Manufacturing of vacuum components

By Mike Olsson, Big Science Sweden

Materials in UHV

ESS approved UHV Materials list:

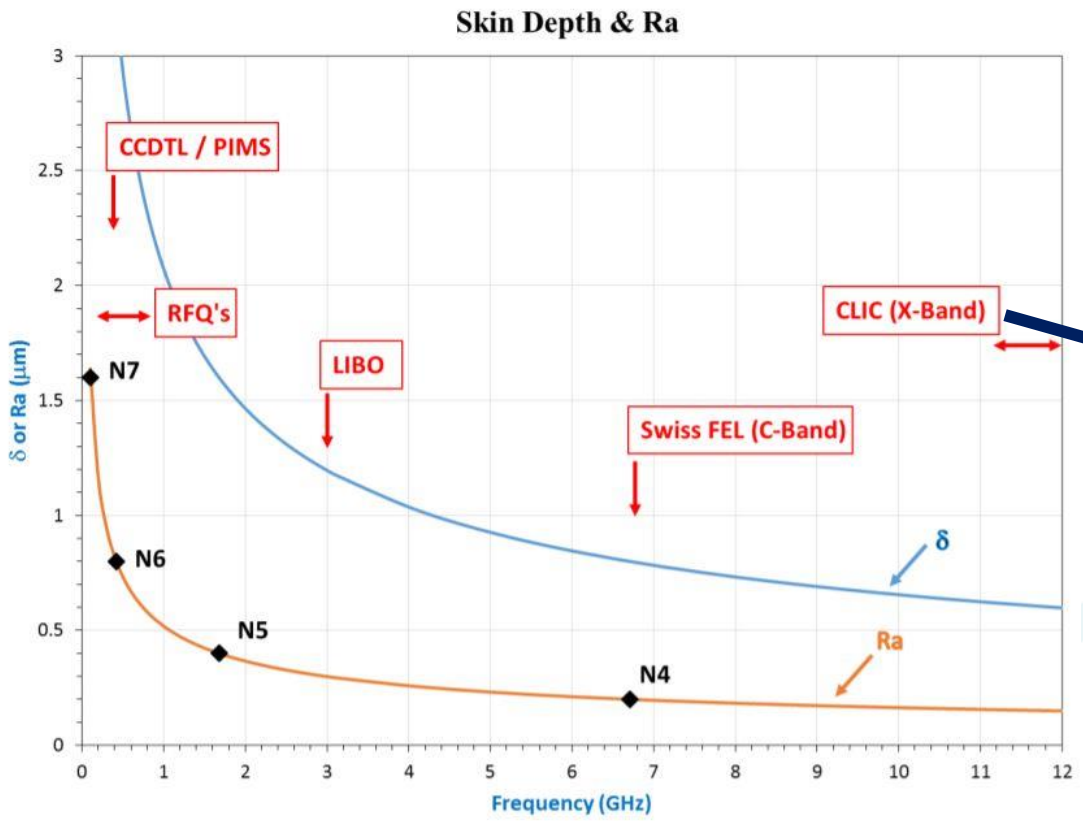
- Stainless Steel ASTM type 304 & 316 series or ISO equivalent
- Copper OFHC (phosphorous de-oxidized grade shall not be used)
- Aluminium and its alloys. Do not use cast components.
- Gold
- Silver
- Titanium
- Molybdenum
- Platinum
- Beryllium Copper
- Ceramic (as Al2O3) >90%
- Machinable glass (Macor)

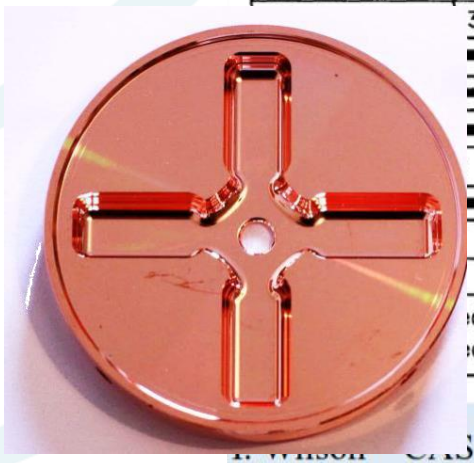
Materials in UHV

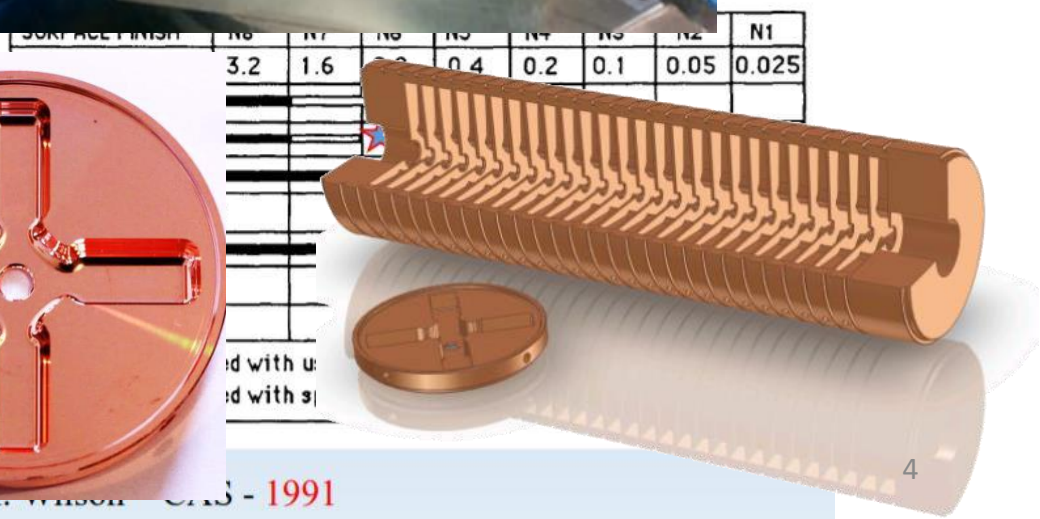
Prohibited Materials List:

- Brass
- All Plastics
- ASTM type 303, free cutting stainless steel
- All Glues
- Soft Solder
- Standard Hard Solder
- Electrical Solder
- Greases
- Silicon or sulphur based machining lubricants when machining any components (only water-soluble machining lubricants are permitted)
- GE Varnish
- Anodized surfaces or any mechanically polished components
- Any material containing: Zinc, Cadmium, Phosphorus, Sodium, Selenium,
- Potassium or Magnesium

Surface roughness Ra







Credit: S. Atieh, CERN

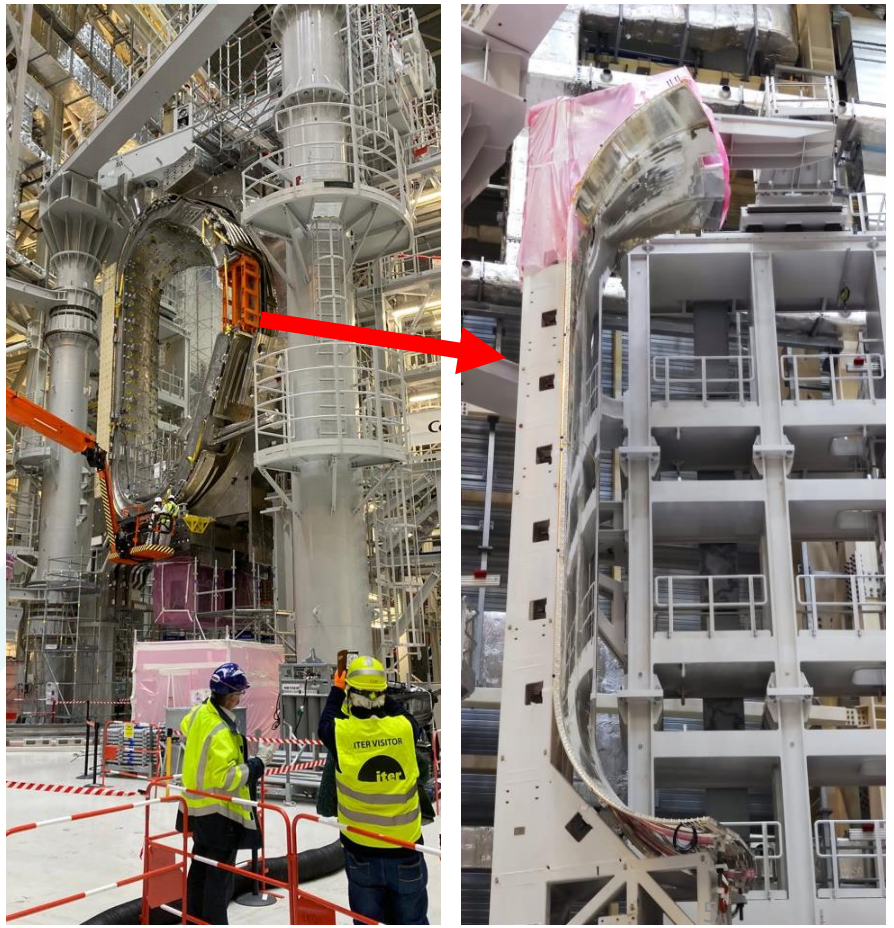
Surface roughness according to ISO 4287:2000 (ITER)

Credit: ITER Vacuum Handbook

Classification	Maximum average Surface Roughness Ra (µm)	Measurement Technique
VQC 1	6.3	Electric stylus
VQC 2	12.5†	Electric stylus
VQC 3	12.5	Electric stylus
VQC 4	12.5	Electric stylus
† Where to satisfy this surface roughness requirement additional machining would be required a rougher surface is accepted provided the surface is easily cleanable and can be shown not to catch fibres when wiped with a lint free cloth.		

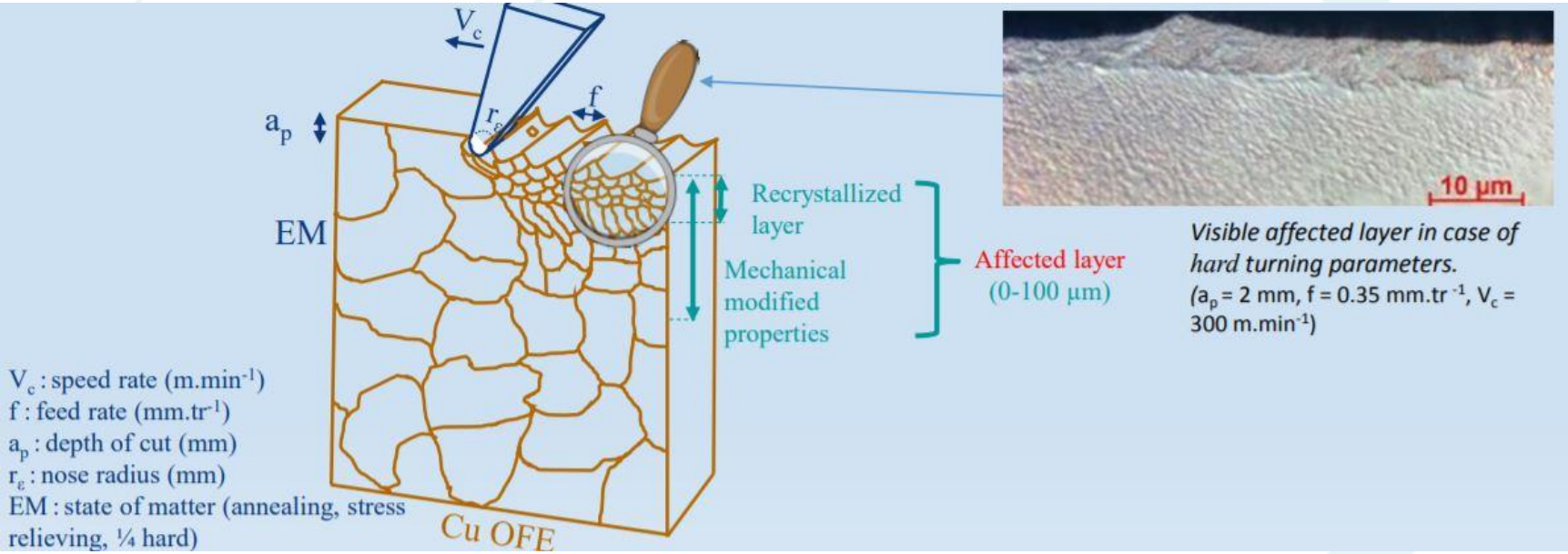
Table 8-1 - Maximum permissible average surface roughness for metals

ESS Ra 0.8 µm up to 3.2 µm



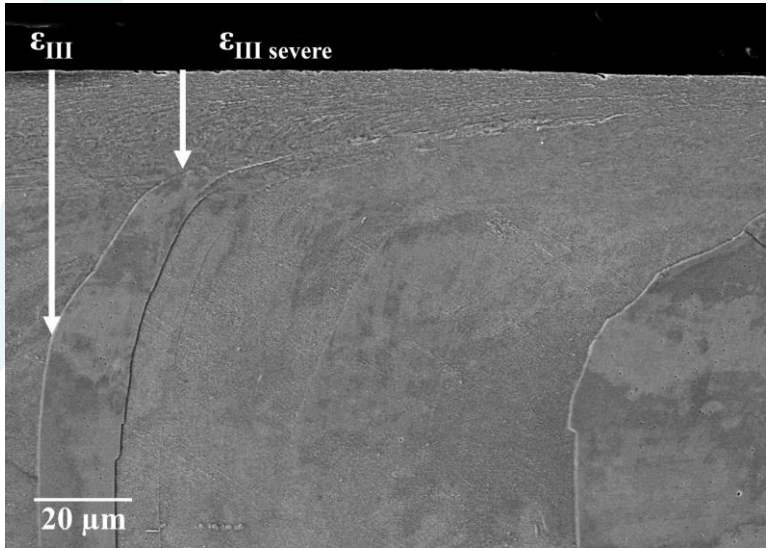
Credit: Marcelo Juni Ferrira

Sub-surface deformations



Credit: S. Atieh, CERN

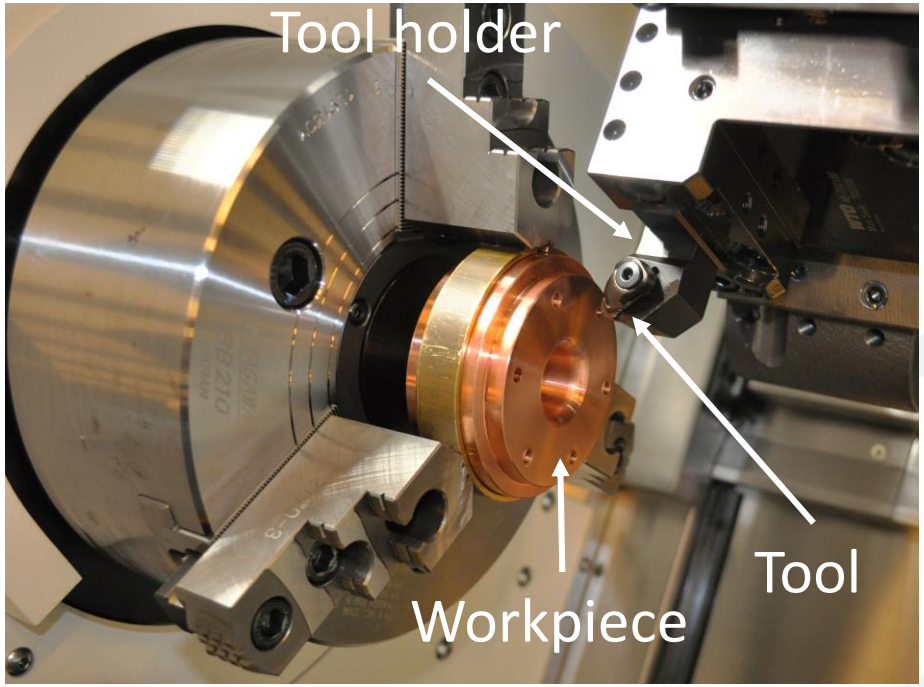
Sub-surface deformation in machined copper



Credit: M. Olsson

Metal cutting and cutting fluids

- Water soluble, non-halogenated and phosphorus and sulphur free
- If possible, finishing by dry-machining or using ethanol as cutting fluid.



Manufacturing – Avoided or less appropriate techniques

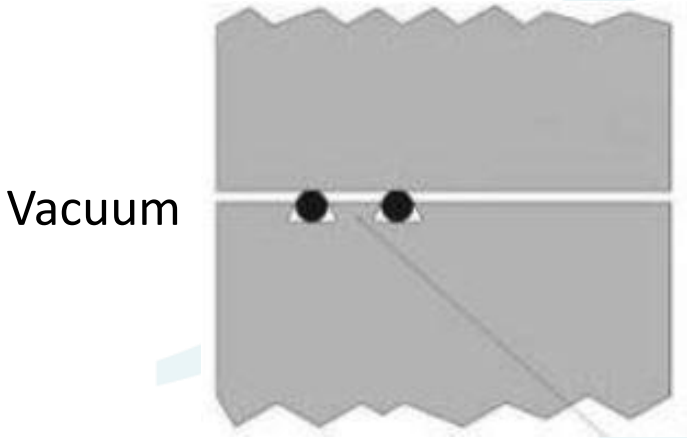
- Polishing – Or with appropriate material (SiC*, Alumina*, Diamond) , Chemical polishing * Caution in case of RF field
- Water, Laser, Plasma cutting – Only for rough machining
- Grinding (abrasive) cutting, honing machining
- Electrical Discharge Machining - Mainly with wire, and if the wire contains Zn (Brass)!
- Surface abrasive techniques to improve the appearance of the surface should be avoided or kept to a minimum.
- Use of files, harsh abrasives, sand, shot or dry bead blasing, polishing pastes is prohibited under normal circumstances.
  - Shot and dry bead blasting can be permitted in some cases.

Credit: S. Atieh, CERN

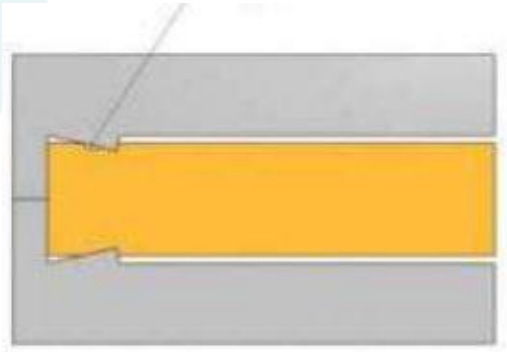
Virtual leaks and tapped holes

- Avoid blind tapped holes due to risk of virtual leaks and trap of contaminations.
  - If unavoidable, use vented screws with flat bottom.

Trapped volume
tortorous leak
path trough threads



Trapped volume
no vent at o-ring seal



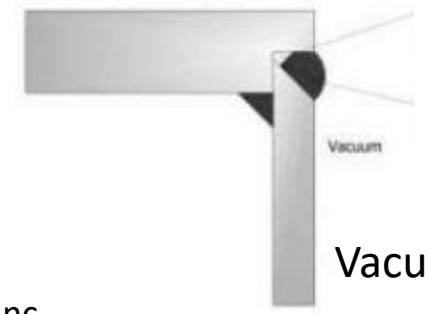
Trapped volumes caused
by uneven torquing of
conflat flanges

Credit: Meyer Tool and MFG Inc.

Welding

- Cleaning Prior to Joining To minimise the risk of trapped contamination
  - Parts and sub-components shall be degreased using solvents or alkaline detergents, rinsed with demineralised water, and dried prior to joining
- Full penetration welds should be utilized wherever possible to avoid pockets where volumes of gas or contaminants can be trapped

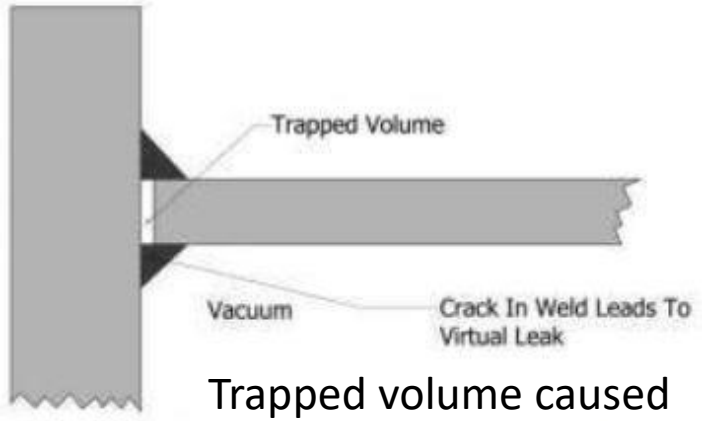
Trapped volumes caused by poor fit up of full penetration welds and lack of penetration



Trapped volume behind Poorly executed full penetration weld

Crack in weld leads to virtual leaks

Vacuum



Trapped volume caused by incorrect weld design

Credit: Meyer Tool and MFG Inc.

Welding

- Welds should be internal (facing the vacuum) if possible
- If for structural reasons double welds are required, allow for an easy path to flow gas from the joint. This could be in the form of a machined hole between the two welds, or a discontinuous weld on the non-vacuum side
- Utilize single pass welds if possible to avoid trapped volumes that could be generated with multi-pass welds

Different types of welds

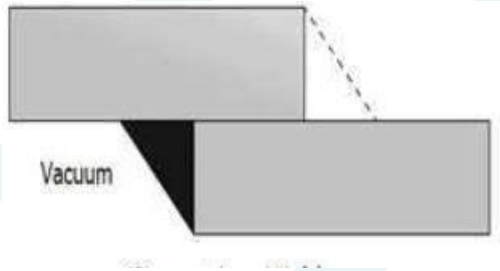
- The use of welds from both sides makes leak testing difficult
  - Risk of trapped volumes forming virtual leaks

Correct butt weld

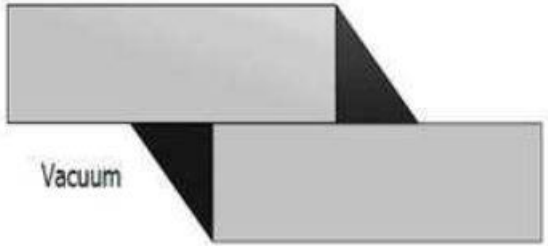
Incorrect butt welds

Lap weld

Correct



Incorrect

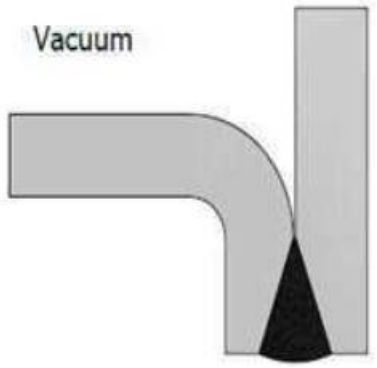


Credit: Meyer Tool and MFG Inc.

Different types of welds

Edge weld

Correct



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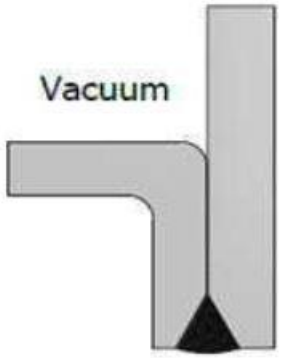
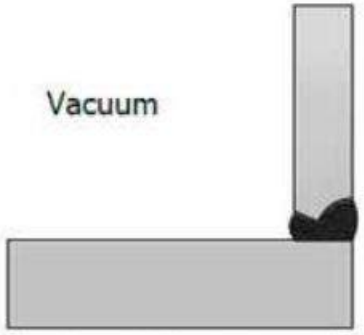


Corner weld

Correct



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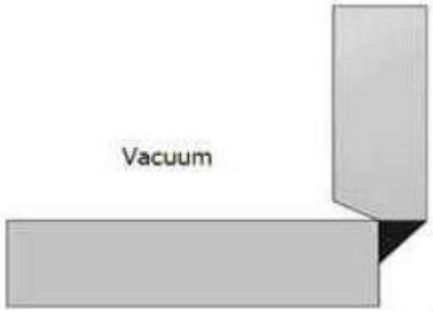
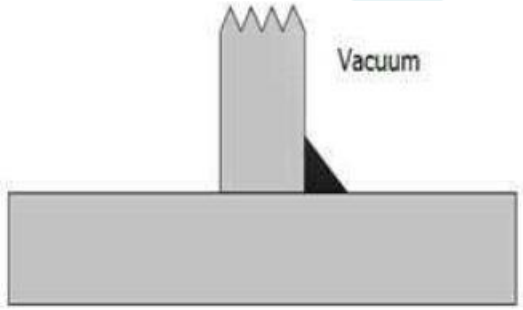


Tee weld

Correct



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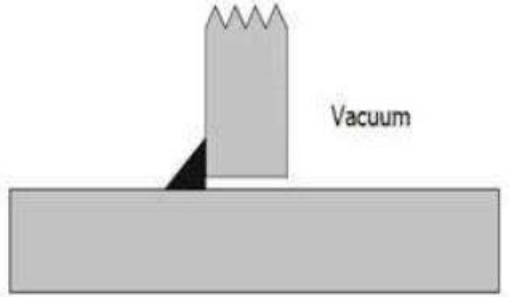
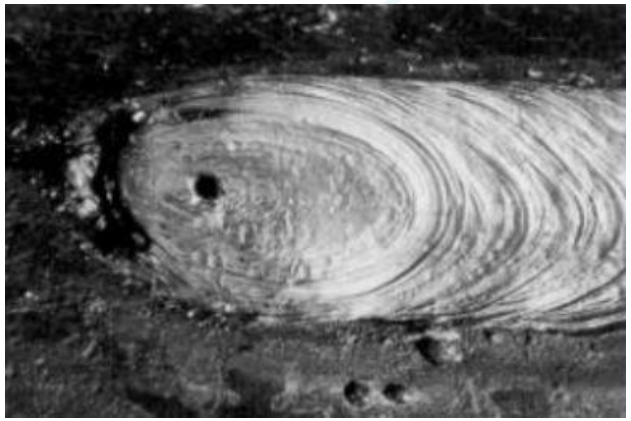


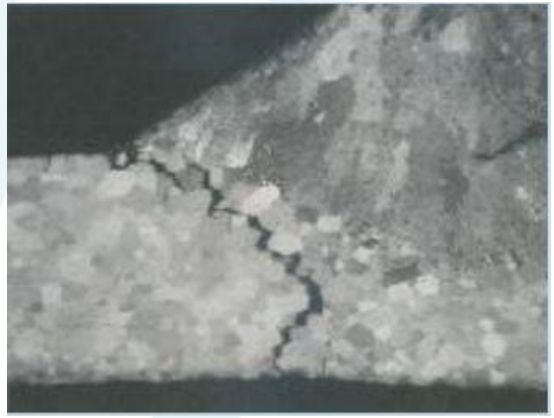
Credit: Meyer Tool and MFG Inc.

Welding defects

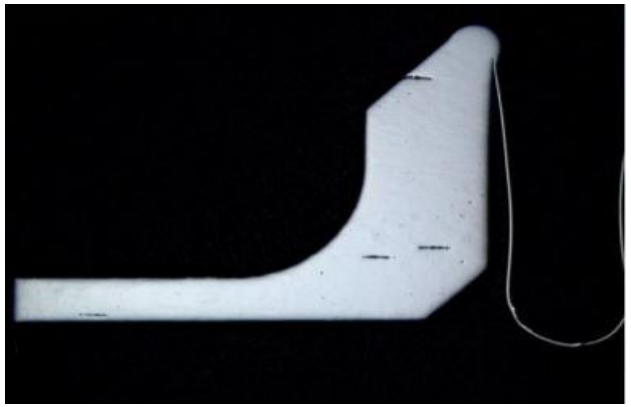
- All weld regions shall be free from scale, voids, blowholes, etc., and there shall be no visible evidence of inclusions.



Shrinkage holes/voids



Hot cracking

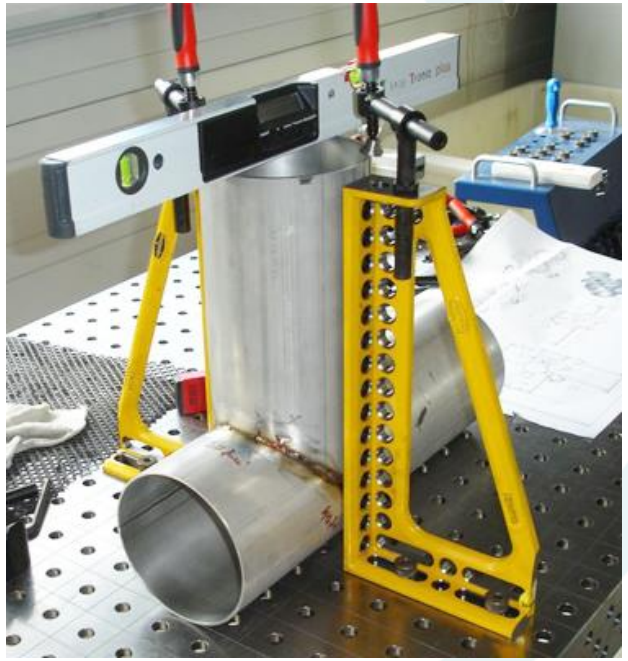


Non metallic inclusions
(Base material defects)

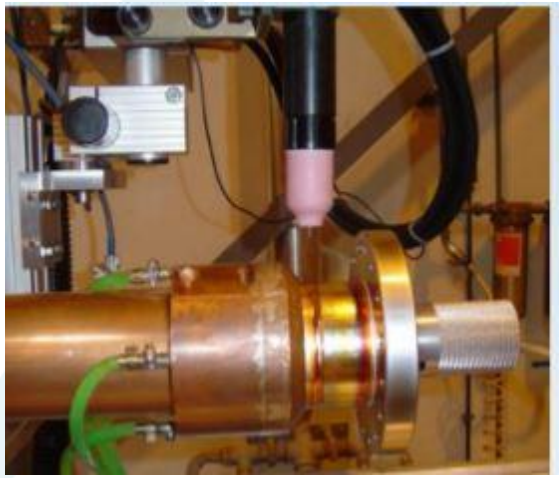
Lack of fusion

Credit: S. Atieh, CERN

TIG welding

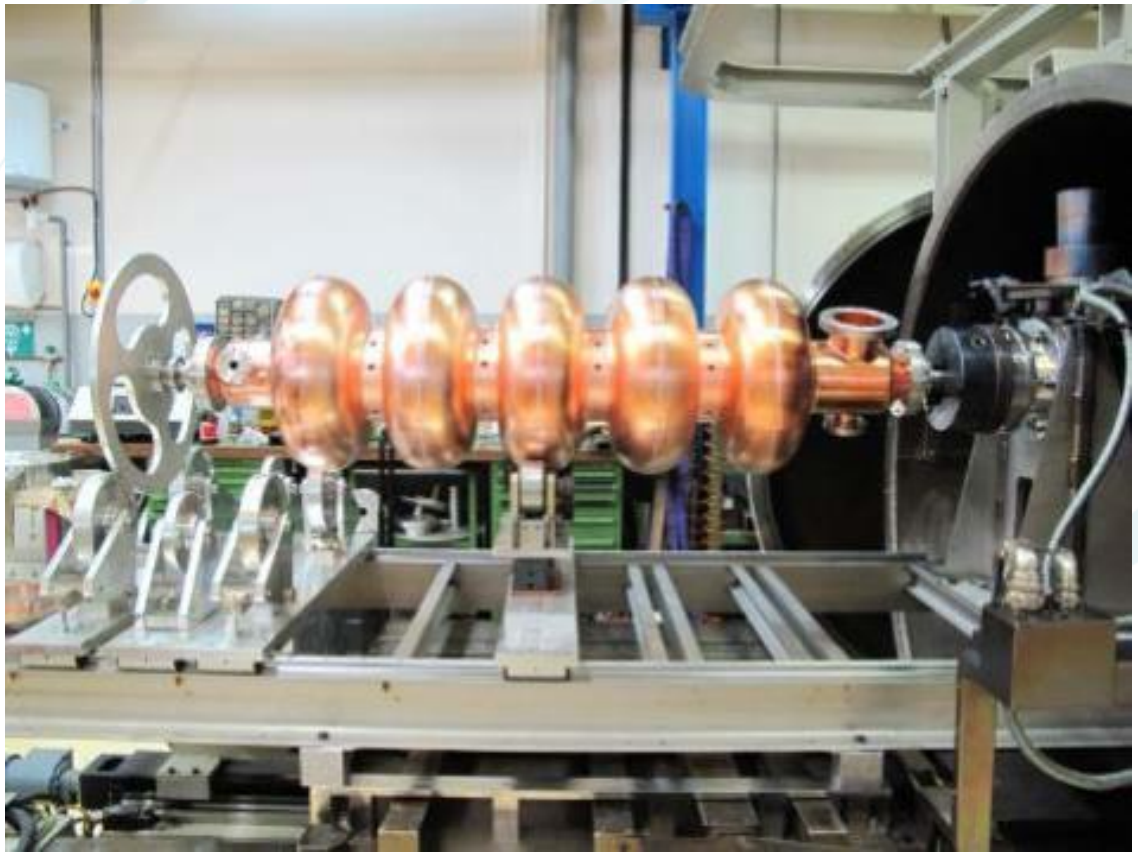


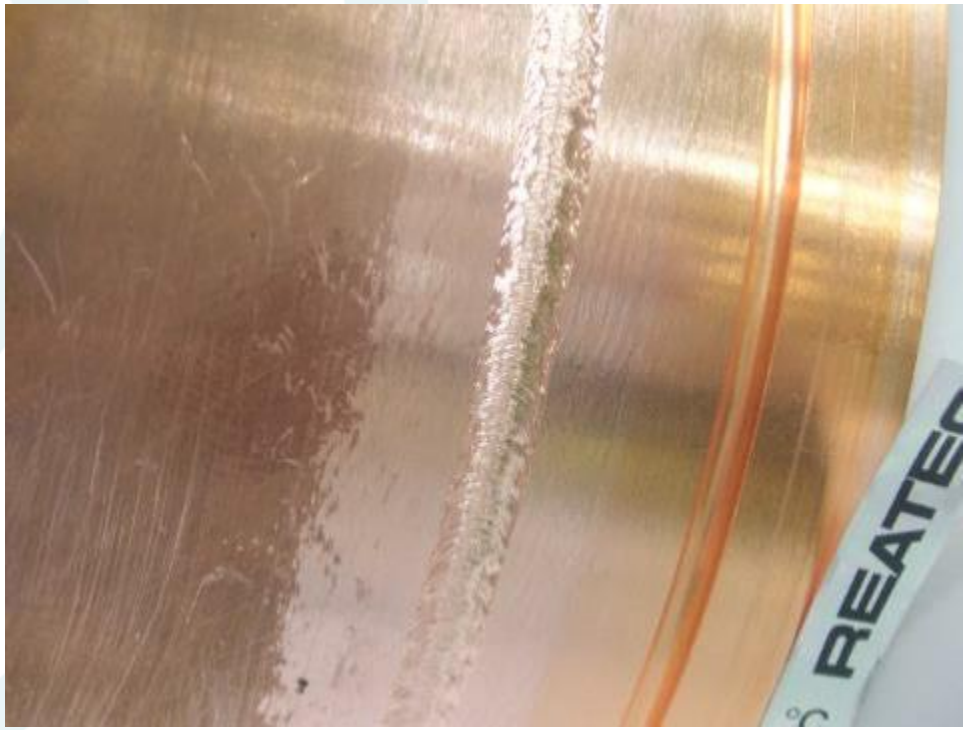
Credit: Vacom



Credit: S. Atieh, CERN

Electron Beam Welding EBW





Credit: S. Atieh, CERN

Inspection and Testing of Production Welded Joints (ITER)

Wall Thickness (wt) (mm)	Preferred Volumetric Examination Method
wt < 8	Radiography
8 < wt < 19	Radiography & Ultrasonic
wt > 19	Ultrasonic or radiography
Note: For wt > 19 mm ultrasonic examination of welds is preferred only in cases where radiographic examination would require excessive exposure times.	

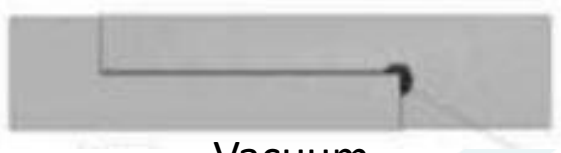
Table 7-2 Range of wall thickness and preferred volumetric examination method to be applied

- Liquid penetrant testing (LPT) or magnetic particle techniques shall not in general be permitted
  - Block leaks temporarily and can be difficult to remove satisfactorily.

Credit: ITER Vacuum Handbook

Brazing

- Brazing shall be carried out in a vacuum, hydrogen or inert gas atmosphere.
- Where the use of brazing flux is unavoidable a cleaning procedure shall be qualified
- All brazed joints shall be inspected visually to ensure that the vacuum exposed braze regions are clean, flush and free from voids, blowholes, etc.



Vacuum

Trapped volumes caused by cracks in interior welds or braze joints

Trapped volume due to poor braze workmanship crack in braze leads to virtual leak

Credit: Meyer Tools MFG Inc.

Brazing

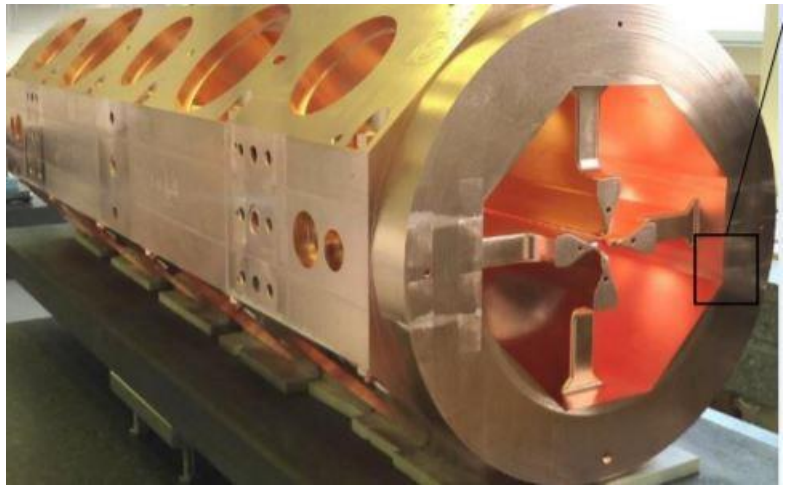
- Allow very good thermal and electrical contacts.
- Assembly clean and UHV compatible.

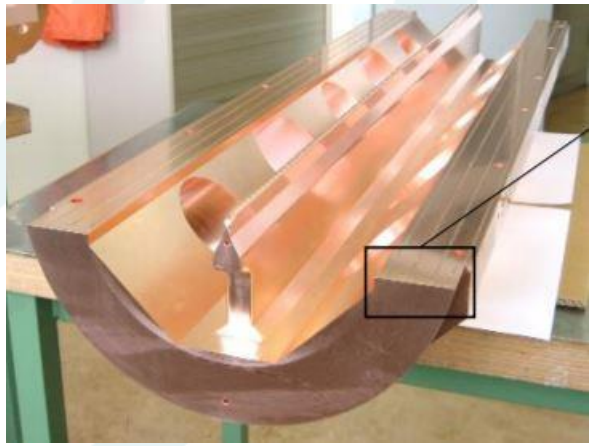
But:

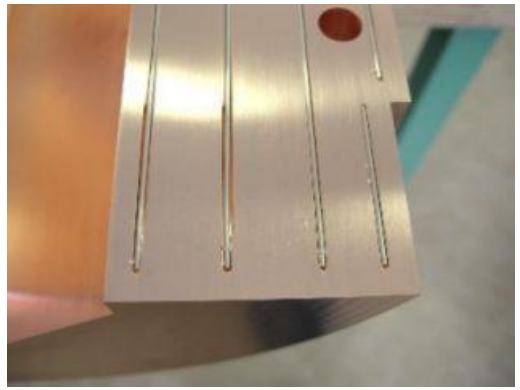
- Heat treatment can affect the properties of the base materials.
- Mechanical tolerances are tight.

Brazing

- Brazing on large surfaces possible.
- Allow high precision assembly with little or no distortion of the components.





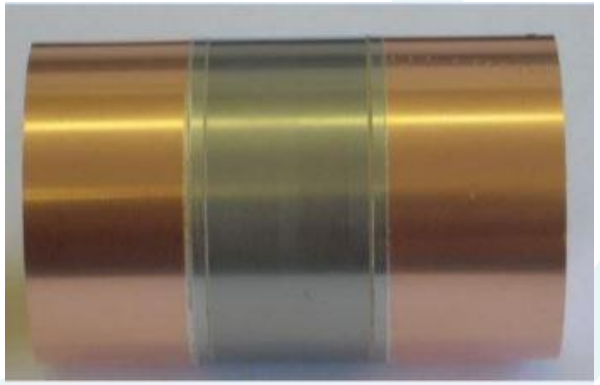


Credit: S. Atieh, CERN

Brazing

- Dissimilar materials can be join.

Nb – Stainless steel



Cu – Stainless steel - Ti

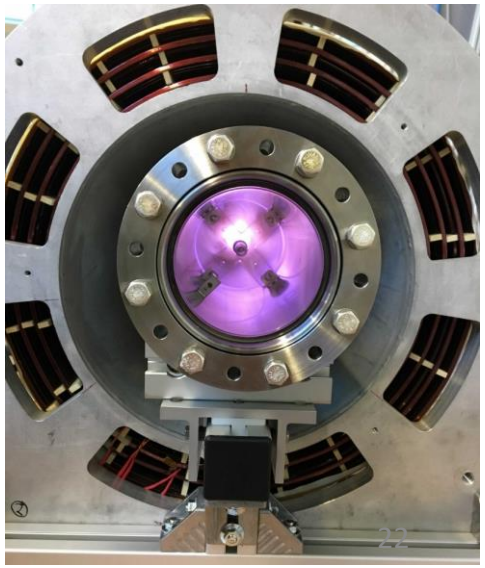
Cu – W

Credit: S. Atieh, CERN

Coatings

Assessment of the coating shall include consideration of:

- The risk of the coating producing trapped volumes and temporary leak blocking.
- The method of applying the surface coating (e.g. painting, chemical, plasma spray, etc.).
- The chemical composition, cleaning and outgassing of the surface coating.
- Test method for adhesion of the surface coating to the substrate.



Magnet sputtering
Credit: Marcelo Juni Ferrira

Summary

- Welding process and welders must be qualified.
- Braze and solder alloys must be of high purity.
- The welding design must avoid virtual leak (trapped volume).
- Quality inspection of the welded/brazed joints is important.
- Cutting fluid must be tested and approved.
- Some techniques must be avoided / tested (air brazing/soldering, EDM, grinding, additive manufacturing,….).
- Welding = distortion = geometrical consideration. Minimum of welds!
- Brazing involves a heat treatment of the complete assembly!
  - The mechanical properties are modified.
  - The grain size can increase (Copper with thin thickness!)
  - Avoid brazing after (electron beam) welding.

Credit: S. Atieh, CERN