In order to fulfill the technical specifications of CERN

- **Final required mechanical properties**

In case of intermediate annealing during forming is needed



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