



**High  
Luminosity  
LHC**

# **Welding requirements and other issues**

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on behalf of the CRAB Cavity Collaboration**

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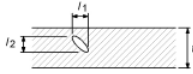
- Summary Quality Welding Requirements
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## □ Summary quality welding requirements:

- According to the EN13445 and due to the lack of any specific standard for niobium welds, the following standard has been used to assess the quality level of imperfections:
  - **EN ISO 13919-2:** Electron and laser beam welded joints. Guidance for quality levels for imperfections-Aluminium and its weldable alloys.
- The table 7 was issued in order to comply with other requirements not covered by this standard (Cryogenic and RF), based on our experience until 3mm of thickness, with this exotic material, nor steel or aluminium, and with the main purpose of avoiding the repairs of these welds:
  - **TABLE 7 from E.S with additional restrictions**

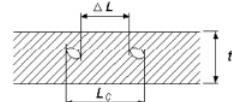
# ➤ Table from the standard ISO 13919-2 level B:

Table 2 — Imperfections

No	Imperfection, designation	EN ISO 6520-1 reference	Remarks	Limits for imperfections for quality levels:		
				moderate D	intermediate C	stringent B
1	Cracks	100	All types of cracks except micro cracks (less than 1 mm <sup>2</sup> crack area). For crater cracks see No 2.	Not permitted	Not permitted	Not permitted
2	Crater cracks	104		Local crater cracks permitted	Local crater cracks Permitted	Not permitted
3	Porosity and gas pores	200	<p>The following conditions and limits for imperfections shall be fulfilled:</p> <p>a) Maximum dimension <math>l</math> (<math>l_1</math>, <math>l_2</math> or <math>h</math>) for a single pore;</p> <p>b) Maximum dimension of the summation of the projected area of the imperfections.</p> <p>Projection is in a direction parallel to the surface and perpendicular to the weld axis. It relates to an area <math>t</math> multiplied by the actual length of the weld or 100 mm, whichever is the smaller.</p> 	<p><math>l</math> or <math>h \leq 0,5 t</math> max. 6 mm</p> <p>Electron beam welding: <math>f \leq 6 \%</math> Laser beam welding: <math>f \leq 10 \%</math></p>	<p><math>l</math> or <math>h \leq 0,4 t</math> max. 5 mm</p> <p>Electron beam welding: <math>f \leq 3 \%</math> Laser beam welding: <math>f \leq 6 \%</math></p>	<p><math>l</math> or <math>h \leq 0,3 t</math> max. 4 mm</p> <p>Electron beam welding: <math>f \leq 1,5 \%</math> Laser beam welding: <math>f \leq 3 \%</math></p>

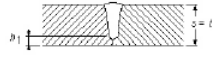
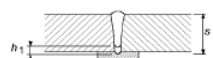
(continued)

Table 2 (continued)

No	Imperfection, designation	EN ISO 6520-1 reference	Remarks	Limits for imperfections for quality levels:		
				moderate D	intermediate C	stringent B
4	Localised (clustered) and linear porosity	2013 2014	<p>The following conditions and limits for imperfections shall be fulfilled:</p> <p>a) Maximum dimension <math>l</math> (<math>l_1</math>, <math>l_2</math> or <math>h</math>) for a single pore;</p> <p>b) Maximum dimension of the summation of the projected area of the imperfections. Projection is in a direction parallel to the surface and perpendicular to the weld axis. It relates to an area <math>t</math> multiplied by weld length, where weld length is the actual length of the weld or 100 mm, whichever is the smaller.</p> <p>In addition:</p> <p>c) The distances <math>\Delta L</math> between the individual pores in clustered or linear porosity shall be assessed. Any two pores closer than:</p> <p>shall be considered a combined porosity.</p> <p>d) Combined porosity is permitted, provided the affected weld length <math>L_c</math> is less than:</p>  <p>Affected weld length <math>L_c</math> for combined porosity. Use d) acceptance limit.</p>	<p><math>l</math> or <math>h \leq 0,5 t</math> max. 6 mm</p> <p><math>f \leq 15 \%</math></p> <p>0,25 <math>t</math> max. 5 mm</p> <p><math>L_c \leq 2 t</math></p>	<p><math>l</math> or <math>h \leq 0,4 t</math> max. 5 mm</p> <p><math>f \leq 5 \%</math></p> <p>0,5 <math>t</math> max. 10 mm</p> <p><math>L_c \leq t</math></p>	<p><math>l</math> or <math>h \leq 0,3 t</math> max. 4 mm</p> <p><math>f \leq 2 \%</math></p> <p>0,5 <math>t</math> max. 15 mm</p> <p><math>L_c \leq t</math></p>

(continued)

Table 2 (continued)

No	Imperfection, designation	EN ISO 6520-1 reference	Remarks	Limits for imperfections for quality levels:		
				moderate D	intermediate C	stringent B
5	Shrinkage cavity	202		Use limits for porosity		
6	Crater pipe	2024		$h \leq 0,15 t$ max. 2 mm	$h \leq 0,1 t$ max. 1,5 mm	$h \leq 0,05 t$ max. 1 mm
7	Solid inclusions	300	Only oxide inclusions permitted	Use limits for porosity		
8	Lack of fusion	401		$h \leq 0,25 s$ max. 1 mm	Not permitted	Not permitted
9	Incomplete penetration	402	<p>Lack of penetration <math>h_1</math> for full penetration welds shall be less than:</p>  <p>Welding into backing:</p>  <p>Partial penetration may be specified for certain applications. Figures below show examples. The limits relate to deviations <math>h_1</math>, resulting in penetrations less than specified. Max. deviation <math>h_1</math>.</p>	$h_1 \leq 0,25 s$ max. 1 mm	Not permitted	Not permitted

$h_1 \leq 0,25 s$

$h_1 \leq 0,2 s$

$h_1 \leq 0,15 s$

Table 2 (continued)

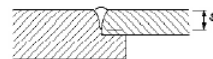
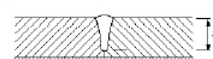
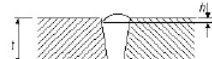
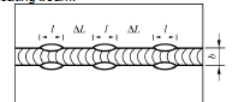
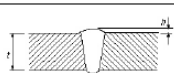
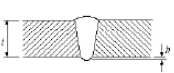
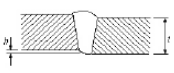
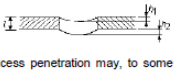
No	Imperfection, designation	EN ISO 6520-1 reference	Remarks	Limits for imperfections for quality levels:		
				moderate D	intermediate C	stringent B
9			<p>Sealing run:</p>  <p>Welding of clad materials. Followed by back gouging and arc welding from clad side.</p> 			
10	Imperfections specific to fillet welds	—	Applicable only for welding with filler materials. Imperfections Nos 12, 14, 16, 17, 18 and 22 according to EN 30042. Limits for imperfection No 13 according to EN 30042 depend on the application and shall be specified individually for each particular case.	Use limits for arc welding, see EN 30042, level D.	Use limits for arc welding, see EN 30042, level C.	Use limits for arc welding, see EN 30042, level B.
11	Undercut	5011 5012	 <p>Pulsating beam:</p> 	$h_1 \leq 0,15 t$ max. 2 mm	$h_1 \leq 0,1 t$ max. 1,5 mm	$h_1 \leq 0,05 t$ max. 1 mm
				$h_1 \leq 0,3 t$ max. 2,5 mm if $l \leq 2 b$ and $\Delta L \geq 5 b$	$h_1 \leq 0,2 t$ max. 2 mm if $l \leq 2 b$ and $\Delta L \geq 5 b$	$h_1 \leq 0,1 t$ max. 1,5 mm if $l \leq 2 b$ and $\Delta L \geq 5 b$

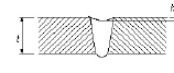
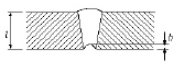
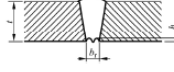
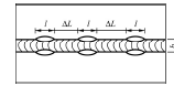


Table 2 (continued)

No	Imperfection, designation	EN ISO 6520-1 reference	Remarks	Limits for imperfections for quality levels:		
				moderate D	intermediate C	stringent B
12	Excess weld metal	502	 To be applied for reinforcement on weld side.	$h \leq 0,2 \text{ mm} + 0,3 t$ max. 5 mm	$h \leq 0,2 \text{ mm} + 0,2 t$ max. 5 mm	$h \leq 0,2 \text{ mm} + 0,15 t$ max. 5 mm
13	Excessive penetration	504		$h \leq 0,2 \text{ mm} + 0,3 t$ max. 5 mm	$h \leq 0,2 \text{ mm} + 0,2 t$ max. 5 mm	$h \leq 0,2 \text{ mm} + 0,15 t$ max. 5 mm
14	Linear misalignment	507	 The limits relate to deviations from the correct position. Unless otherwise specified, the correct position is that when the centerlines coincide.	$h \leq 0,25 t$ max. 3 mm	$h \leq 0,15 t$ max. 2 mm	$h \leq 0,1 t$ max. 1 mm
15	Sagging	509	 The excess penetration may, to some extent, compensate for the sagging. Only for welding of thin plate materials where $b \geq 0,5 t$ and $t \leq 2 \text{ mm}$ .	$h \leq 0,3 t + h_2$ max. $0,5 t$	$h \leq 0,2 t + h_2$ max. $0,3 t$	$h \leq 0,1 t + h_2$ max. $0,2 t$

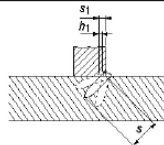
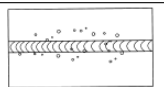
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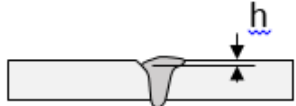
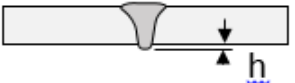

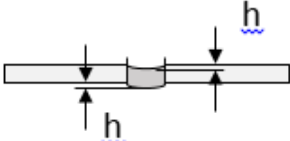
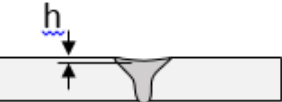

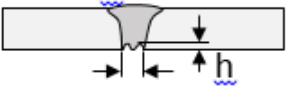
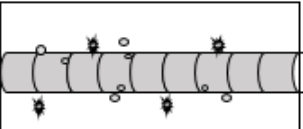
No	Imperfection, designation	EN ISO 6520-1 reference	Remarks	Limits for imperfections for quality levels:		
				moderate D	intermediate C	stringent B
16	Incompletely filled groove	511		$h \leq 0,15 t$ max. 2 mm	$h \leq 0,1 t$ max. 1,5 mm	$h \leq 0,05 t$ max. 1 mm
17	Root concavity	515		$h \leq 0,3 t$ max. 1 mm	$h \leq 0,2 t$ max. 0,5 mm	$h \leq 0,1 t$ max. 0,5 mm
18	Shrinkage groove	5013	 Pulsating beam: 	$h \leq 0,15 t$ max. 2 mm if $l \leq 2 b$ and $\Delta L \geq 5 b$	$h \leq 0,1 t$ max. 1,5 mm if $l \leq 2 b$ and $\Delta L \geq 5 b$	$h \leq 0,05 t$ max. 1 mm if $l \leq 2 b$ and $\Delta L \geq 5 b$

(continued)

Table 2 (concluded)

No	Imperfection, designation	EN ISO 6520-1 reference	Remarks	Limits for imperfections for quality levels:		
				moderate D	intermediate C	stringent B
19	Deviation from specified joint axis			$h_1 \leq 0,15 s_1$ max. 1 mm	$h_1 \leq 0,1 s_1$ max. 0,5 mm	$h_1 \leq 0,05 s_1$ max. 0,3 mm
20	Weld spatter	602		Acceptance depends on applications. Spatter is assumed to be of identical composition to the base and filler metals.		

➤ Table from our E.S with restrictions for RF- Cryogenic and others...

EN ISO 6520-1 reference	Imperfection designation	Remarks	Limits for imperfections
5011 5012	Undercut		h max 0.1 mm
504	Excessive penetration		h max 0.1 mm
507	Linear misalignment		h max 0.1 mm
509	Sagging		h max 0.2 mm
511	Incompletely filled groove		h max 0.2 mm
515	Root concavity		h max 0.1 mm
5013	Shrinkage groove		Not acceptable
602	Weld spatter		Not acceptable

**Summary Welding qualifications:** <https://edms.cern.ch/document/1536724/1>

	<i>Coupon</i>	<i>Received</i>	<i>Qualified</i>	<i>Observations</i>
1	Nb/Nb thickness 3 mm + beam tube piece (weld performed from one side) to qualify the longitudinal of the beam tube.	Yes (from <a href="#">Nioவை</a> )	Yes	Coupon needed only for beam tubes, already produced.
2	Nb/Nb thickness 3 mm + beam tube piece (weld performed from both sides) to qualify the circular of the beam tube.	Yes (from <a href="#">Nioவை</a> )	Yes	Coupon needed only for beam tubes, already produced.
3	Nb/NbTi thickness 6.5 mm + beam tube piece (weld performed from both sides) to qualify the dissimilar joint of the beam tube between niobium tube & NbTi ring.	Yes (from <a href="#">nioவை</a> )	Yes	Coupon needed only for beam tubes, already produced.
4	Nb/Nb thickness 4 mm (weld performed for one side) to qualify the circular of the cavity: 2 plates full penetration in 4mm, approx. dimensions each piece: width (100/150) mm x (250/300)mm of length.	Yes (from <a href="#">Nioவை</a> )	No (Not compliant with RF restrictions)	Coupon request to J-Lab. See the details in the following page
5	Nb/Nb thickness 4 mm (weld performed for both sides) to qualify the longitudinal and circular of the cavity: 2 plates full penetration in 4mm, approx. dimensions each piece: width (100/150) mm x (250/300)mm of length.	Yes (from <a href="#">Nioவை</a> )	No (Not compliant with RF restrictions)	Coupon request to J-Lab See the details in the following page.
6	Nb/Nb thickness 3mm to qualify the circular extremity assembly to the cavity (welded from two sides): 2 tubes (plates rolled), full penetration in 3mm of thickness (3.15mm is ok), diameter between 60 - 100mm & total length approx. 150mm. One of the tubes should be constrained to simulate the presence of the cavity.	No		Coupon request to J-lab See the details in the following pages.
7	Dissimilar weld NbTi/Nb with partial penetration to qualify the joint between NbTi tuner support & Niobium bowl: Coupon as the real geometry.	No		Coupon request to J-Lab.

**COUPONS:** According to ASME IX paragraph QW-215.1: the WPS qualification test coupon shall be prepared with the joint geometry duplicating the one used in production. **If the production weld includes a lap-over** (completing the weld by re-welding over the starting area of the weld), such lap-over shall be included in the WPS qualification test coupon.

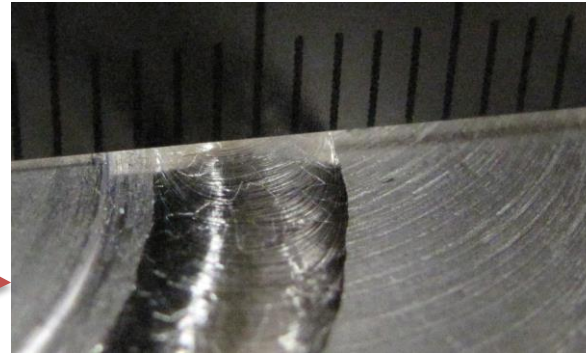
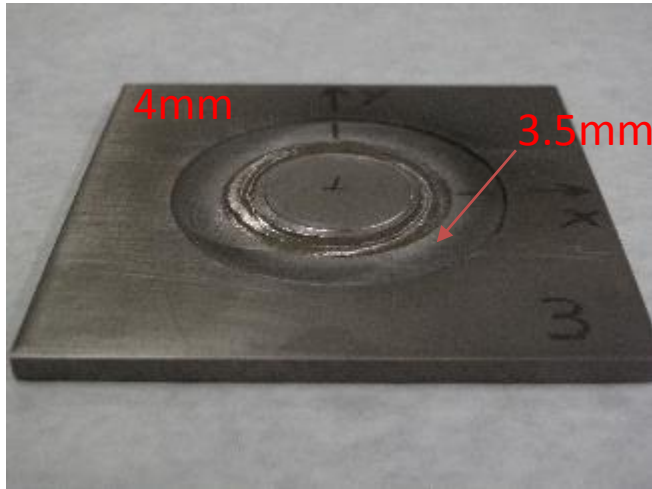
**NOTES (others):**

1. 4 samples are still needed to qualify all welds
2. Third party is not required
3. The qualification criteria for the mechanical testing is according to ASME
4. The samples shall be in compliance with the RF restrictions.



## □ Summary test performed at CERN

### Nb weld for HOM (DQW): under qualification



Longitudinal in 4mm



**No superficial defects found**, compliance with the table 7 and the standard EN13913-2 level B:

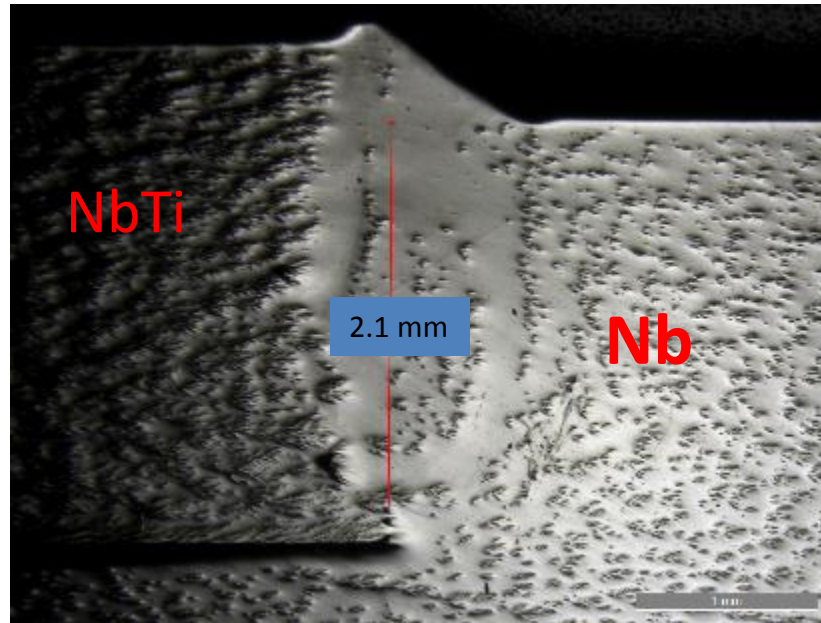
- 511: Completely filled groove
- 5011 & 5012: No Undercut

Other defects will be measured in the metallographic examination

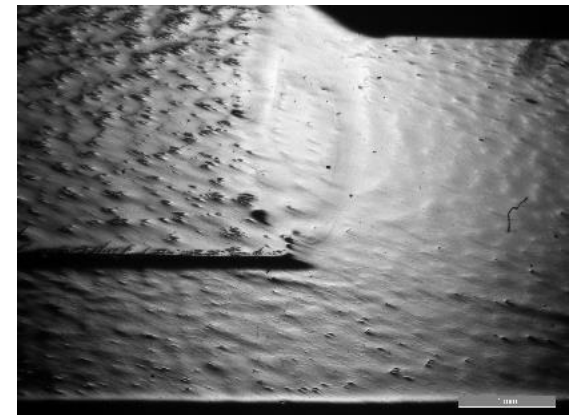
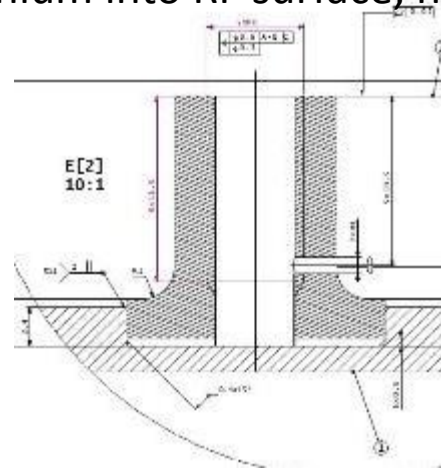
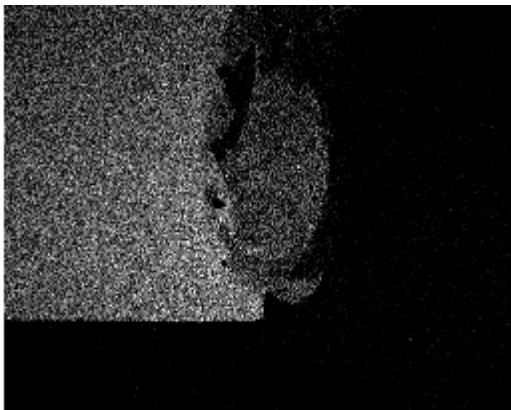
Preliminary results in 4mm SATISFACTORY, weld feasible.

# Nb/Nb55Ti weld

Penetration depth of  $\approx 2$  mm achieved as specified



No evident diffusion of Titanium into RF surface, no significant weld distortion



EN/MME

## **- Actions and Conclusions:**

- RF side is currently studying the impact on the frequency caused by the geometry and dimensions of the welds concerning the table 7.
- Re-calculations to reduce the thickness until 3mm in the weld areas. This reduction should be smooth with a slope according to the Codes.



# High Luminosity LHC



The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

