

T5.5 Case study for Problem-Based Learning (PBL)

Title of Case Study / Problem-based learning case:

Joining/qualification/NDT of small diameter and thin thickness stainless steel tubes for Aerospace Applications

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Background

- Tubes material: ASI 316L
 - Diameter 3.17 mm
 - Thickness 0.8 mm
- Tubes contain non-dangerous fluid/gas but excessive penetration is acceptable if complies with acceptance criteria
- Process/product needs to be qualified according to [ECSS-Q-ST-70-39C](#) (free download) “Welding of metallic materials for flight hardware”
- Defined by end-user:
 - Safety level 1
 - Weld sensitivity level A
 - Acceptance criteria: tensile strength > 350 MPa
- Limited space and accessibility for welding

Technical challenge

- Define welding process: which process could be applied? Why and what would you choose?
- Type of joint: butt weld
- ECSS standard:
 - Acceptance criteria: see § 10
 - Welding process verification (=PQR): see § 11
 - Table 12-2: Tests to be performed on parts performed during production of flight hardware
- Weld preparation: points off attention
- NDT
 - Define suitable NDT methods according to ECSS
 - Visual inspection:
 - how do you measure undercut and incompletely filled groove
 - can endoscopy be used to inspect internally?



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- Compare analogic radiographic film (RT-F) against digital radiography (RT-D & RT-CR): what is the best solution? Can Eddy be current be used?
- Compare dye penetrant coloured against fluorescent: what is the best solution?
- Destructive testing
 - Is hardness measurement useful and feasible?
 - What to measure in tensile test?

Illustration of the case study



Figure 1: example of a welded sample

Detailed solution/ process

- Weld process:
 - Best option: TIG orbital welding with pulsed current without filler metal (Figure 2)
 - Other possibilities:
 - Micro plasma orbital welding: head size might not be fit into confined space
 - Friction welding: post-processing on the side is difficult
 - Laser: rotate tube possible for subassemblies, but not for final weld
 - Brazing: type of joint implies mechanical tensile/shear strength
 - Electron beam: vacuum, rotate tube possible for subassemblies, but not for final weld
 - Mechanical connection: often not acceptable for aerospace application, e.g. leakage, tightness, ...
- Weld preparation:
 - Clamping for proper alignment (high-low): alignment tools (Figure 3)



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- Positioning and quality check of the electrode (Figure 4)
- Deburring (Figure 6) due to mechanical cutting/deformation:
 - Laser cutting
 - Deburring on the inside after cutting
- Figure 4 NDT
 - Visual inspection:
 - how do you measure incompletely filled groove: macro + image processor to measure (Figure 7).
 - Table 10.1 incompletely filled groove
 - Orbital welding without filler metal: hard (almost impossible) to avoid incompletely filled groove due to gravity of the welding pool, certainly for thin materials and small diameters
 - Difference between original german/english DIN 29595 standards and ECSS (Figure 8)
 - Internal inspection – boroscopy:
 - [Opticon Benelux](#)
 - Jeet: pt.jeet-videoscope.com
 - Compare analogic radiographic to digital
 - ISO 17636-1 for film
 - Thickness (see Figure 12)
 - Ellipse => §7.1.1 (see Figure 11)
 - ISO 17636-2 for digital (Figure 9)
 - Difficult interpretation of images
 - Fluorescent (Figure 10): EN 3452-1: product family ISO 3452-2, I A (or other) a (or other) Level 3
- Destructive testing
 - Hardness: not possible due to limited thickness (also not hardenable)
 - Tensile test results (see Figure 13):
 - tensile strength on full pipe using inserts at the end (no elongation or yield due to not standardized).
 - Acceptance criteria ECSS (see Figure 14): The criteria of acceptance for the values of the tensile test shall be specified by the customer.
- Welding parameters (see Figure 15)
 - Change parameters per sector to avoid lack of penetration but also to reduce excessive penetration/incompletely filled groove (= optimize heat balance)
 - Parameter optimization required (small process window)



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Additional pictures/information

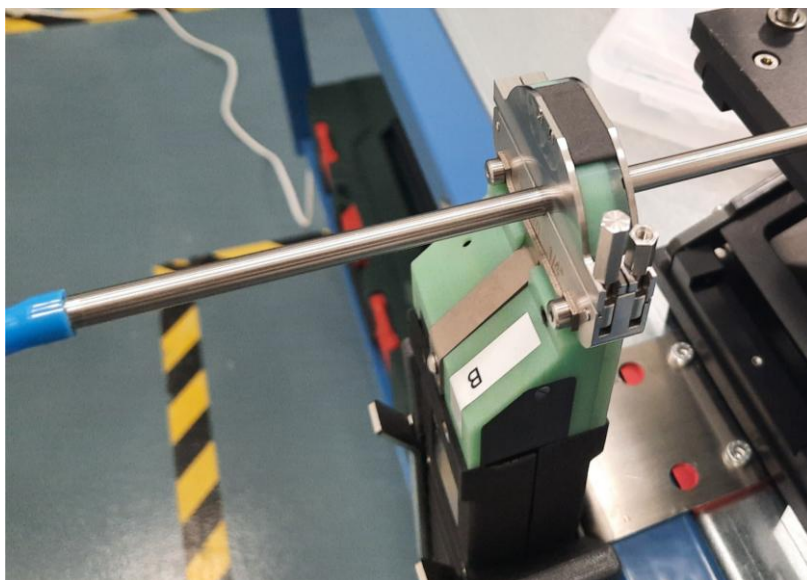


Figure 2: orbital welding head

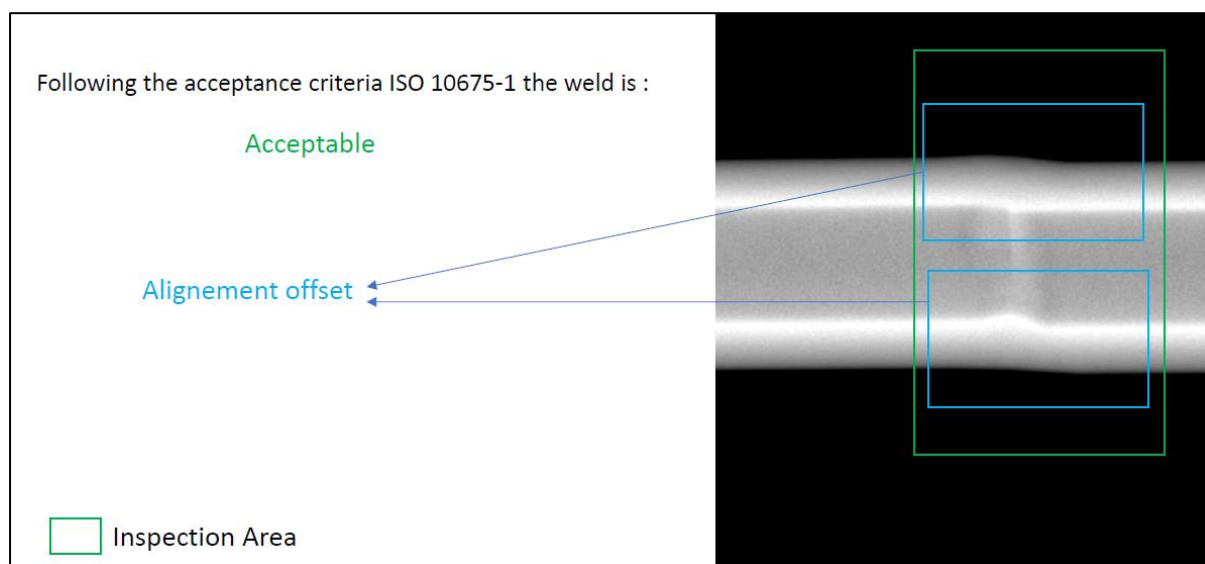


Figure 3: alignment off-set on radiographic image



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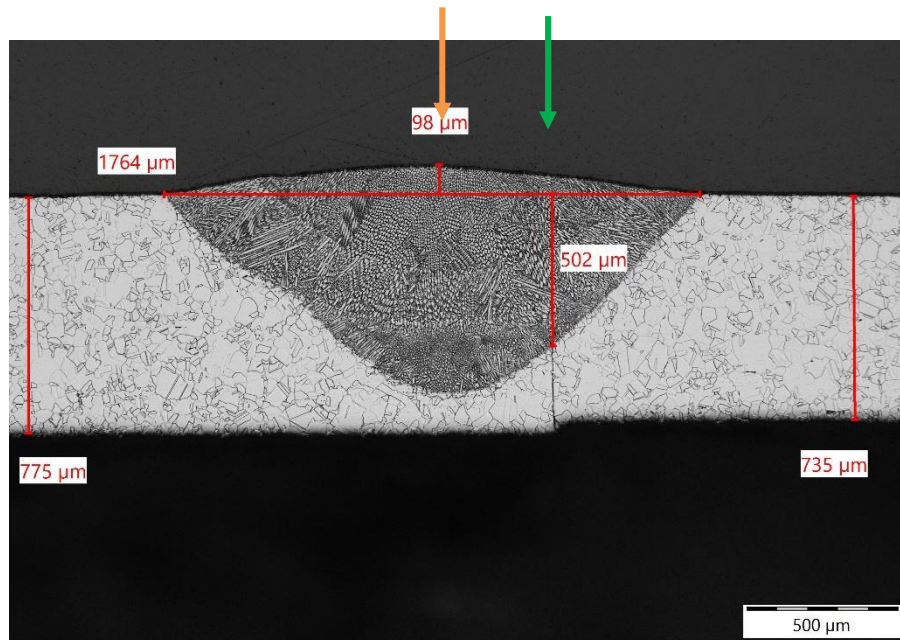


Figure 4: Alignment of the tungsten electrode not perfectly aligned (0,38mm to much to the left): orange arrow indicates the current position – green arrow indicates the correct position



Figure 5: degradation of tungsten electrode, type WS2 (1mm with top angle 18° & top diameter 0,5mm): 2 left are used electrodes and the 2 right are new ones



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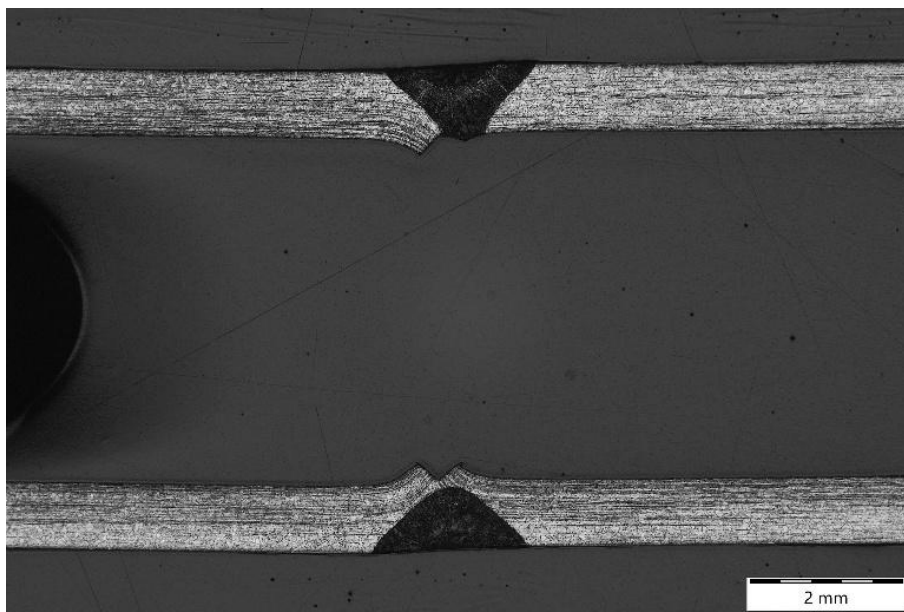


Figure 6: burs on the inside of the tubes due to mechanical cutting

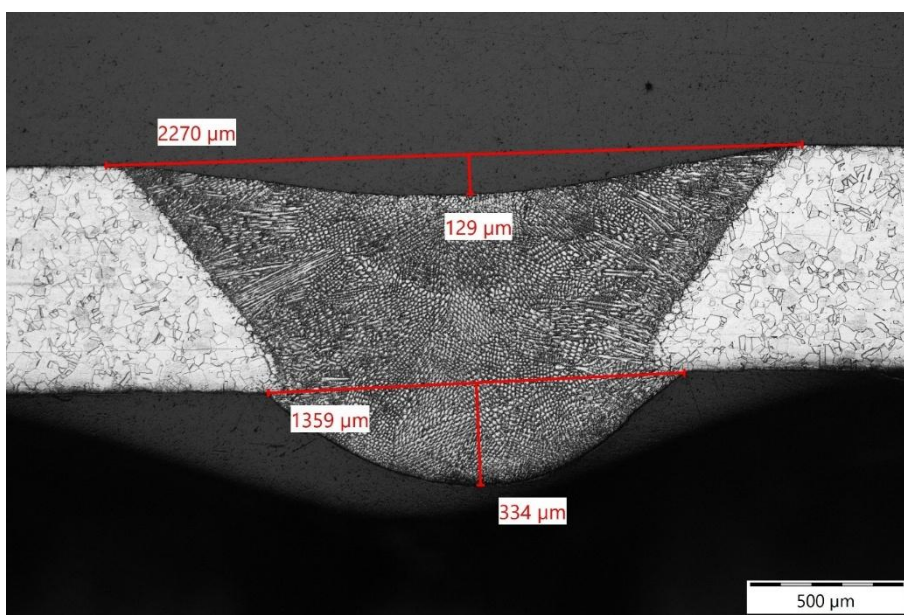


Figure 7: Incompletely filled groove

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ECSS extract, table 10-1

NOTE The data of Table 10-1 is based on [DIN 29595:2007-04](#) Table 1 "Limits for external imperfections – Quality levels". Reproduction of this table was granted by DIN

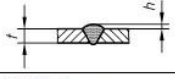
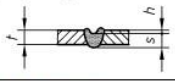
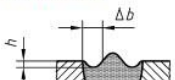
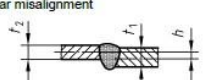
Table 10-1: Outer features for fusion welds

Reproduced by permission of DIN Deutsches Institut für Normung e.V. The definitive version for the implementation of this standard is the edition bearing the most recent date of issue, obtainable from Beuth Verlag GmbH, Burggrafenstraße 6, 10787 Berlin, Germany.

Serial Number	Reference according to ISO 6520-1	Designation and Remarks	Process reference per ISO 4063	Material Group (a)	Limits for imperfections for quality levels (b)		
					A	B	C
1	502	Excess weld metal 	141, 15	A B C	$h \leq 0,2t + 1,2 \text{ mm}$		$h \leq 0,2t + 2,0 \text{ mm}$
				D	$h \leq 0,2t + 1,8 \text{ mm}$		$h \leq 0,2t + 2,5 \text{ mm}$
			511, 52	A B C D	$h \leq 0,3t \leq 5 \text{ mm}$		
2	511	Incomplete filled groove 	141, 15, 511, 52	A B C D	Unacceptable		$h \leq 0,1t \leq 1 \text{ mm}$ $t \leq s$

DIN 25955 – english version

Table 1 — Limits for external imperfections – Quality levels

Item	Reference number as in DIN EN ISO 6520-1	Designation and remarks	Symbol for type of weld as in DIN EN 22553	Reference number as in DIN EN ISO 4063	Material group ^a	Quality levels for imperfections		
						A	B	C
1	502	Excess weld metal 	II V	141, 15, 311	A B C	$h \leq 0,2r + 1,2 \text{ mm}$		$h \leq 0,2r + 2,0 \text{ mm}$
					D	$h \leq 0,2r + 1,8 \text{ mm}$		$h \leq 0,2r + 2,5 \text{ mm}$
			II	511, 52	A B C D	$h \leq 0,3r \leq 5$		
2	511	Incompletely filled groove 	II V	141, 15, 311, 511, 52	A B C D	Not permitted; for welds produced by mechanical welding using filler material this characteristic is to be agreed separately.		$h \leq 0,1r \leq 1 \text{ mm}, s \geq r$ For welds produced by mechanical welding using filler material this characteristic is to be agreed separately.
3	—	Incompletely filled groove 	—	511	A B C D	Not permitted	$b \geq 4h$	
4	507	Linear misalignment 	II V	141, 15, 311,	A B C D	$h \leq 0,1r + 0,25 \text{ mm}$ for flat joints $h \leq 0,2r + 0,3 \text{ mm}$ for curved joints		$h \leq 0,3r + 0,3 \text{ mm}$
				511, 52		$h \leq 0,1r \leq 1,0 \text{ mm}$		

DIN 25955 – German version (original)



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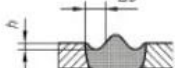
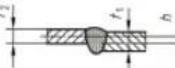
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DIN 29595:2007-04

Tabelle 1 — Grenzwerte für äußere Unregelmäßigkeiten – Bewertungsgruppen

Lfd. Nummer	Referenz-Nr nach DIN EN ISO 6520-1	Benennung und Bemerkungen	Symbol für Nahtart nach DIN EN 22553	Ordnungsnummer nach DIN EN ISO 4063	Werkstoffgruppe ^a	Bewertungsgruppen für Unregelmäßigkeiten		
						A	B	C
1	502	zu große Nahtüberhöhung 	II V	141, 15, 311	A B C	$h \leq 0,2 \, i + 1,2 \, \text{mm}$		$h \leq 0,2 \, i + 2,0 \, \text{mm}$
						$h \leq 0,2 \, i + 1,8 \, \text{mm}$		$h \leq 0,2 \, i + 2,5 \, \text{mm}$
			II	511, 52	A B C D	$h \leq 0,3 \, i \leq 5$		
2	511	Decklagenunterwölbung 	II V	141, 15, 311, 511, 52	A B C D	Nicht zulässig, für mechanisch geschweißte Nähte ohne Schweißzusatz ist dieses Merkmal gesondert zu vereinbaren.		
						$h \leq 0,1 \, i \leq 1 \, \text{mm}, s \geq i$ Für mechanisch geschweißte Nähte ohne Schweißzusatz ist dieses Merkmal gesondert zu vereinbaren.		
3	—	Nahttrandunterwölbung 	—	511	A B C D	Nicht zulässig	$h \geq 4 \, h$	
4	507	Kantenversatz 	II V	141, 15, 311,	A B C D	$h \leq 0,1 \, i + 0,25 \, \text{mm}$ für ebenen Stoß $h \leq 0,2 \, i + 0,3 \, \text{mm}$ für gekrümmten Stoß		$h \leq 0,3 \, i + 0,3 \, \text{mm}$
				511, 52		$h \leq 0,1 \, i \leq 1,0 \, \text{mm}$		

Summary for incompletely filled groove, quality level A & B:

ECSS	Not permitted
DIN 25955 – English version	Not permitted; for welds produced by mechanical welding using filler material this characteristic is to be agreed separately.
DIN 25955 – German version (original)	Nicht zulässig, für mechanisch geschweißte Nähte ohne Schweißzusatz ist dieses Merkmal gesondert zu vereinbaren. Not permitted; for mechanically welded seams without filler material , this feature must be agreed separately.

Figure 8: incompletely filled groove – ECSS and DIN standards



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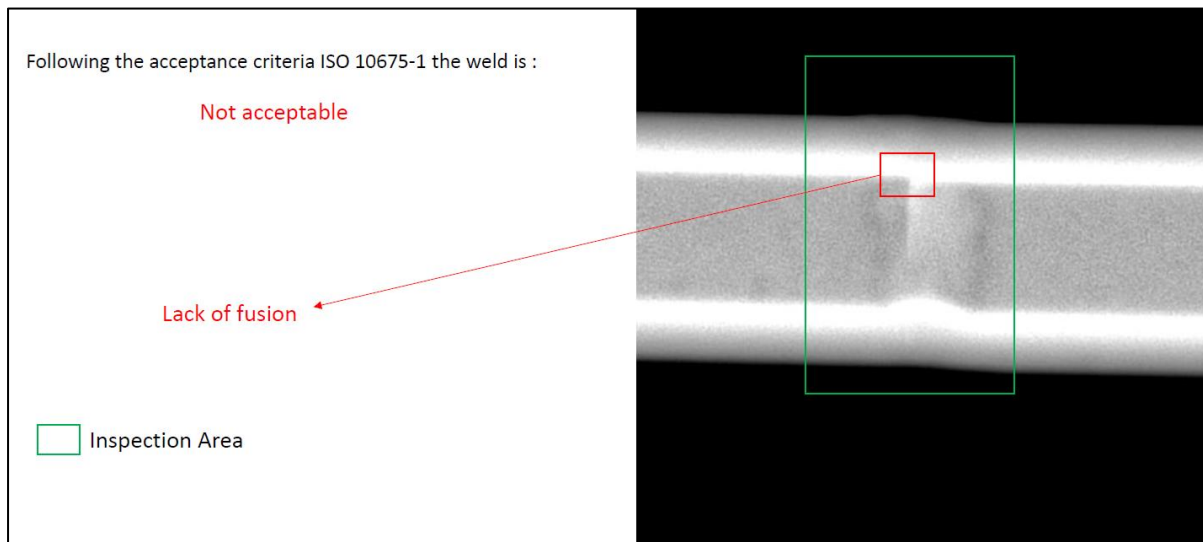


Figure 9: Difficulty of digital radiographic inspection: technical and interpretation

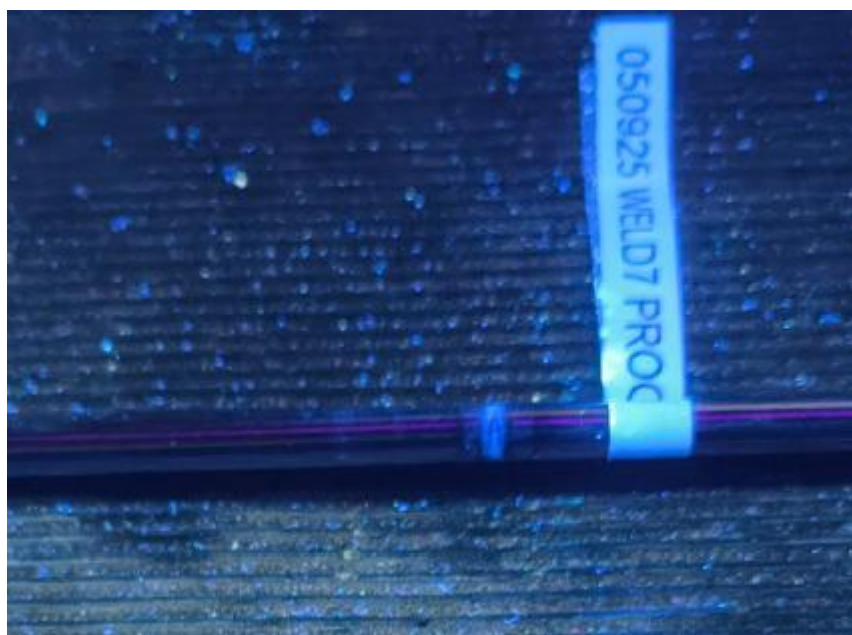


Figure 10: fluorescent testing



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7.1 Test arrangements

7.1.1 General

Normally radiographic techniques in accordance with 7.1.2 to 7.1.9 shall be used.

X-ray film shall be placed as close to the object as possible.

The elliptical technique (double wall and double image) in accordance with Figure 11 should not be used for external diameter $D_e > 100$ mm or wall thickness $t > 8$ mm or weld width $> D_e/4$. Two 90° displaced images are sufficient if $t/D_e < 0,12$; otherwise three images are needed. The distance between the two projected weld images shall be about one weld width.

When it is difficult to carry out an elliptical examination at $D_e \leq 100$ mm, the perpendicular technique in accordance with 7.1.7 may be used (see Figure 12). In this case, three exposures 120° or 60° apart are required.

For test arrangements in accordance with Figures 11, 13, and 14, the inclination of the beam shall be kept as small as possible and be such as to prevent superimposition of the two images. The source-to-object distance, f , shall be kept as small as possible for the technique shown in Figure 13, in accordance with 7.6. The IQI shall be placed close to the film with a lead letter F.

Other radiographic techniques may be agreed by the contracting parties when it is useful, e.g. for reasons such as the geometry of the piece or differences in material thickness. In 7.1.9 an example of such a case is presented. Multi-film techniques shall not be used to reduce exposure times on uniform sections. Additionally, thickness compensation with the same material may be applied.

NOTE In Annex A, the minimum number of radiographs necessary is given in order to obtain an acceptable radiographic coverage of the total circumference of a butt weld in pipe.

Figure 11: Non-destructive testing of welds - Radiographic testing - Part 1: X- and gamma-ray techniques with film (ISO 17636-1)



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7.2.1 X-ray devices up to 1 000 kV

To maintain a good flaw sensitivity, the X-ray tube voltage should be as low as possible. The maximum values of X-ray tube voltage versus thickness are given in Figure 20.

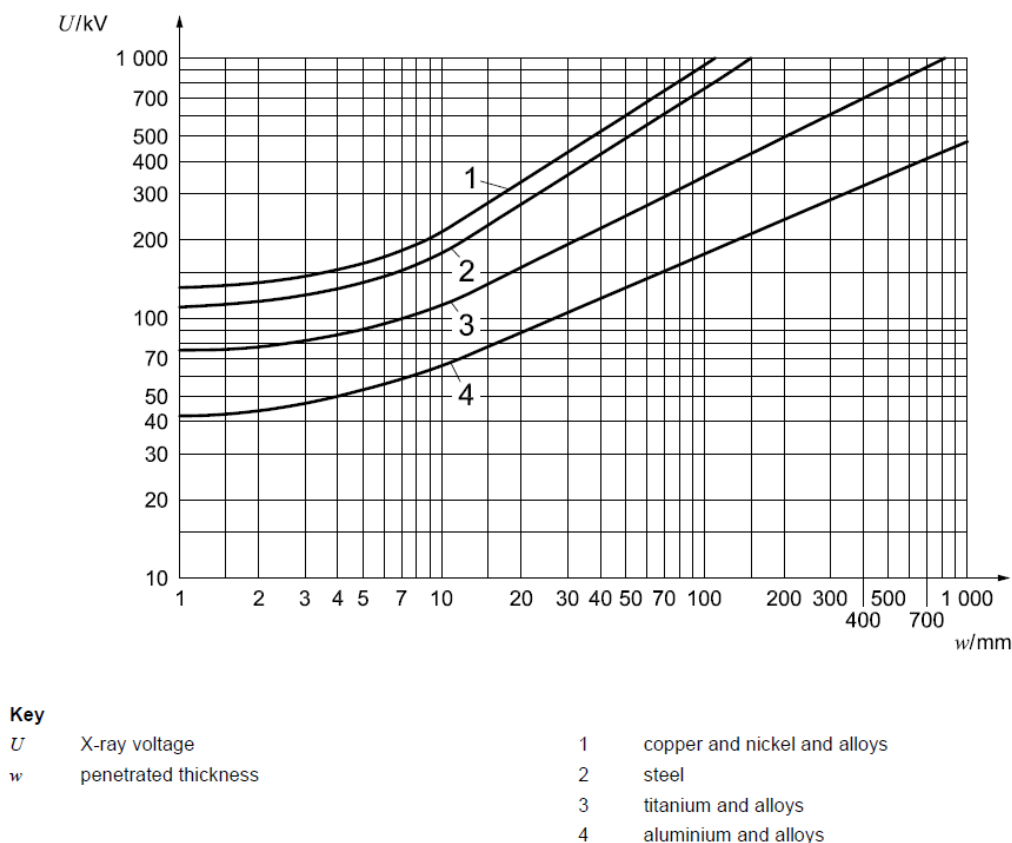


Figure 12: maximum values of X-ray tube voltage versus thickness (EN ISO 17636-1): 0,6mm thickness is not in the graph

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1. Client information								
Requested by: _____				Reference: _____				
Requirement: ECSS-Q-ST-70-39C								
Remark(s): -								
2. General test information								
Date of test: 03/12/2025				Test standard: ISO 4136				
Test temperature: 22,0 °C				Test method: ISO 6892-1 method A				
3. Test results								
Test specimen number	Outside diameter d_o [mm]	Inside diameter d_i [mm]	Area S_0 [mm ²]	Tensile strength F_m [N]	Tensile strength F_m [MPa]	Fracture location	Remarks (Fracture appearance, type of imperfections)	Result
5W161-PQR1-W3	6,34	4,627	14,790	8747	591,4	Weld metal	-	-
5W161-PQR1-W4	6,34	4,593	14,999	8904	593,7	Weld metal	-	-
5W161-PQR1-W5	6,35	4,603	14,993	8837	589,4	Weld metal	-	-



Figure 13: tensile test results

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9.2.3 Tensile test

- a. Test specimens and testing for transverse and longitudinal tensile tests of butt joints shall be in accordance with ISO 4136:2012.

NOTE ASTM E8M-13 is an equivalent standard.

- b. For friction stir welds, advancing and retreating sides of the test specimens shall be marked prior to testing.
- c. The criteria of acceptance for the values of the tensile test shall be specified by the customer.

Figure 14: Acceptance criteria ECSS Q-ST-70-39C, paragraph 9.2.3 Tensile test

Sectors									
No.:	NOMINAL (Deg) Start_End	I-Nom.(A) Hi / Lo	t (s) Hi / Lo	v (mm/min) Tool Hi/Lo	Wire Hi/Lo	MEASURED I-Meas.(A) Hi / Lo	U-Meas.(V) Hi / --	v (mm/min) -- / Lo	Q (J/mm) Hi_Lo
1	90°	19.0/6.1	0.091/0.091	125/125		18/0	8.5	125	22.0
2	180°	18.3/6.1	0.091/0.091	125/125		18/0	8.3	125	21.5
3	270°	17.4/6.1	0.091/0.091	125/125		17/0	8.2	124	20.1
4	365°	16.5/6.1	0.091/0.091	125/125		16/0	8.1	125	18.7
5	°								
6	°								

Figure 15: sectoral welding parameters

The Purpose of the elaborated Case Studies

Case studies are structured examinations of real-world situations or challenges designed to bridge theory and practice. They are developed both as a research method and as a learning tool to strengthen analytical and problem-solving skills. By engaging with authentic industrial scenarios, students gain practical insight into complex professional environments.

The purpose of this case studies is to encourage active, learner-centred engagement. They support approaches such as problem-based learning by enabling students to work independently or collaboratively, with or without instructor guidance. Through analysing theoretical concepts within realistic contexts, students learn to interpret data and test results, evaluate alternative courses of action, and develop well-reasoned, creative solutions.

This approach is particularly valuable in sectors such as aerospace, defence, and advanced manufacturing, where challenges are multifaceted and solutions are rarely singular. Because multiple valid solutions often exist, guided facilitation is frequently beneficial to help students structure their reasoning, assess trade-offs, and justify their decisions effectively.



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Competence unit coverage:

AILEEN competence units		Covered CU
AW_01	Welding: Advanced Metallic Materials in Aerospace and Defence Sectors	
AW_02	Welding: Advanced Welding Processes and Equipment in Aerospace and Defence Sectors	x
AW_03	Welding: Advanced Welding Applications in Aerospace and Defence Sectors	
AW_04	Welding: Introduction to brazing technology Knowledge for quality brazed joints	
AW_05	Welding: Fundamentals of Industrial Brazing: Main Processes, Quality Standards & Applications	
AI_01	Inspection: Non-Destructive Testing (NDT) in Additive Manufacturing for metals and polymers	
AI_02	Inspection: Metrology in Additive Manufacturing for metals and polymers	
AI_03	Inspection: Inspection of AM parts. Material Quality	
AAM_01	AM: Qualification, Certification and Standards for AM in A&D	
AAM_02	AM: Quality Assurance & Quality Control for AM in Aerospace & Defence	
AAM_02/3	AM: Design of AM parts for A&D (2 courses - for DED & PBF)	
AD_01	Digital: Introduction to Digital Technologies in Advanced Manufacturing	
AD_02	Digital: Data Acquisition and Analysis	
AD_03	Digital: Industrial Internet of Things (IIoT) and Advantages in Advanced	
AD_04	Digital: Artificial Intelligence and Advantages in Advanced	
AD_05	Digital: Automation and Advantages in Advanced Manufacturing	
AD_06	Digital: Potentials of Advanced Simulation and Modelling in Advanced	
AD_07	Digital: Potentials of Digital Twins and Smart Factory Automation in Advanced Manufacturing	
AD_08	Digital: Unlocking the Potential of 3D Models Beyond Technical Drawings in the Aerospace and Defence Sector	
AG_02	Green: Sustainable Design and Environmental Compliance in Aerospace and Defence	

