ONDERZOEK • ADVIES • OPLEIDING • INFOTHEEK

Belgian Welding Institute npo

Benny Droesbeke

Nelis Vandermeiren

ISO 9001 CERTIFIED VINÇOTTE — BELAC Nr 606-TEST EN ISO 17025 — VCA* CERTIFIED VINÇOTTE

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Belgian Welding Institute, npo

- Independent expert center for welding technologies and materials weldability, promoting the collective interest of:
  - Companies
  - Training and research centers
  - Schools
  - Persons engaged in the field of welding and joining of materials
- Founding member of International Institute of Welding (IIW)
- About 240 members, mostly Belgian companies
- Belgian representative for CEN and ISO welding standards
- BWI is certified/accredited according to :
  - ISO 9001:2015
  - ISO 17025 for fracture mechanical and CLP testing (Classification, Labelling and Packaging)
  - ISO 9227 for salt spray testing
  - VCA*

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Activities

- Welding Coordinators IWE, IWT, IWS
- Welding Coordinators EWCP-1090-2 (RWC-B)
- Welding Technology (WT-C, WT-S)
- Visual Welding inspector IWIP (IWI-C, IWI-S)
- Visual Welding inspector VT Level 2
- In company training courses regarding welding technology
- (Weld) quality system: EN 1090, EN 15085

The Belgian Welding Institute believes strongly in cooperation and joint organisation with local or international (sector) organisations, research- and training institutes or schools, in joint consultation, to fill the needs of the market in a quick and efficient manner.

- Helping companies to interpret and correctly apply standards
- Company specific advice and consultation
- Promote knowledge transfer around standards via workshops and seminars
- Report on new standards coming out
- Website standards: www.nal-ans.be

- Weld Procedure Qualification
- Weldability studies (physical welding simulation, reheat cracking, hot ductility)
- Residual life assessments (creep tests)
- Fracture mechanical testing (CTOD, CT, KIC, crack growth)
- (Corrosion-) Fatigue testing

Corrosion
- Salt spray
- Climatic testing
- Tests for evaluating pitting, crevice, galvanic and stress corrosion
- Immersion & Electro chemical tests
- Determining corrosion hazard of solutions and mixtures on metals

Failure investigation and metallography
- Metallography on various materials
- Hardness testing
- Ferrite measurements on all metals
- Grain size determination
- Multidisciplinary investigations, on-site and in the lab
- SEM investigations, replica technique

- Guidance of companies up to and including certification audits
- Application-based research into welding techniques and material weldability
- Development of innovating applications and new welding and joining techniques
- Study and development of industrial prototypes
- Technical assistance: welding process, production technique, base and welding materials
- Advice during production and in quality control
- Assistance in developing or adapting Welding Procedures

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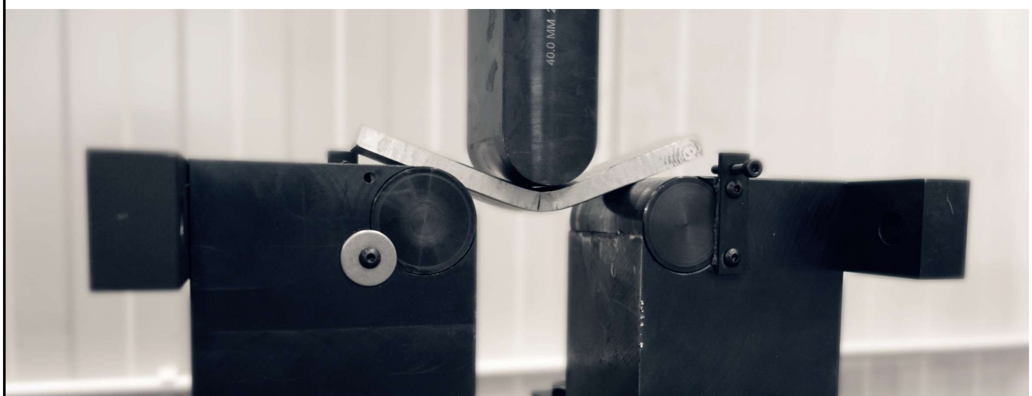
- ONDERZOEK
- ADVIES
- OPLEIDING
- INFOTHEEK

MATERIALS & WELD TESTING

Destructive Testing of welded joints



According to EN ISO 15614-1

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Overview

1. Introduction
2. Tensile testing
3. Bend testing
4. Impact testing
5. Hardness Vickers testing
6. Macroscopic examination

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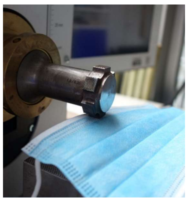
1. Introduction

- Can you imagine a world without welds?
- In every component, from small to large welding technology is very important!



Facemask you are wearing

Airplane you fly

Chair you are sitting on

Water slide of an outdoor swimming pool you (or your kids) are having fun

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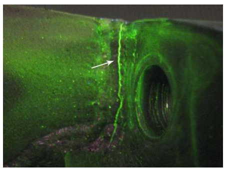
1. Introduction

- After welding and any post-weld heat treatment (PWHT), but before painting, welds are non-destructive tested.
- **Non-Destructive Testing (NDT)**
  - **Definition:** Process of inspecting a component for discontinuities or cracks , without destroying the serviceability of the system
  - **Main purpose:**
    - Ensure product integrity
    - Ensure product reliability
    - Control the manufacturing process
    - Lower production costs
    - Maintain a uniform level of quality



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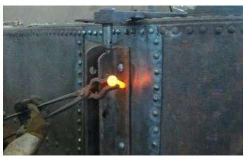
1. Introduction

- However, unfortunately failure still occurs…
- Failure or fracture of Liberty Ships


  - The accident was caused by occurrence and development of brittle crack, which were due to the lack of **fracture toughness** of welded joint.

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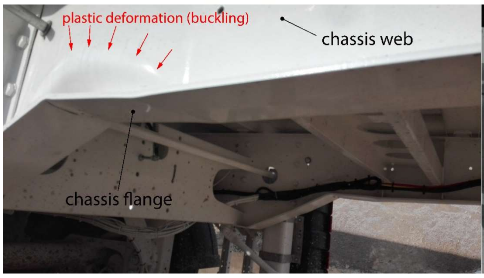
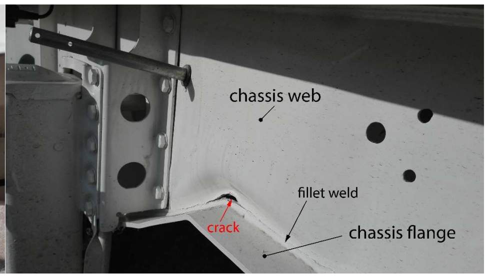
1. Introduction

- Failure or truck trailer





- Failure caused by insufficient **tensile strength** of the chassis web. However, a high-strength material was specified, the welding company used a regular, cheaper an lower strength steel for the construction of the chassis. During a performance test, the chassis failed due to overload.

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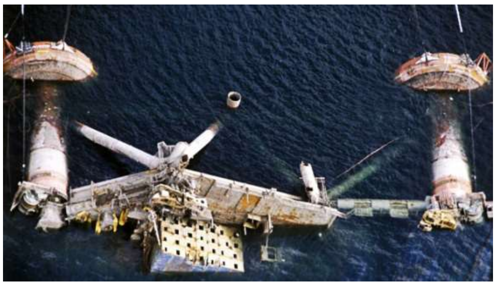
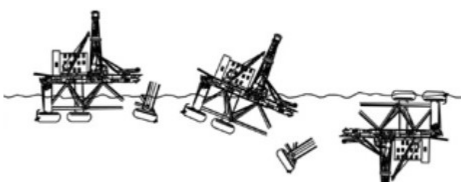
1. Introduction

- Failure of the Alexander L Kielland offshore platform (1980)





Process of capsize of Alexander L. Kielland

- During a storm in the North Sea, one of the lower tubular bracings failed resulting in complete disaster. In approximatly 20 minutes, the platform capsized.
- These initial cracks in the fillet weld was caused by the presence of hydrogen in combination with high stresses an a **high hardness** (susceptible microstructure) in the Heat Affected Zone (HAZ) of the weld.

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1. Introduction

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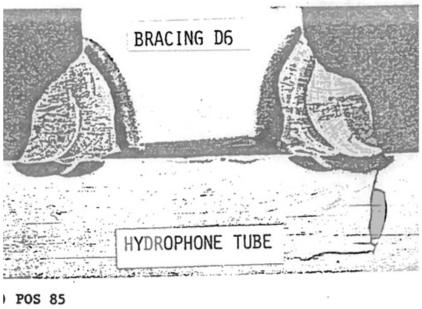
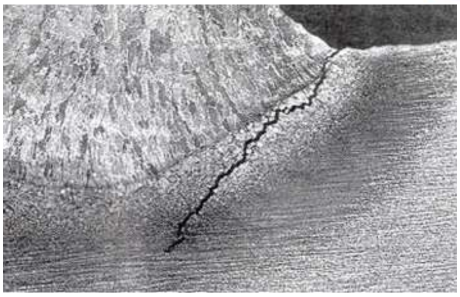
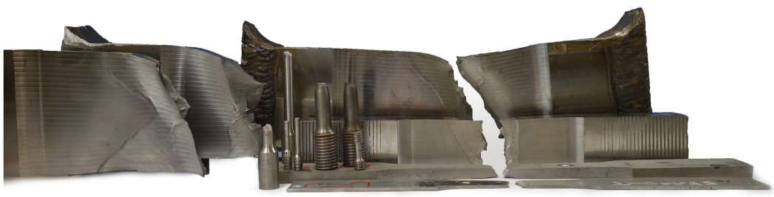




  - During a storm in the North Sea, one of the lower tubular bracings failed resulting in complete disaster. In approximatly 20 minutes, the platform capsized.
  - These initial cracks in the fillet weld was caused by the presence of hydrogen in combination with high stresses an a **high hardness** (susceptible microstructure) in the Heat Affected Zone (HAZ) of the weld.

1. Introduction

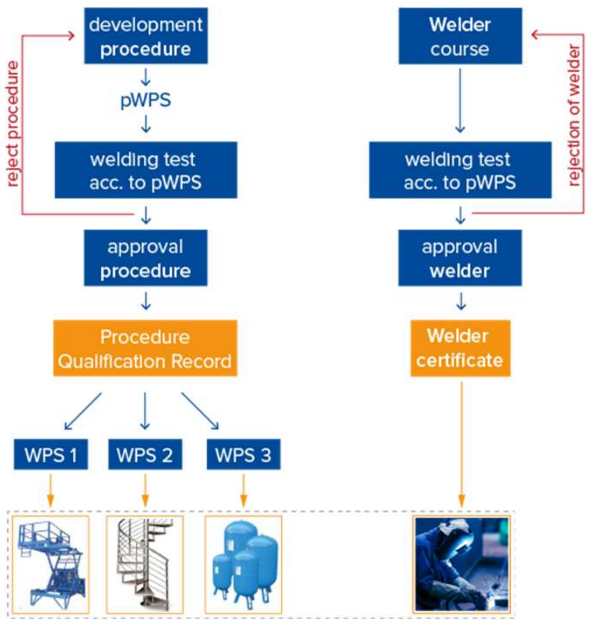
- In order to assure the appropriate weld quality and mechanical properties of the welded joint(s), destructive tests are performed
- **Destructive Testing (DT)**
  - **Definition:** Process of testing a specimen until failure occurs to determine the mechanical properties of a component
  - **Mechanical (physical) properties:**
    - Ductility: Tensile test, bend test
    - *Truck trailer* Yield and ultimate tensile strength: Tensile test
    - *Liberty ship* Fracture toughness: Impact test, Fracture toughness testing (CTOD, KIc, J…)
    - *Kielland* Fatigue strength: fatigue testing
    - *Kielland* Microstructure: macroscopic examination, hardness testing



1. Introduction

Define all essential welding parameters and weld a test specimen

Quality verification by
Non-Destructive Testing (NDT)
Destructive Testing (DT)



Production welds are welded within the allowed approved range of all essential welding parameters

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1. Introduction

- Specification and qualification of welding procedures for metallic materials - Welding procedure test is specified in the appropriate part of ISO 15614:
  - PART 1: Arc and gas welding of **steels and arc welding of nickel and nickel alloys**
  - PART 2: Arc welding of **aluminium and its alloys**
  - PART 3: Fusion welding of non-alloyed and low-alloyed cast irons
  - …
  - PART 14: Laser-arc hybrid welding of steels, nickel and nickel alloys
  - https://www.iso.org/search.html?q=15614
- Throughout this training, the specifications and requirements according to EN ISO 15614-1 will be used

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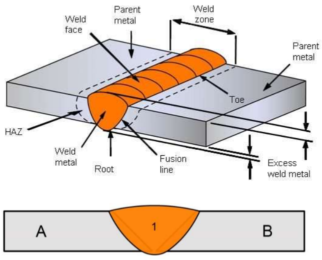
1. Introduction

- Extent of testing according to ISO 15614-1:Level 2



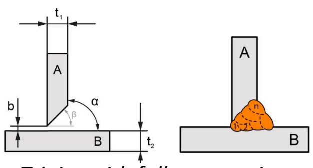
Butt Weld (BW)

Table 2 — For level 2: Examination and testing of the test pieces

Test piece	Type of test	Extent of testing
Butt joint with full penetration — Figure 1 and Figure 2	Visual testing	100 %
	Radiographic or ultrasonic testing	100 %
	Surface crack detection	100 %
	Transverse tensile test	2 specimens
	Transverse bend test	4 specimens
	Impact test	2 sets
	Hardness test	required
	Macroscopic examination	1 specimen
T- joint with full penetration — Figure 3 Branch connection with full penetration — Figure 4 f	Visual testing	100 %
	Surface crack detection	100 %
	Ultrasonic or radiographic testing	100 %
	Hardness test	required
	Macroscopic examination	2 specimens
Fillet weld — Figure 3 and Figure 4 f	Visual testing	100 %
	Surface crack detection	100 %
	Hardness test	required
	Macroscopic examination	2 specimens

1. Introduction

- Extent of testing according to ISO 15614-1:Level 2



T-joint with full penetration

Table 2 — For level 2: Examination and testing of the test pieces

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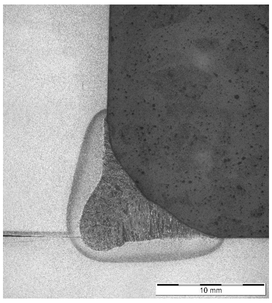
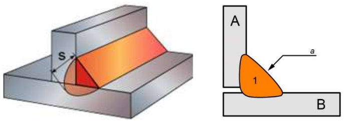
Fillet weld — Figure 3 and Figure 4 f	Visual testing	100 %
	Surface crack detection	100 %
	Hardness test	required
	Macroscopic examination	2 specimens

1. Introduction

- Extent of testing according to ISO 15614-1:Level 2





Fillet Weld (FW)

Table 2 — For level 2: Examination and testing of the test pieces

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	Surface crack detection	100 %
	Transverse tensile test	2 specimens
	Transverse bend test	4 specimens
	Impact test	2 sets
	Hardness test	required
	Macroscopic examination	1 specimen
T- joint with full penetration — Figure 3 Branch connection with full penetration — Figure 4 f	Visual testing	100 %
	Surface crack detection	100 %
	Ultrasonic or radiographic testing	100 %
	Hardness test	required
	Macroscopic examination	2 specimens
Fillet weld — Figure 3 and Figure 4 f	Visual testing	100 %
	Surface crack detection	100 %
	Hardness test	required
	Macroscopic examination	2 specimens

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MATERIALS & WELD TESTING

Tensile testing

INTRODUCTION: BASE MATERIAL

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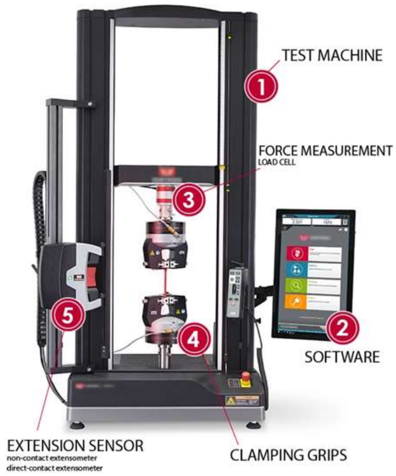
2. Tensile test – BASE MATERIAL

- Tensile test
  - A tensile test applies tensile (pulling) force to a material and measures the specimen's response to the stress.
  - Test specimen (with known dimensions) is mounted into the clamping grips (4) of the test machine (1)
  - A tensile (pulling) force is applied in one-direction
  - The FORCE (kN or N) is measured by a load cell
  - The extension is measured by an extensometer (5)
  - The test is stopped until failure occurs



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2. Tensile test – BASE MATERIAL

- Tensile test

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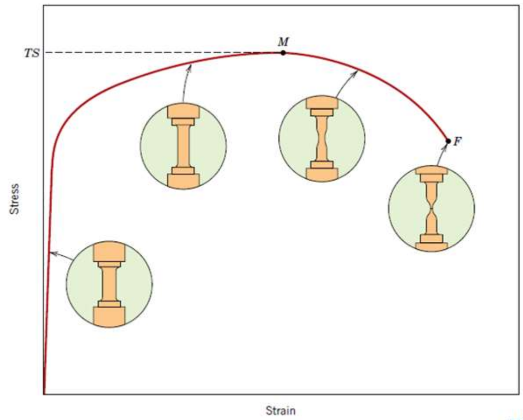
2. Tensile test – BASE MATERIAL

- Response of the test specimen
  - Stress is measured by the load applied divided by the cross sectional area of the test specimen
  - Strain is measured by the extensometer mounted on the test specimen
  - Stress vs strain is typically plotted in a stress-strain curve:
    - Elastic deformation (linear)
    - E + Plastic deformation
    - Necking occurs after a max. value is reached
    - Failure of the test specimen



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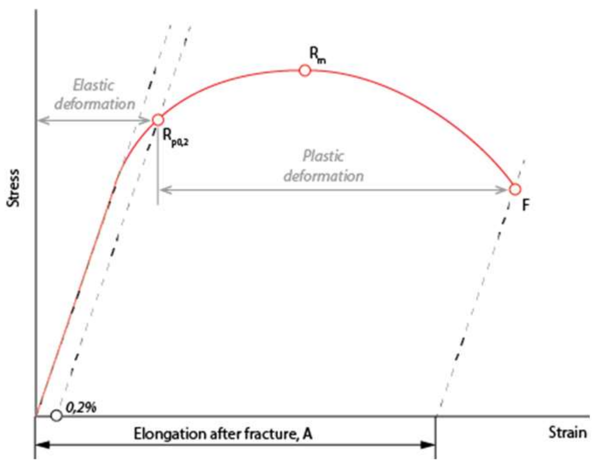
2. Tensile test – BASE MATERIAL

- Mechanical properties to be determined
  - **Strength**: Yield strength, R_{eH} and Tensile strength, R_m
  - **Ductility**: Percentage elongation after fracture, A



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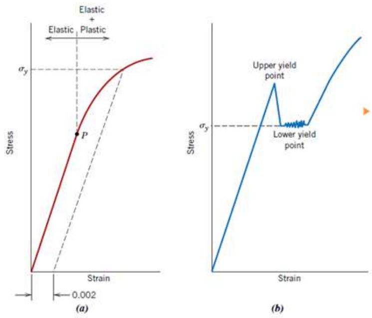
2. Tensile test – BASE MATERIAL

- Yielding and yield strength
  - Most structures are designed to ensure that **only elastic deformation** will result when a stress is applied.
  - A structure or component that has plastically deformed—or experienced a permanent change in shape—may not be capable of functioning as intended.
  - the stress level at which plastic deformation begins, is defined as the yield stress or where the phenomenon of yielding occurs:

Material without yielding phenomena

- Proof strength or offset yield strength is determined by drawing a line parallel to the linear portion of the curve with an offset equal to a prescribed plastic extension
- E.g. 0,2%

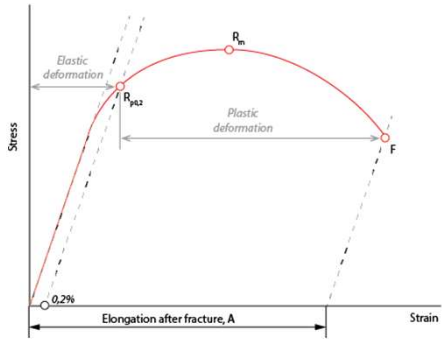


Material with yielding phenomena

- Upper and lower yield point will be determined

2. Tensile test – BASE MATERIAL

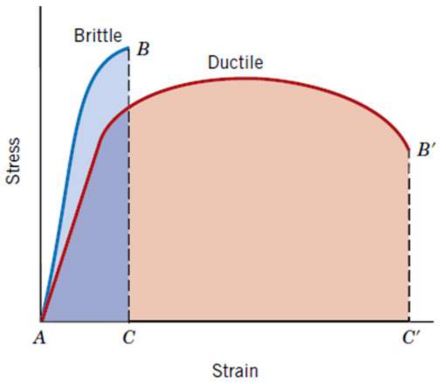
- Tensile strength
  - After yielding, the stress necessary to continue plastic deformation in metals increases to a maximum value, Rm. And then decreases to the eventual fracture, point *F*.
  - The tensile strength is defined as the max. value on the engineering stress-strain curve

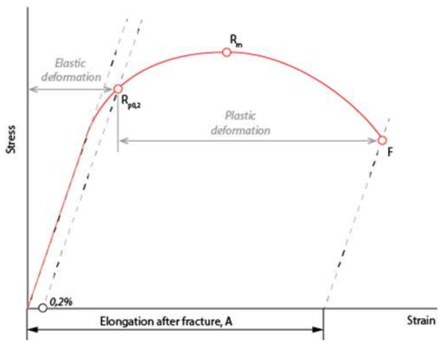


  - If this stress is applied and maintained, the material will fracture and eventually fail.

2. Tensile test – BASE MATERIAL

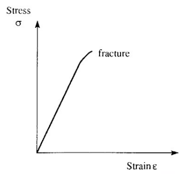
- Ductility
  - It is a measure of the degree of plastic deformation that has been sustained at fracture.
  - Metal that experiences very little or no plastic deformation upon fracture is termed **brittle**.
  - Ductility may be expressed as percent elongation

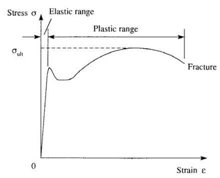




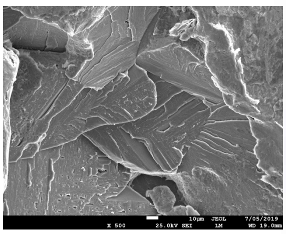
2. Tensile test – BASE MATERIAL

- Ductility

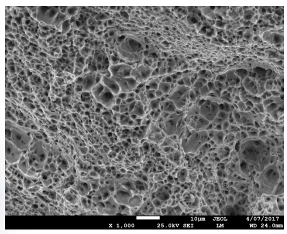




- Brittle fracture
  - Cleavage (rapid crack propagation)
  - No necking
  - Flat shape



- Ductile fracture
  - Micro-voids
  - Necking
  - cup-and-cone shape



2. Tensile test – BASE MATERIAL

- Summary
  - Mechanical properties to be determined
    - Yield strength, R_{eH}
    - Tensile strength, R_m
    - Percentage elongation after fracture, A
  - Tensile test method for metallic materials
    - ISO 6892-1: Method of test at room temperature (23°C ± 5 °C)
    - ISO 6892-2: Method of test at elevated temperature (> room temperature)
    - ISO 6892-3: Method of test at low temperature (From +10°C to -196°C)
  - Requirements can be found in the product standard of the base material

    See ISO/TR 20172 for all European materials

    For example:
    - EN 10025-3: Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels (S275 to S460)

2. Tensile test – BASE MATERIAL

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  - Requirements can be found in the product standard of the base material

    See ISO/TR 20172 for all European materials

    For example:
    - EN 10025-3: Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels (S275 to S460)

Table 5 - Mechanical properties at ambient temperature for normalized steel

Designation		Minimum yield strength R_{eH} [a] MPa [b] Nominal thickness mm								Tensile strength R_m [a] MPa [b] Nominal thickness mm			Minimum percentage elongation after fracture [a] % $L_0 = 5,65 \sqrt{S_0}$ Nominal thickness mm					
According EN 10027-1 and CR 10260	According EN 10027-2	≤ 16	>16 ≤ 40	>40 ≤ 63	> 63 ≤ 80	> 80 ≤ 100	> 100 ≤ 150	> 150 ≤ 200	> 200 ≤ 250	≤ 100	> 100 ≤ 200	> 200 ≤ 250	≤ 16	>16 ≤ 40	>40 ≤ 63	> 63 ≤ 80	> 80 ≤ 200	> 200 ≤ 250
S275N S275NL	1.0490 1.0491	275	265	255	245	235	225	215	205	370 to 510	350 to 480	350 to 480	24	24	24	23	23	23
S355N S355NL	1.0545 1.0546	355	345	335	325	315	295	285	275	470 to 630	450 to 600	450 to 600	22	22	22	21	21	21

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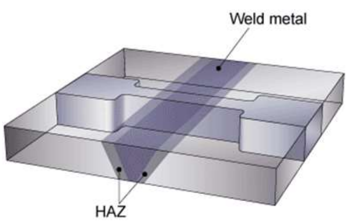
MATERIALS & WELD TESTING

Tensile testing

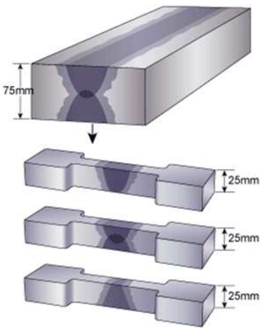
WELDED JOINTS

2. Tensile test – WELDED JOINT

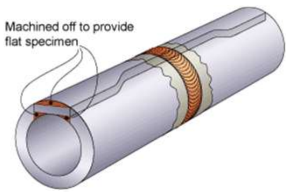
- Flat tensile test specimens will be machined so that the following 'zones' are tested:
  - Both parent metals
  - Both Heat Affected Zones (HAZ)
  - Weld metal



Full thickness transverse tensile test



Multiple tensile tests performed to ensure the full thickness is tested



Flat cross joint tensile specimen machined from tube

2. Tensile test – WELDED JOINT

Destructive testing

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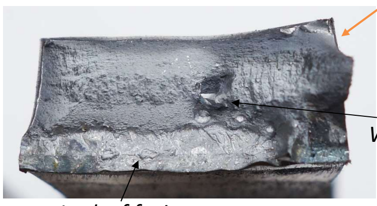
2. Tensile test – WELDED JOINT

- Mechanical property to be determined:
  - Tensile strength

Note! Transverse tensile test of a welded joints involves testing of 3 different areas (BM, WM and HAZ) with each there own mechanical properties. Therefore, measuring of yield strength and elongation is not performed as the result would be inaccurate and unreliable.

Additionally:

- Location of fracture will be reported
- Fracture surface will be observed for welding imperfections



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2. Tensile test – WELDED JOINT

- Requirement according to ISO 15614-1:
  - The tensile strength of the test specimen shall **not be less** than the corresponding **specified minimum value** for the **parent metal** unless otherwise specified prior to testing.
    - If the tensile test specimen fails in the parent metal, the test specimen comply with the above requirement

Example 1:

- If the tensile test specimen fails in the welded material, the measured tensile strength shall be compared to the minimum value for the parent metal

Example 2:

BM 1: S355
***470 MPa** < Rm < 630 MPa*

Rm = 540 MPa
Acceptable

Rm = 380 MPa
Not-Acceptable

BM 2: S355
***470 MPa** < Rm < 630 MPa*

2. Tensile test – WELDED JOINT

- Requirement according to ISO 15614-1:
  - For dissimilar parent metal joints, the tensile strength shall not be less than the minimum value specified for the parent material having the lowest tensile strength.

Example 3:

BM 1: S460Q
***550 MPa** < Rm < 720 MPa*

Rm = 540 MPa
Not-Acceptable

Rm = 380 MPa
Not-Acceptable

Rm = 620 MPa
Acceptable

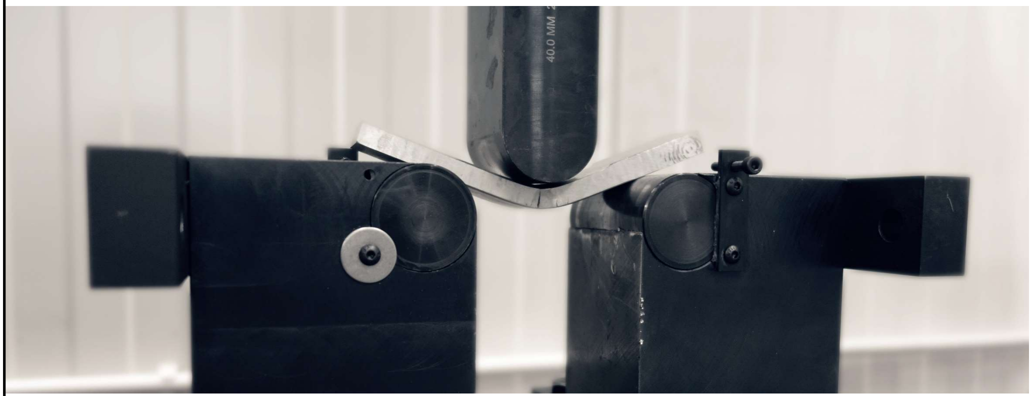
BM 2: S690QL
***770 MPa** < Rm < 940 MPa*

2. Tensile test – WELDED JOINT

- Summary
  - Mechanical properties to be determined
    - Tensile strength, R_m
  - Tensile test method for metallic materials
    - ISO 4136: Destructive tests on welds in metallic materials — Transverse tensile test
  - Requirement
    - Acc. ISO 15614-1: Tensile strength of the test specimen shall not be less than the corresponding specified minimum value for the parent metal.
    - Or customer requirements (design value)

MATERIALS & WELD TESTING

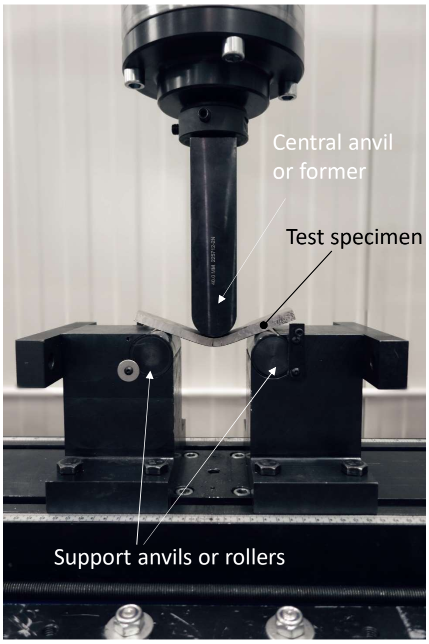
Destructive Testing of welded joints



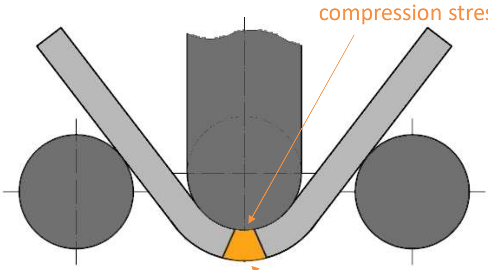
BEND TESTING

3. Bend Test

- A bend test specimen, containing a weld, is placed on 2 lower support anvils
- It is bend by applying a force through the central anvil, until a bend angle of 180° is reached.
- After the test, the test specimen is visually inspected in order to:
  - Verify the ductility of the material
  - Reveal the presence of welding imperfections like
    - Cracks
    - Lack of fusion
    - Porosities
    - …



3. Bend Test



- Ductility or applied elongation is determined by the Diameter of former & rollers and the thickness of the test specimen
  - Equal to 4 x thickness of the test specimen for base material with elongation A ≥ 20%
  - Base material with elongation < 20%, the following formula shall be applied:

$$d = \frac{100 \times t_s}{A} - t_s$$

- **A** required elongation (e.g. 15%)
- t_s thickness of the test specimen
- **d** diameter of the former/roller

3. Bend Test

- A bend test of friction stir weld (Acceptable)

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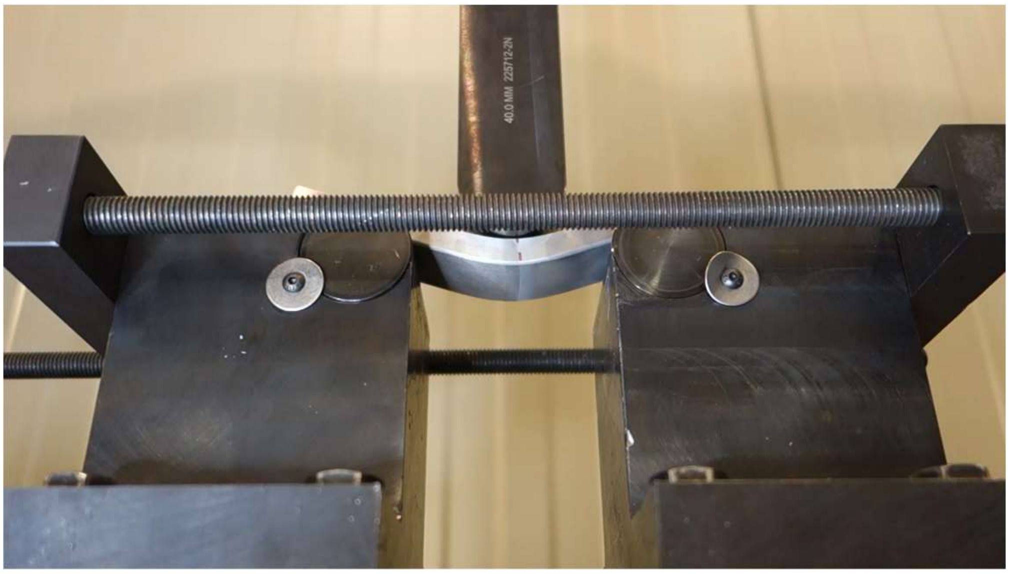
3. Bend Test

- A bend test of friction stir weld (Not-Acceptable)

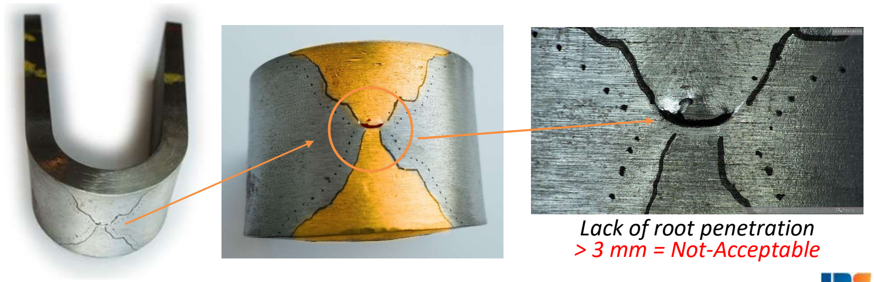


40

3. Bend Test

- Requirement according to ISO 15614-1:
  - During testing, the test specimens shall not reveal any imperfection **>3 mm** in any direction.
    - Remember the acceptable tensile test of double sided butt weld (BW)?

    - Bend test results:



Lack of root penetration
> 3 mm = Not-Acceptable

3. Bend test

- Summary
  - Mechanical properties to be applied
    - elongation, A
  - Tensile test method for weld in metallic materials
    - ISO 5173: Bend tests
  - Requirement:
    - Acc. to ISO 15614-1: During testing, the test specimens shall not reveal any imperfection >3 mm in any direction.
    - This is done by a visual inspection and measurement of cracks found on the bend test specimen, after bending.

- ONDERZOEK
- ADVIES
- OPLEIDING
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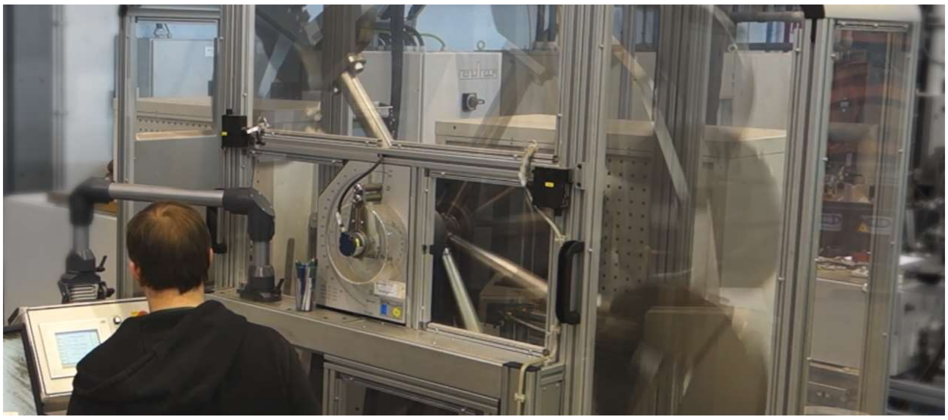
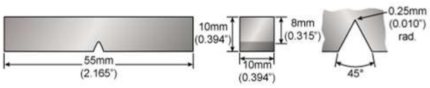
MATERIALS & WELD TESTING

Destructive Testing of welded joints

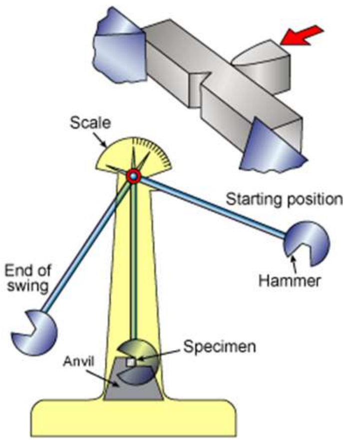


IMPACT TESTING

4. Impact test

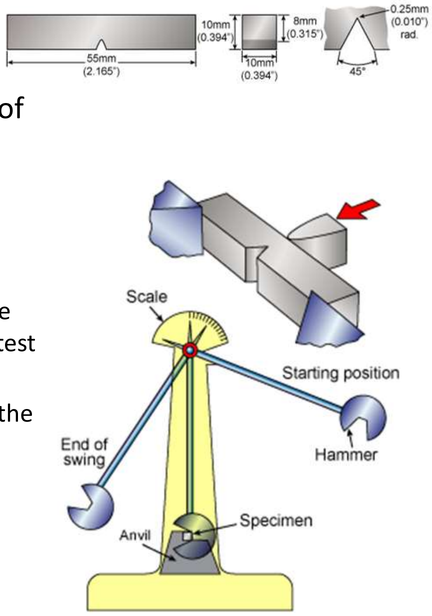


- An impact test measures the energy absorbed (toughness) during the fracture of a specimen with standard dimensions and geometry when subjected to very rapid (impact) loading.
- Test sequence
  - Standard test specimens with dimensions of 10 x 10 x 55 mm are machined
  - A V-Notch with a depth of 2 mm is machined in the test specimen in order to obtain a local stress-concentration
  - Test specimens are cooled down to a pre-defined test temperature (e.g. -20°C)
  - One by one, a test specimen is placed into the Charpy impact testing machine as shown
  - The specimen is fractured and the pendulum swings through



4. Impact test

- An impact test measures the energy absorbed (toughness) during the fracture of a specimen with standard dimensions and geometry when subjected to very rapid (impact) loading.
- Test sequence
  - The height of the swing being a measure of the amount of energy absorbed by fracturing the test specimen
  - Conventionally three specimens are tested at the desired test temperature

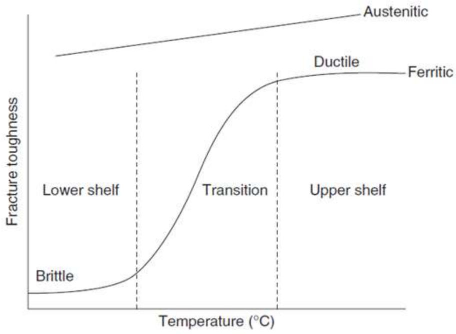


4. Impact test

4. Impact test

- Brittle vs ductile (mild steels)
  - If impact testing is carried out over a range of temperatures the results of energy absorbed versus temperature can be plotted






You would like a Transition Temperature as low as possible. For the Liberty-ships this temperature was above 0°C

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4. Impact test

- **Requirement acc. ISO 15614-1:**
- The average value of the three specimens shall meet the specified requirements. For <u>each notch location</u>, one individual value may be below the <u>minimum average value specified</u>, provided that it is not less than 70 % of that value.
- Min. average value specified:
  - Specified by the customer (customer requirement) or product standard
  - Specified by the base material product standard:
    - S235JR (27J @20°C)
    - S235K2 (40J @-20°C)
    - S235J2 (27J @-20°C)
    - S235L6 (60J @-60°C)

Impact property Energy Joules (J)			Test tempe-rature
27J	40J	60J	°C
JR	KR	LR	20
J0	K0	L0	0
J2	K2	L2	-20
J3	K3	L3	-30
J4	K4	L4	-40
J5	K5	L5	-50
J6	K6	L6	-60

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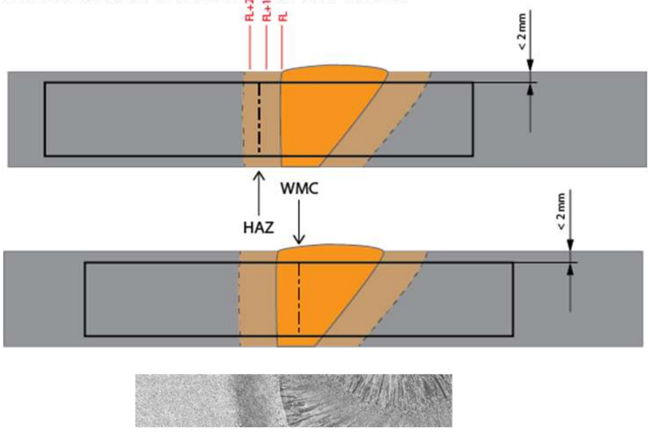
4. Impact test

- Notch location
  - WM: mid-point of the notch shall be at the weld centreline
  - HAZ: mid-point of the notch shall be at 1 mm to 2 mm from the fusion line
- Sampling of the test specimens:
  - Specimens shall be sampled from a maximum of 2 mm below the upper surface of the parent metal and transverse to the weld.



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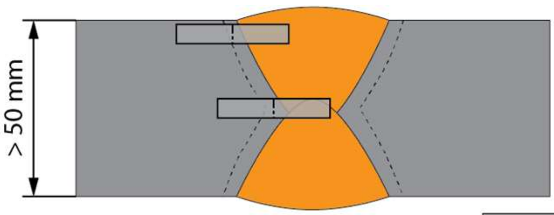
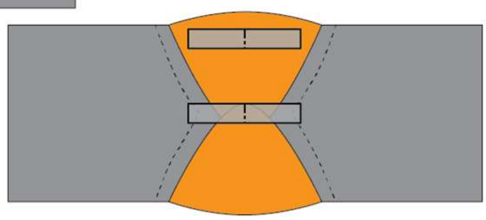
4. Impact test

- For butt joints where the material thickness is t > 50 mm,
  - two additional sets of specimens shall be taken from the root area
    - one set taken in the weld
    - one set taken from the HAZ



Notch locations in HAZ



Notch locations in WMC

50

4. Impact test

- Summary
  - Mechanical properties to be determined
    - Impact absorbed energy (Joule)
  - Tensile test method for weld in metallic materials
    - ISO 9016: Impact tests
  - Requirement acc. ISO 15614-1:
    - The average value of the three specimens shall meet the specified requirements
    - For each notch location, one individual value may be below the minimum average value specified, provided that it is not less than 70 % of that value.

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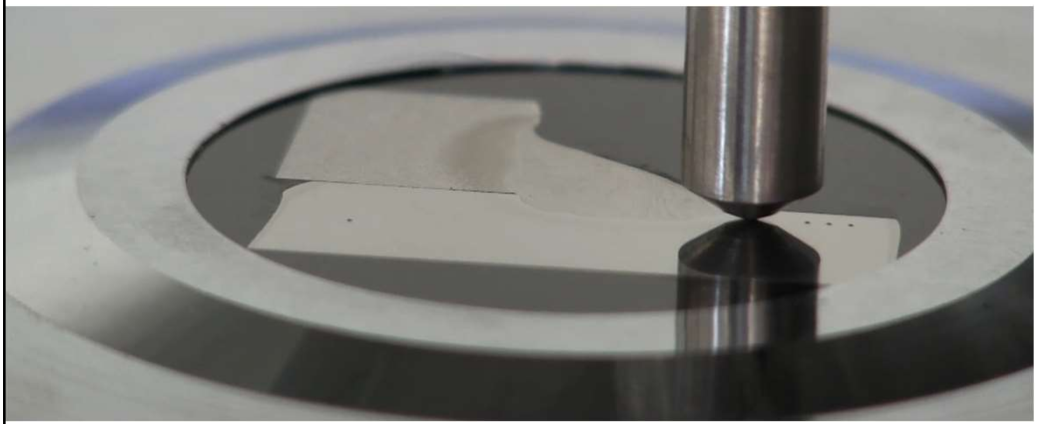
MATERIALS & WELD TESTING

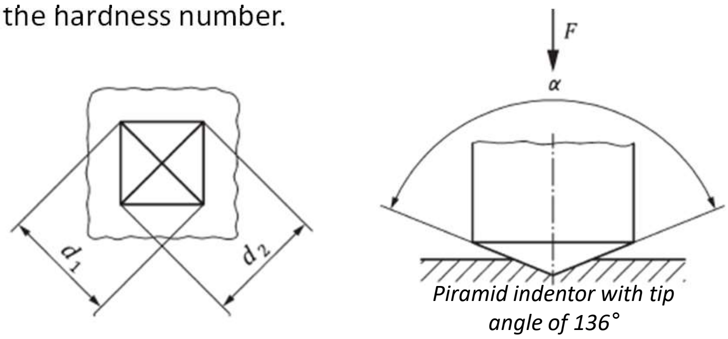
Destructive Testing of welded joints



HARDNESS VICKERS TEST

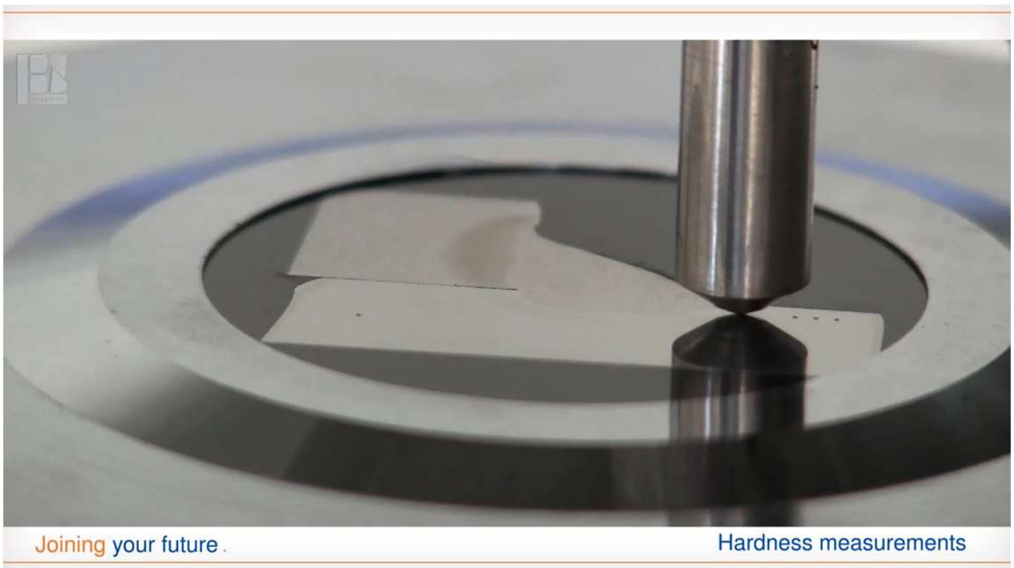
5. Hardness Vickers test – HV

- Hardness Vickers (HV) test measures the resistance to localized plastic deformation of a material or microstructure by using a diamond indenter, with a pyramid shape to make an indentation
- After 10 – 15 seconds the test force is removed, the diagonal lengths of the indentation left in the surface of the resulting indentation is measured and related to a hardness number – (e.g. 215 HV10)
- The softer the material, the larger and deeper the indentation, and the lower the hardness number.



Piramid indentor with tip angle of 136°

5. Hardness Vickers test – HV



5. Hardness Vickers test – HV

- Vickers hardness is calculated by the use of 2 parameters

$$\text{Vickers hardness} \approx 0{,}1891 \times \frac{F}{d^2}$$

  - Test force, F in newtons (N)
    - HV10 = test force of 10 kg or 100N
    - HV1 = test force of 1 kg or 10N
    - HV0,1 to HV100 possible
  - Average value of the two diagonal lengths d_1 and d_2 (mm)

- Vickers Hardness measurements are used to
  - Estimate the ultimate tensile strength of carbon steels
  - For welds, control of hardness is important to ensure that hydrogen cracking does not occur. Hard brittle microstructures that are susceptible to hydrogen cracking such as martensite are unlikely.
    - Therefore, hardness measurements will be made on a cross-section of the welded joint at a location where the highest cooling rates are expected (weld start location)

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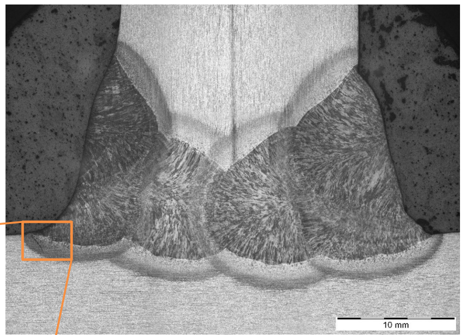
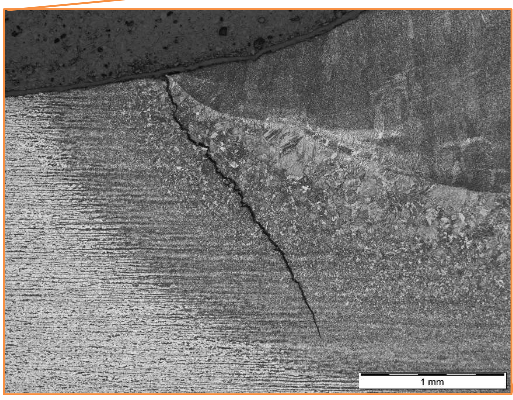
5. Hardness Vickers test - HV

- Example case
  - HV10 values of above 400 have been measured in the HAZ of a welded T-joint.
  - Martensitic microstructure was observed





- Even more critical, (hydrogen) cracks could be found

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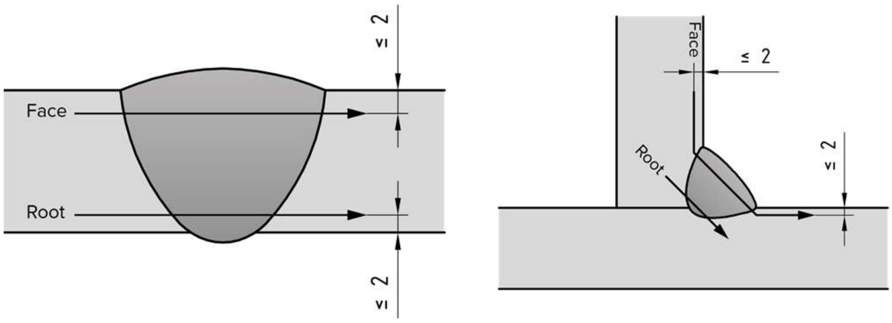
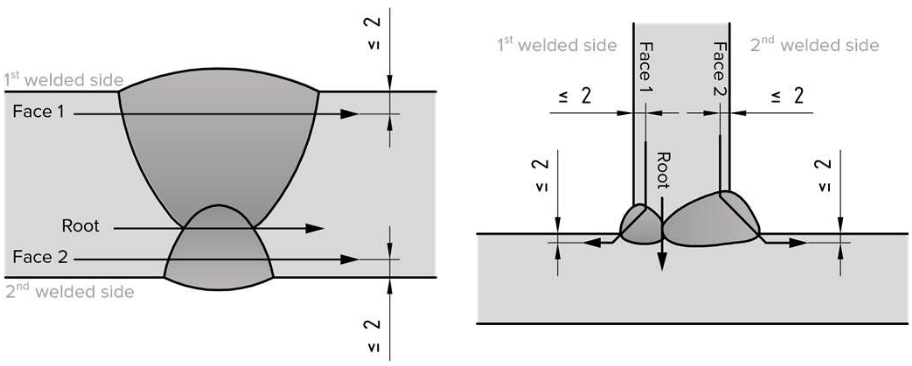
5. Hardness Vickers test - HV

- Hardness measurements according to ISO 15614-1
  - For weld thicknesses less than or equal to 5 mm, only one row of indentations shall be made at a depth of up to 2 mm below the upper surface of the welded joint.
  - For weld thicknesses over 5 mm, one row of indentation from each side shall be made at a depth of up to 2 mm from the surface.



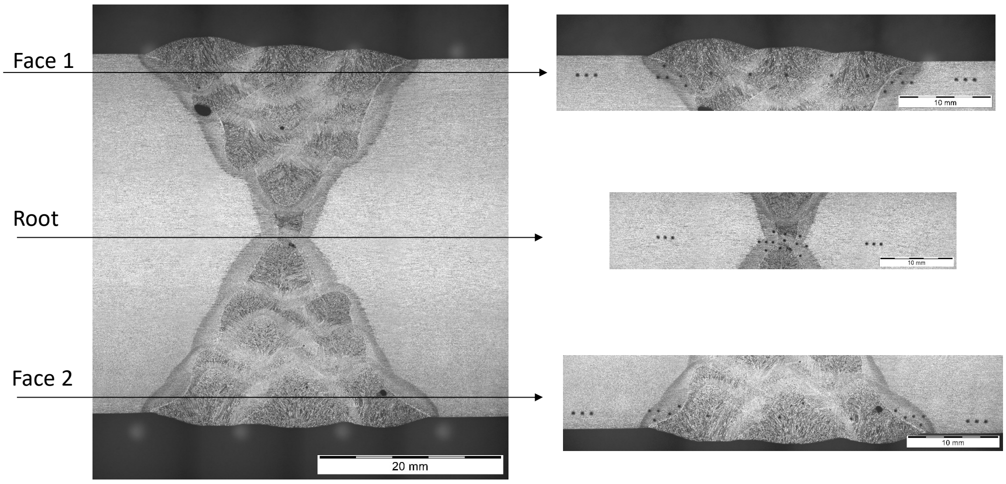
5. Hardness Vickers test - HV

- Hardness measurements according to ISO 15614-1
  - For double sided welds, one additional row of indentations shall be made through the root area.



5. Hardness Vickers test - HV

- Hardness measurements according to ISO 15614-1
  - Example of double sided weld



5. Hardness Vickers test - HV

- Requirements according to ISO 15614-1
  - Depending upon the used base material and application of a Post Weld Heat Treatment (PWHT) (Yes/No)

Steel groups ISO/TR 15608	Non-heat treated	Heat treated
1[a], 2[b]	380	320
3[b]	450	380
4, 5	380[c]	350[c]
6	—	350
9.1	350	300
9.2	450	350
9.3	450	350

[a] If hardness tests are required.
[b] For steels with min R_{eH} > 890 MPa, special values shall be specified.
[c] For certain materials, higher values may be accepted, if specified before the welding procedure test.

  - Note! Requirements for groups 6 (non-heat treated), 7, 10 and 11 and any dissimilar metal joints shall be specified prior to testing.

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Destructive Testing of welded joints

MACROSCOPIC EXAMINATION

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6. Macroscopic Examination

- A macrographic cross-section taken from the weld is often called simply a 'macro'.
- It is a full thickness slice through the weld, polished and etched to reveal the shape and microstructure of the weld.
  - macro specimen surface is **first ground** flat using a series of successively finer wet grit silicon carbide papers (Grid 120 – Grid 1200).
  - **subsequent polishing** is carried out using fine particle diamond paste on a cloth-covered polishing wheel.
  - The polishing removes all the grinding scratches, and the macro specimen has a mirror finish at this stage.
  - Macro specimen is etched in order to reveal their microstructures

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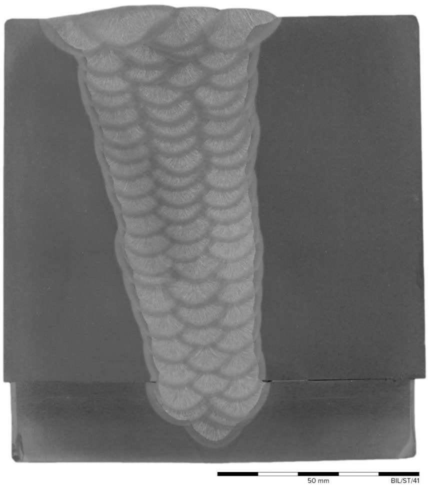
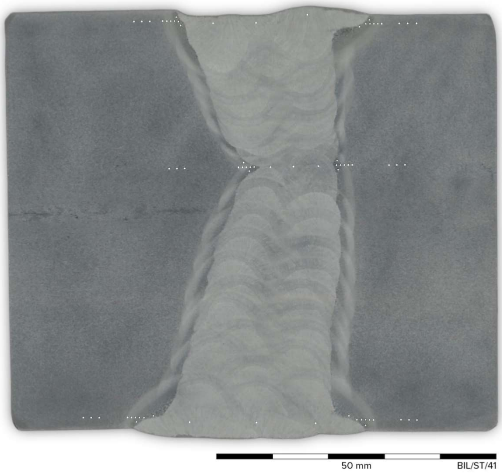
6. Macroscopic Examination

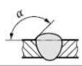
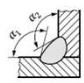
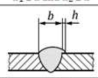
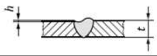
- Examples of macroscopic samples of welded joints





6. Macroscopic Examination

- After etching, the macroscopic sample is evaluated according to the specified quality levels acc. to ISO 5817:
  - <u>Level B</u>: highest weld quality
  - <u>Level C</u>: intermediate weld quality
  - <u>Level D</u>: lowest weld quality

No.	Reference to ISO 6520-1	Imperfection designation	Remarks	t mm	Limits for imperfections for quality levels D	C	B
1.12	505	Incorrect weld toe	— butt welds 	≥ 0,5	$\alpha \geq 90°$	$\alpha \geq 110°$	$\alpha \geq 150°$
			— fillet welds  $\alpha_1 \geq \alpha$ and $\alpha_2 \geq \alpha$	≥ 0,5	$\alpha \geq 90°$	$\alpha \geq 100°$	$\alpha \geq 110°$
1.13	506	Overlap		≥ 0,5	$h \leq 0{,}2\ b$	Not permitted	Not permitted
1.14	509	Sagging	Smooth transition is required	0,5 to 3	Short imperfections: $h \leq 0{,}25\ t$	Short imperfections: $h \leq 0{,}1\ t$	Not permitted
	511	Incompletely filled groove		> 3	Short imperfections: $h \leq 0{,}25\ t$, but max. 2 mm	Short imperfections: $h \leq 0{,}1\ t$, but max. 1 mm	Short imperfections: $h \leq 0{,}05\ t$, but max. 0,5 mm

6. Macroscopic Examination

- For weld procedure qualification, the limits for imperfections as specified acc. ISO 15614-1 apply

Table 4 — Acceptance levels for imperfections

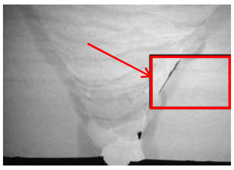
ISO 5817 Ref. no.	ISO 6520-1 Ref. no.	Designation	Level 1	Level 2 Quality level to ISO 5817
1.1	100	Crack	Not permitted	B (not permitted)
1.5	401	Lack of fusion (incomplete fusion)	Not permitted	B (not permitted)
1.6	4021	Incomplete root penetration	Not permitted	B (not permitted)
1.7	5011 5012	Continuous undercut Intermittent undercut	No specific requirements	C
1.9	502	Excess weld metal (butt weld)	No specific requirements	C
1.10	503	Excessive convexity (fillet weld)	No specific requirements	C
1.11	504	Excess penetration	No specific requirements	C
1.12	505	Incorrect weld toe	No specific requirements	C
1.16	512	Excessive asymmetry of fillet weld (excessive unequal leg length)	h ≤ 3 mm	B
1.21	5214	Excessive throat thickness	No specific requirements	C
—	—	All other imperfections[a]	No specific requirements	B

[a] If required by the application standard or specified, micro crack sensitive materials may need specific examination.

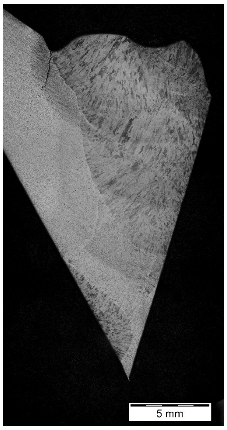
- For production welds, usually Level C is applied

6. Macroscopic Examination

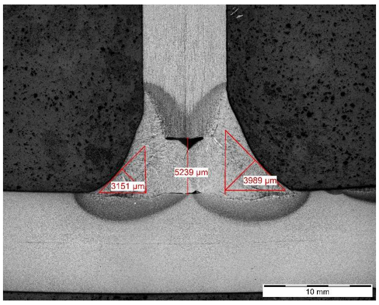
- Examples of welding imperfections



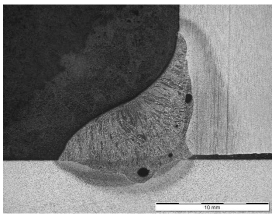
Lack of sidewall fusion



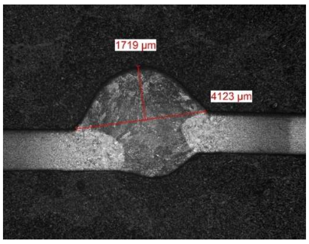
Crack



Lack of fusion



Porosities



Excess weld metal

Contact

ing. Nelis Vandermeiren, IWE
Project Engineer
T +32 (0)9 292 14 25
nelis.vandermeiren@bil-ibs.be

Belgisch Instituut voor Lastechniek vzw
Technologiepark-Zwijnaarde 48, B-9052 Zwijnaarde
info@bil-ibs.be | www.bil-ibs.be

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