PART I (Technology): Basic of welding tehnology

2016-1-RO01-KA202-024508

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PART I (Technology): Basic of welding tehnology

1. GENERAL WELDING ASPECTS

1.1 Classification and schematic presentation of welding processes

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Aim & Objectives

Module Aim:	Provide basic knowledge about classification of welding processes
Number of hours:	1 hour
Learning Outcomes:	• Welding processes classification • Arc welding processes (TIG, MAG, MMA etc.)
ECVET:	

Lecture Outline

- This lecture deals with classification and schematic presentation of welding processes.

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Section 1. A master chart of welding processes

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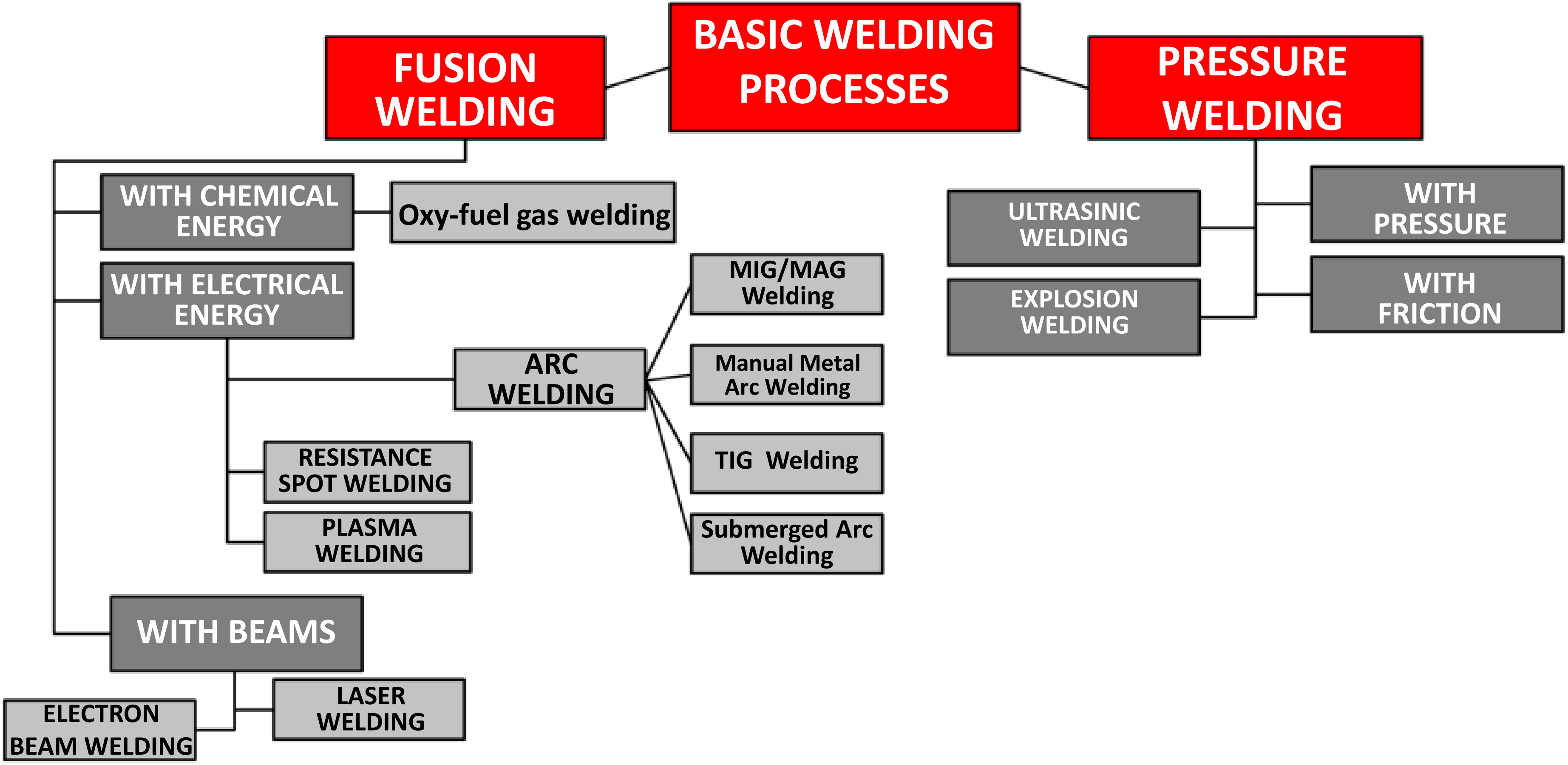
A master chart of welding processes



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Section 2. Schematic presentation of fusion welding processes

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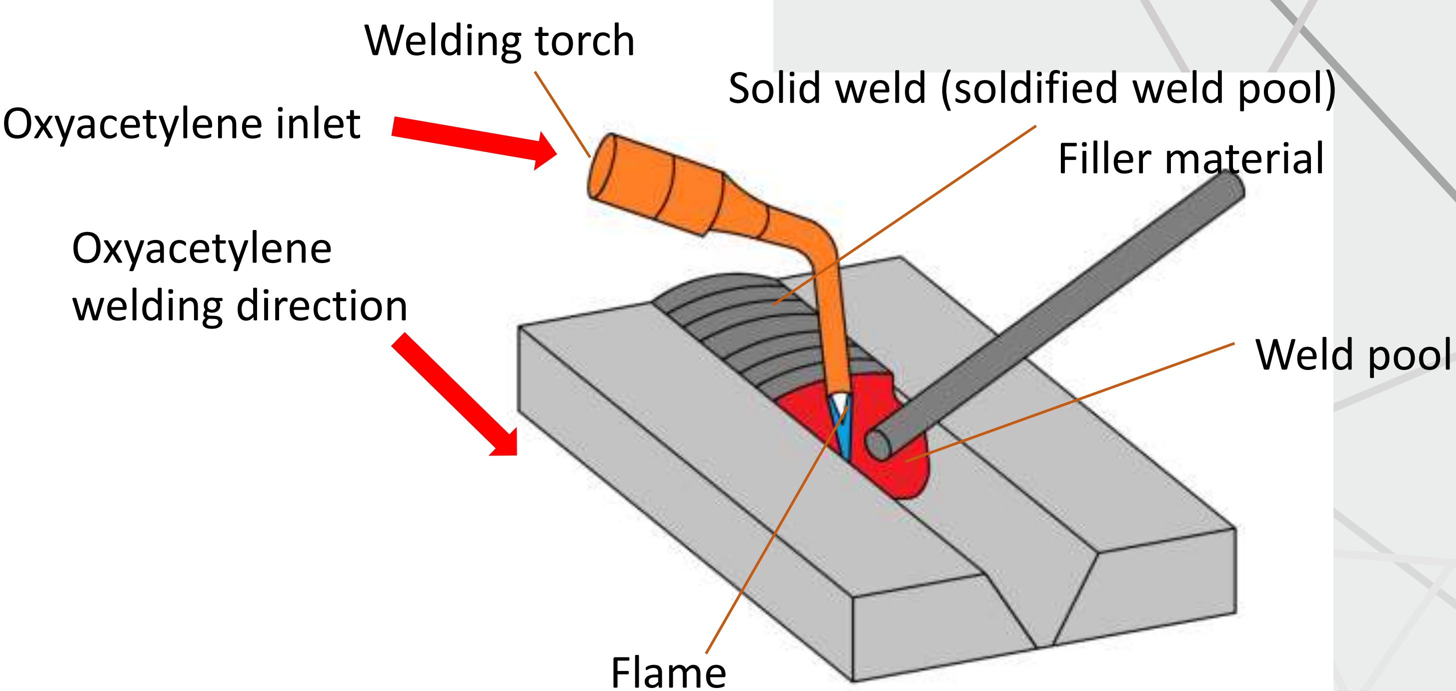
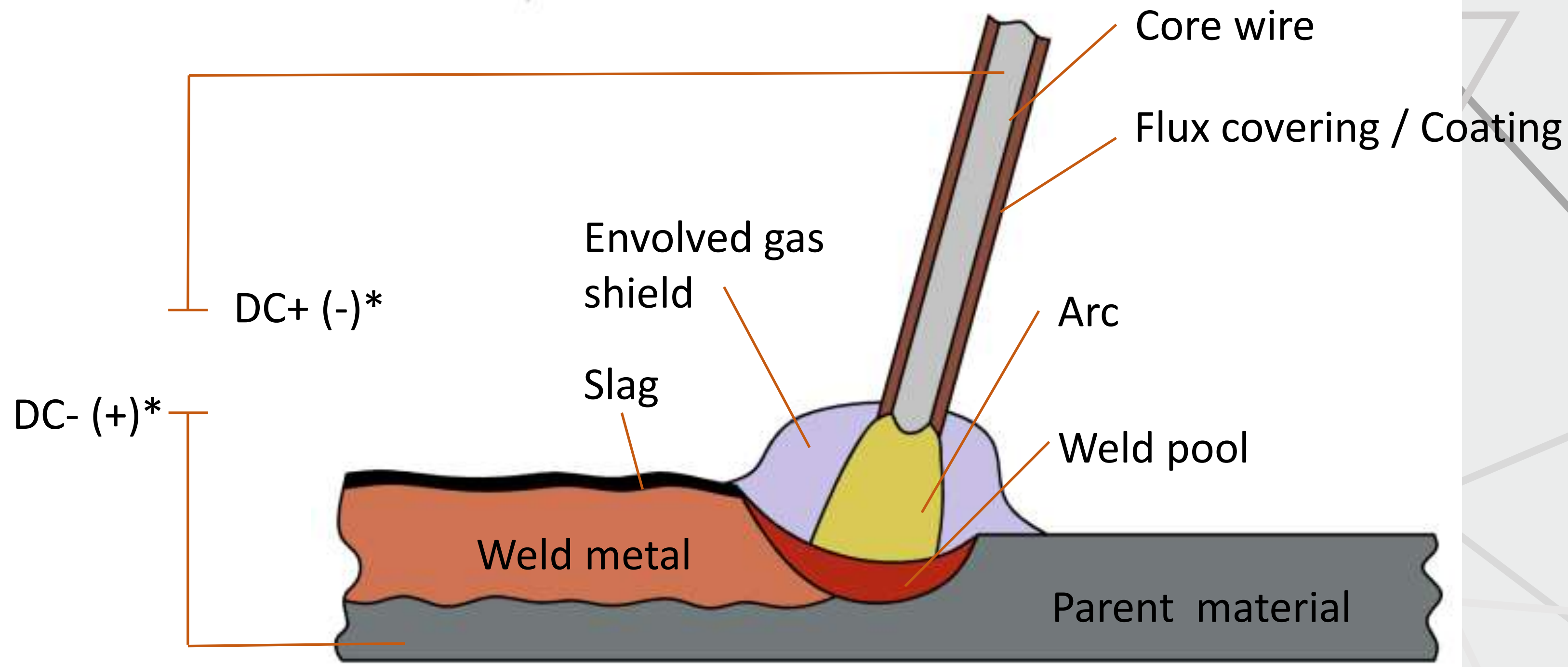
FUSION WELDING

- OXY-GAS WELDING (Oxyacetylene welding - 311)



FUSION WELDING

- Manual Metal Arc (MMA) WELDING (111)



*** Current type and polarity is based on flux covering type. Must see manufacturer instructions!!**

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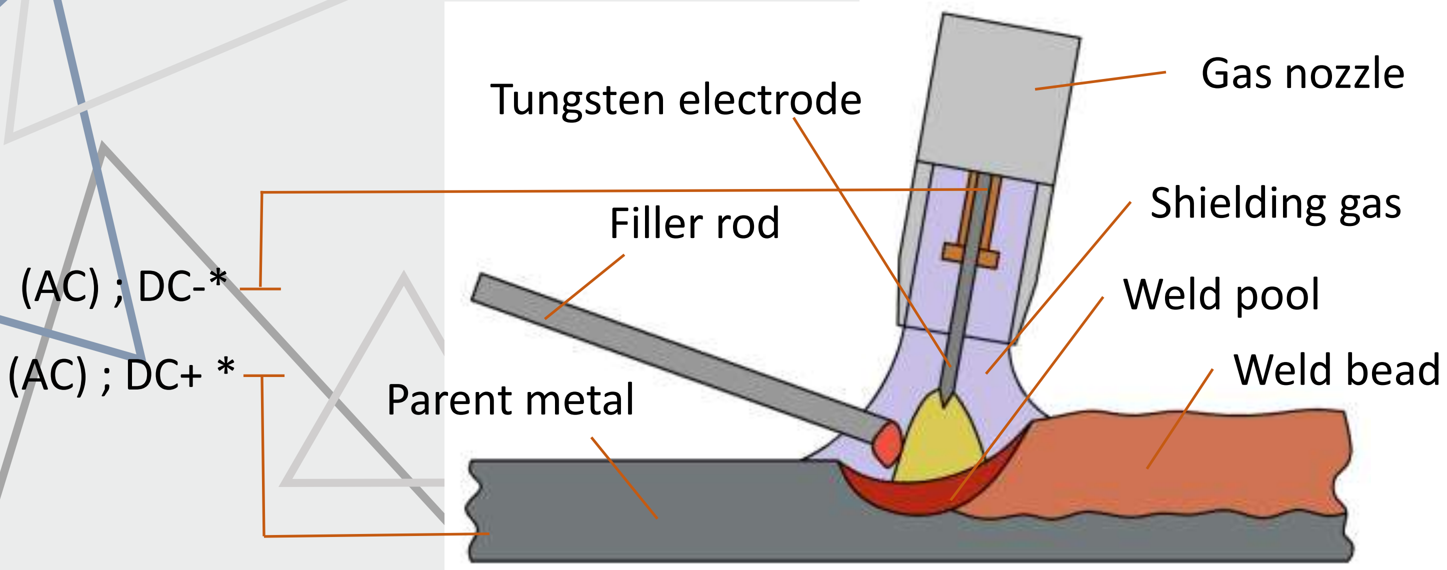
FUSION WELDING

- Gas-shielded arc welding with non-consumable tungsten electrode (14) - TIG WELDING

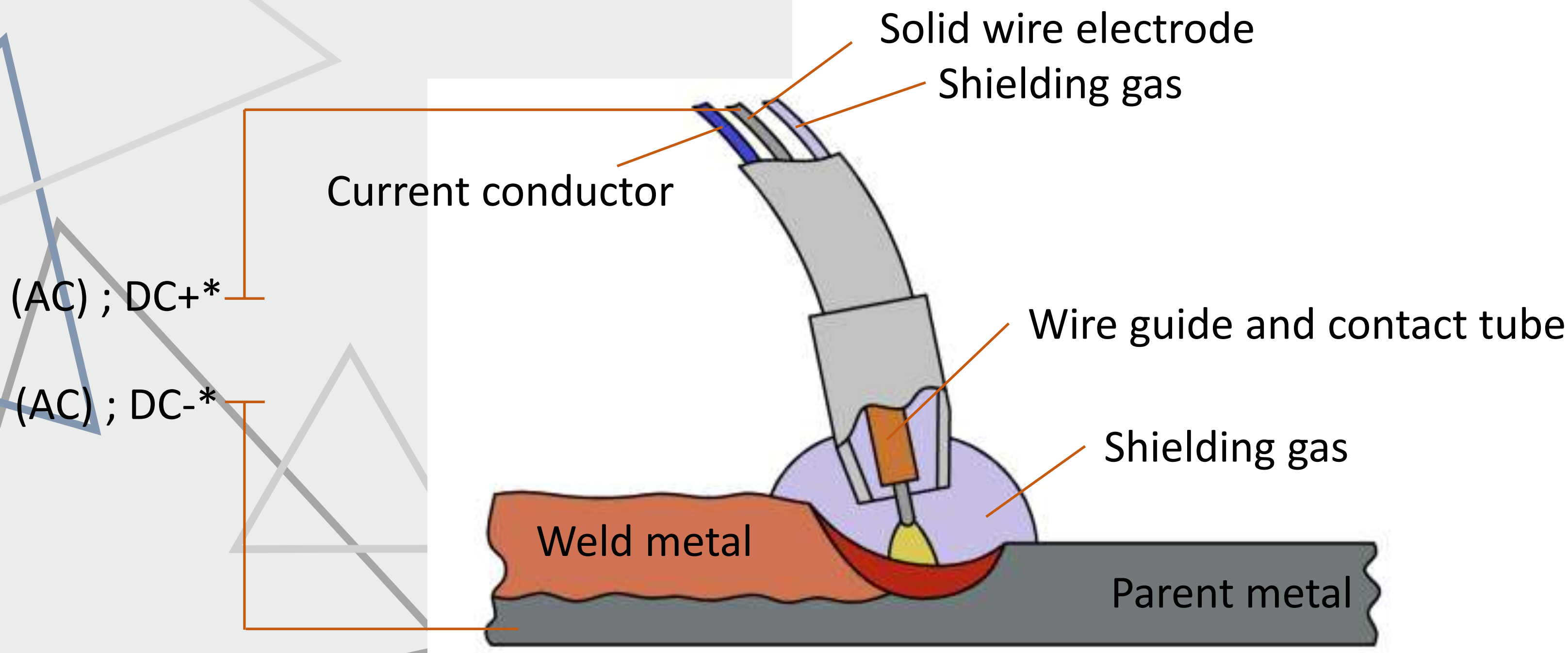
Processes: 142, 143, 145, 146, 147



*** Current type and polarity must be adapted to basic material. Aluminium and Magnesium must be set to AC current. In other cases Tungsten electrode (welding torch) must be set to DC- !**

FUSION WELDING

- Gas-shielded metal arc welding (13) – MAG (GMAW) WELDING - Processes: 131, 132, 133, 135, 136, 137

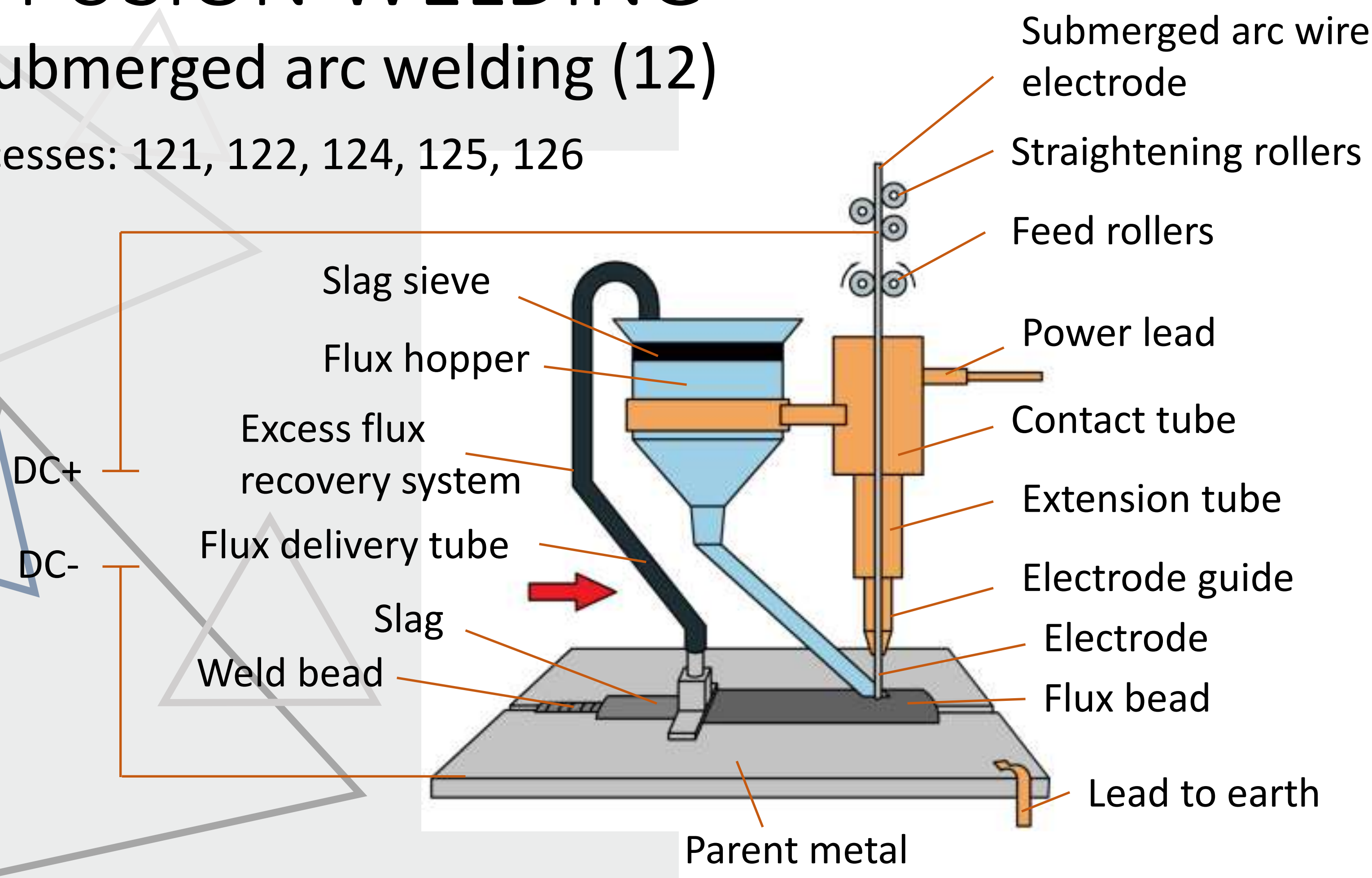


*** In most cases the used current type and polarity for MAG welding processes is DC+ on solid wire electrode. In some cases (welding of aluminium) the current is set to AC.**

FUSION WELDING

- Submerged arc welding (12)

Processes: 121, 122, 124, 125, 126



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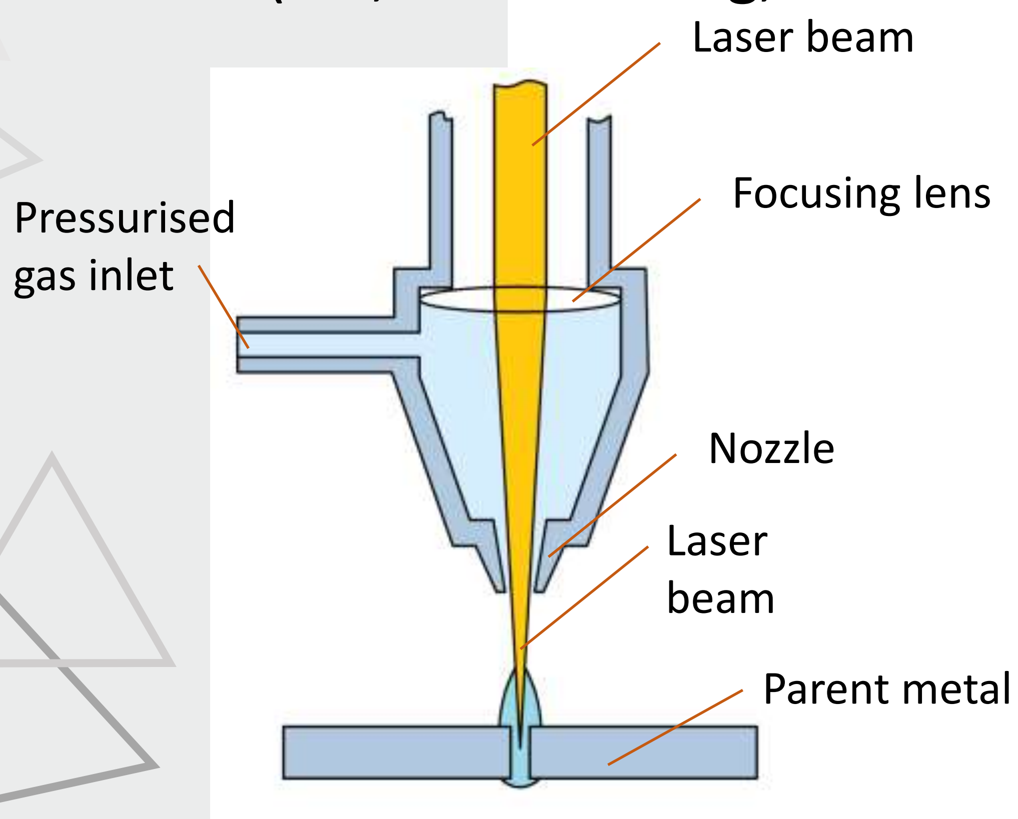
FUSION WELDING

- LASER WELDING (52 ;521 – Nd-Yag, 522 – CO2)

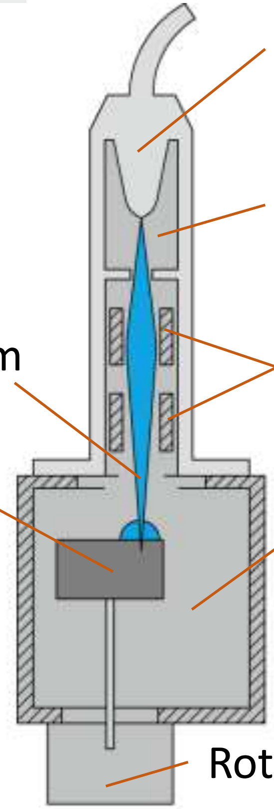


FUSION WELDING

- ELECTRON BEAM WELDING (51);

511- in vacuum; 512 - in atmosphere;

513 - with addition of shielding gases



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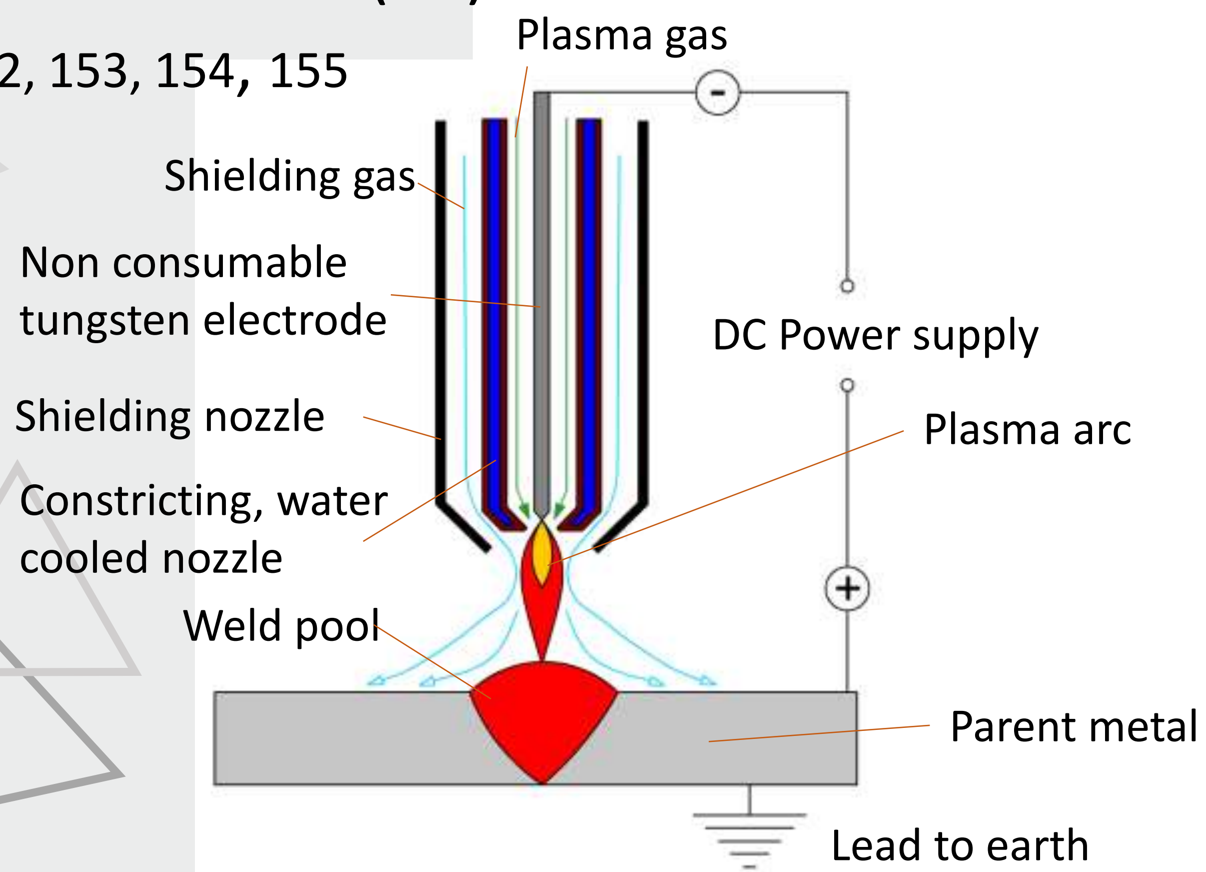
FUSION WELDING

- PLASMA ARC WELDING (15)

Processes: 151, 152, 153, 154, 155



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Useful Topic Related Links

OXY-GAS WELDING

MMA WELDING

MAG WELDING

SUBMERGED ARC WELDING (SAW)

LASER BEAM WELDING

ELECTRON BEAM WELDING

PLASMA ARC WELDING

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PART I (Technology): Basic of welding tehnology

1. GENERAL WELDING ASPECTS

1.2. Reference numbers of welding processes (EN ISO 4063)

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Aim & Objectives

Module Aim:	Provide basic knowledge about reference numbers used for welding processes
Number of hours:	1 hour
Learning Outcomes:	• Understanding of Reference numbers
ECVET:	

Lecture Outline

- This lecture deals with reference numbers used in welding processes.

1. General welding aspects

1.2 Reference numbers used for welding processes (EN ISO 4063)

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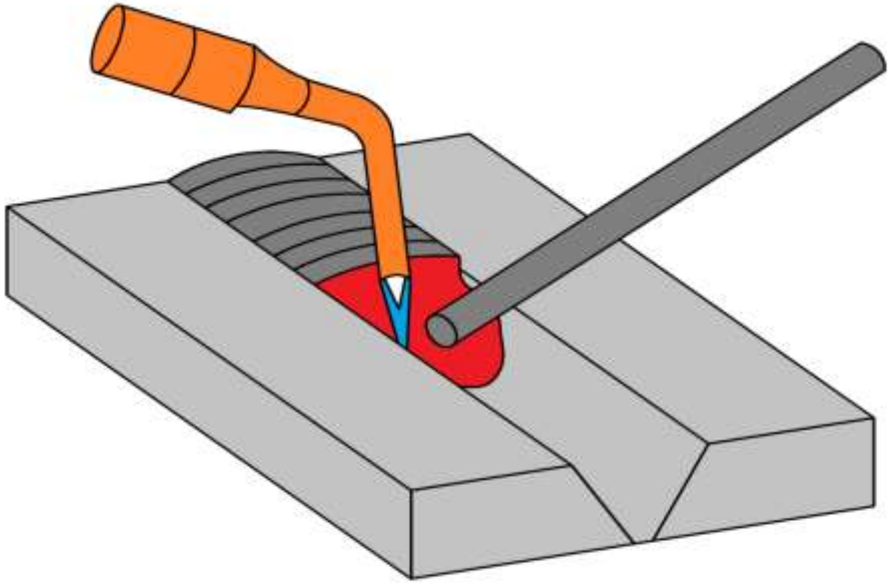
Reference numbers of basic welding processes (EN ISO 4063)

- Oxyacetylene welding

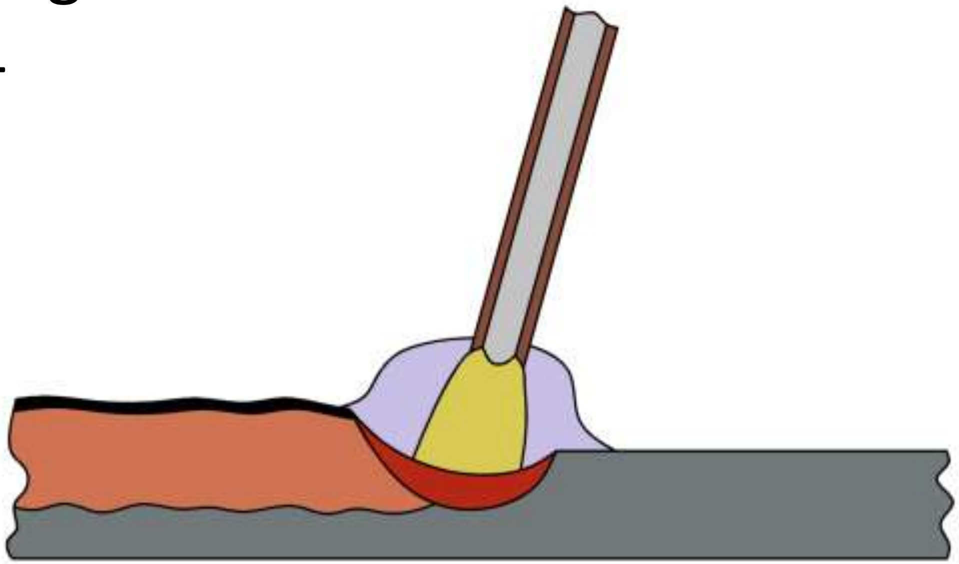
- Reference number: 311



Reference numbers of basic welding processes (EN ISO 4063)

- Manual metal arc welding
  Reference number: 111

- Common abbreviation:
  MMA welding



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Reference numbers of basic welding processes (EN ISO 4063)

14 = Gas-shielded arc welding with non-consumable tungsten electrode

141 = TIG welding with solid filler material (wire/rod)

142 = Autogeneous TIG welding

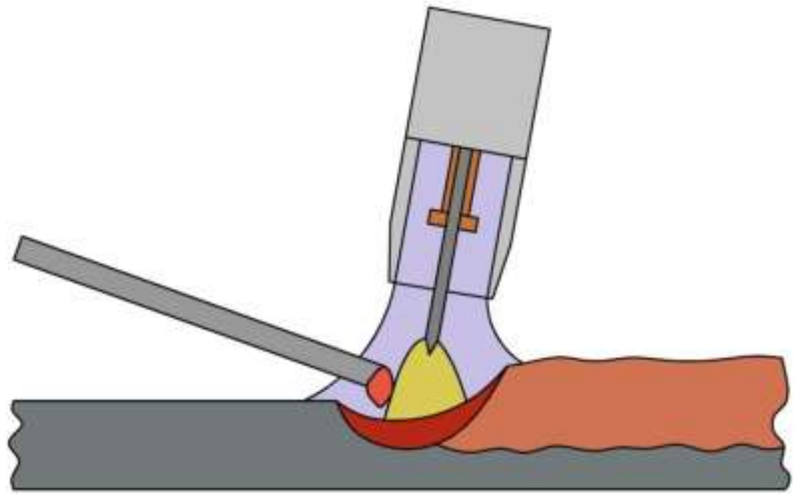
143 = TIG welding with tubular cored filler material (wire/rod)

145 = TIG welding using reducing gas and solid filler material (wire/rod)

146 = TIG welding using reducing gas and tubular cored filler material (wire/rod)

14 = Gas-shielded arc welding with non-consumable tungsten electrode using active gas (TAG welding)

- TIG WELDING



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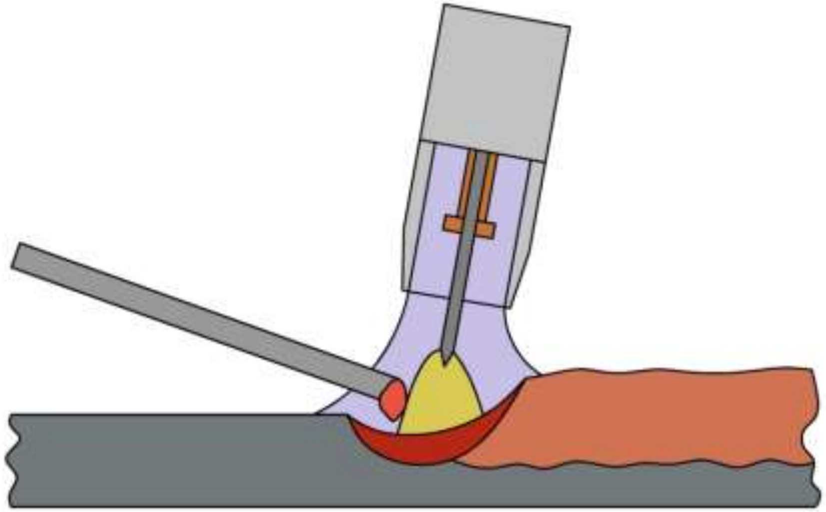
Reference numbers of basic welding processes (EN ISO 4063)

- MIG welding with solid wire electrode, 131
- MAG welding with solid wire electrode, 135
- MIG welding with flux cored electrode, 132
- MAG welding with flux cored electrode, 136
- MIG welding with metal cored electrode, 133
- MAG welding with metalcored electrode, 138



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Reference numbers of basic welding processes (EN ISO 4063)

12 = Submerged arc welding; abbreviated as SAW

121 = Submerged arc welding with solid wire electrode

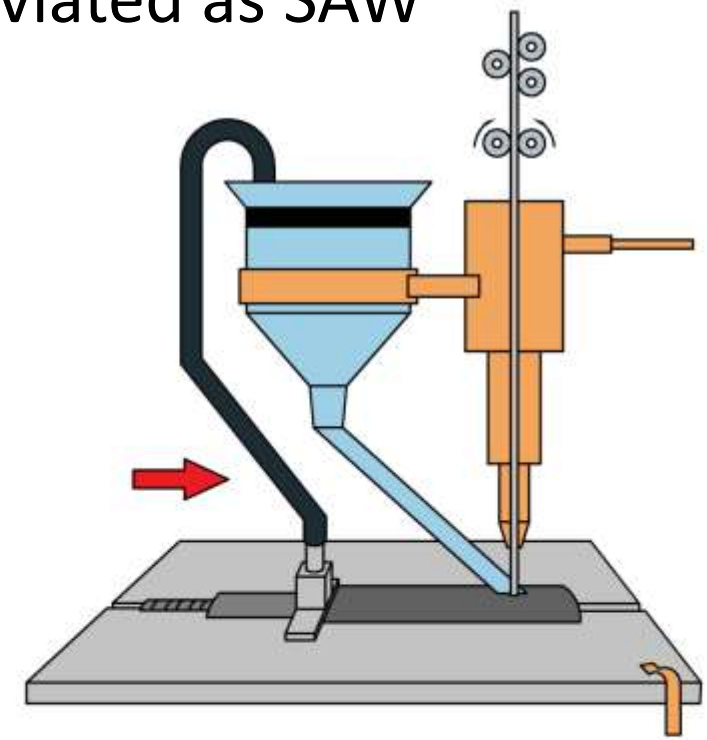
122 = Submerged arc welding with strip electrode

124 = Submerged arc welding with metallic powder addition

125 = Submerged arc welding with tubular cored electrode

126 = Submerged arc welding with solid wire electrode

127 = Submerged arc welding with cored strip electrode



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Reference numbers of basic welding processes (EN ISO 4063)

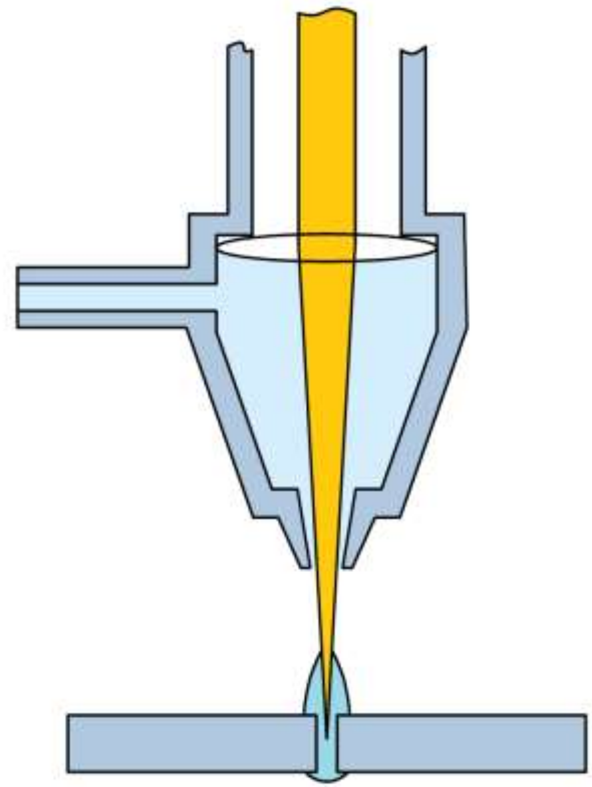
- LASER WELDING = 52

 - Reference number of processes:

(521 = Solid state laser welding

522 = Gas laser welding

523 = Diode laser welding



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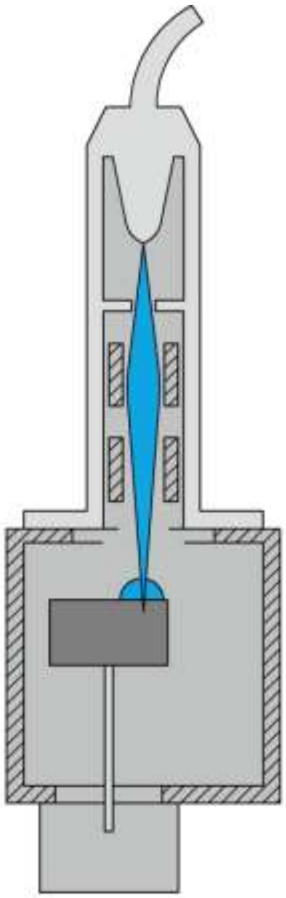
Reference numbers of basic welding processes (EN ISO 4063)

- ELECTRON BEAM WELDING; 51
- 511 = Electron beam welding in vacuum
- 512 = Electron beam welding in atmosphere
- 513 = Electron beam welding with addition of shielding gases



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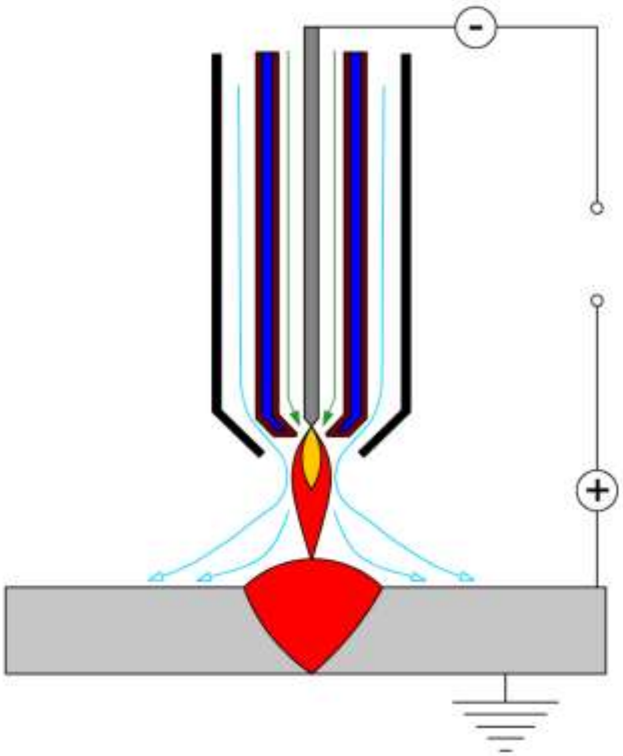
Reference numbers of basic welding processes (EN ISO 4063)

- PLASMA ARC WELDING; 15
- 151 = Plasma MIG welding
- 152 = Powder plasma arc welding
- 153 = Plasma welding with transferred arc
- 154 = Plasma arc welding with non-transferred arc
- 155 = Plasma arc welding with semi-transferred arc



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Useful Topic Related Links

www.youtube.com/watch?v=WHpqqmVjHho

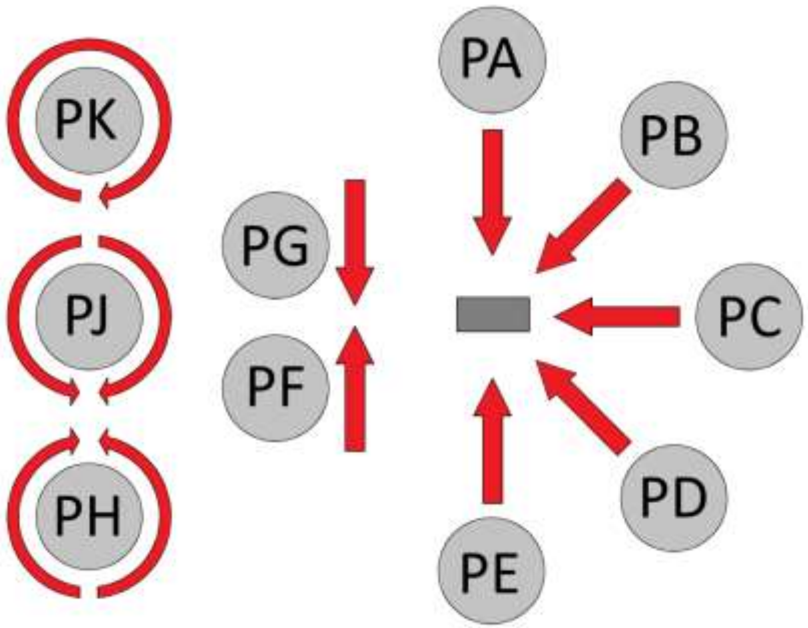
https://www.youtube.com/watch?v=n5x2BgHaxfM

https://www.youtube.com/watch?v=HAcuPmrFfL0

PART I (Technology): Basic of welding tehnology

I.1. GENERAL WELDING ASPECTS

I.1.3. Welding position and terminology (EN ISO 6947)



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Aim & Objectives

Module Aim:	Provide basic knowledge about welding positions according to EN ISO 6947
Number of hours:	1 hour
Learning Outcomes:	• Understanding of different welding positions
ECVET:	

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Lecture Outline

- This lecture deals with presentations of welding positions according to EN ISO 6947 (Welding and allied processes - Welding positions).

I.1. General welding aspects

I.1.3. Welding position and terminology (EN ISO 6947)

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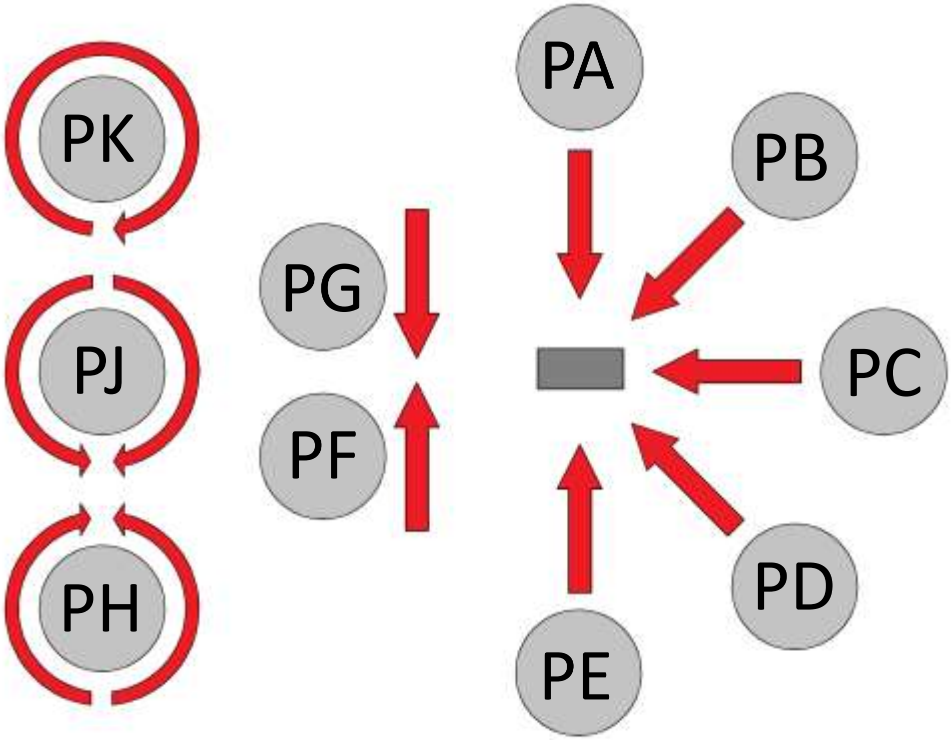
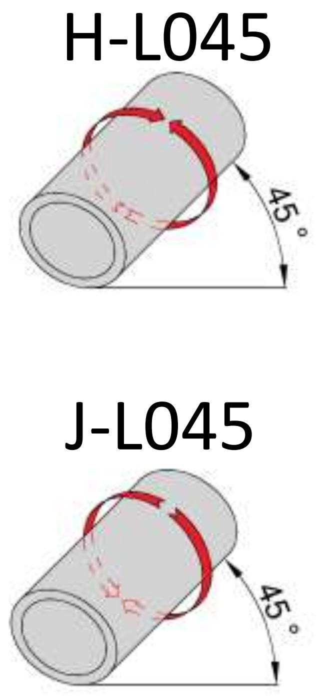
WELDING POSITIONS DIAGRAM





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WELDING POSITIONS – ABBREVATION EXPLAINATION

WELDING POSITIONS:

- **PA** -> Flat position
- **PB** -> Horizontal vertical
- **PC** -> Horizontal
- **PD** -> Horizontal overhead
- **PE** -> Overhead
- **PF** -> Vertical up
- **PG** -> Vertical down
- **PK** -> Pipe position for orbital welding

PJ -> Pipe position for welding downwards

PH -> Pipe position for welding upwards

H-L045 -> Fixed pipe position for welding upwards

J-L045 -> Fixed pipe position for welding downwards

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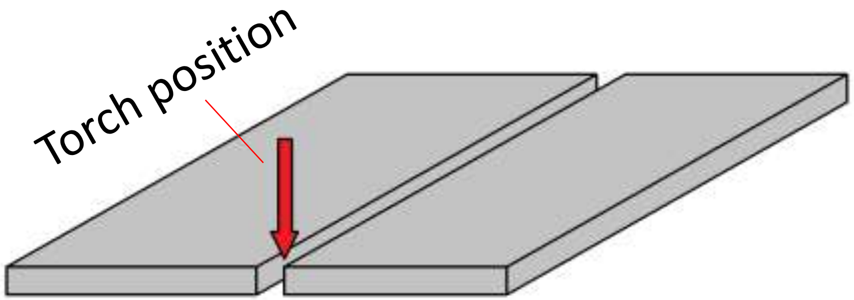
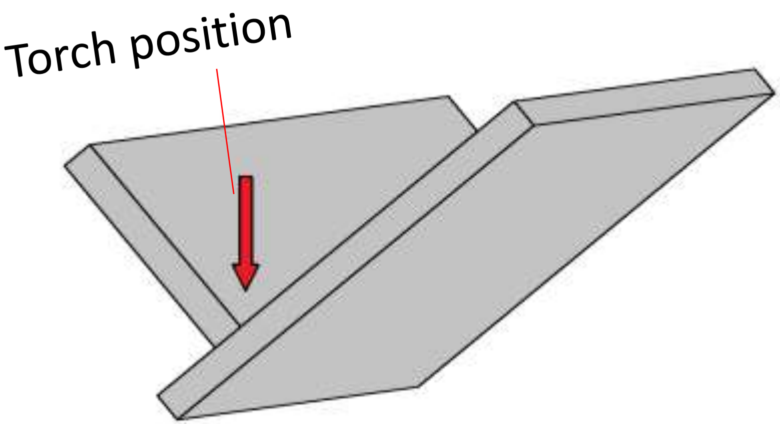
WELDING POSITIONS – SOME EXAMPLES

PA → Flat position - PLATES





PA → Flat position - PLATES

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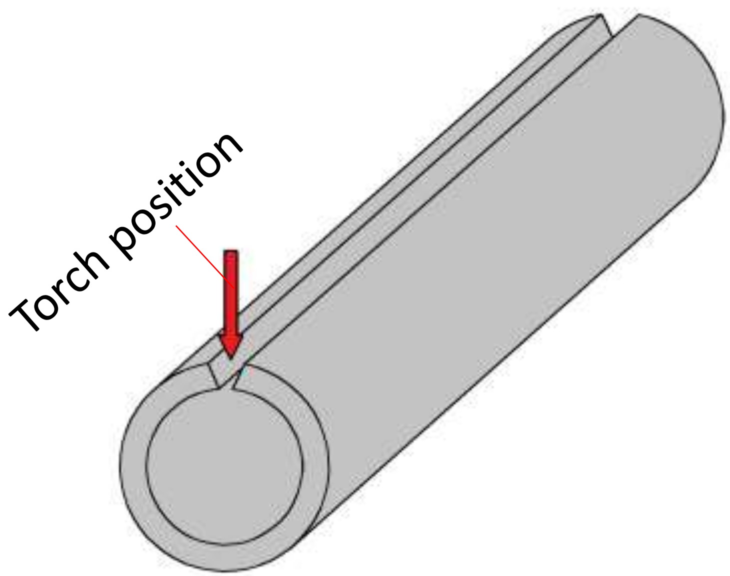
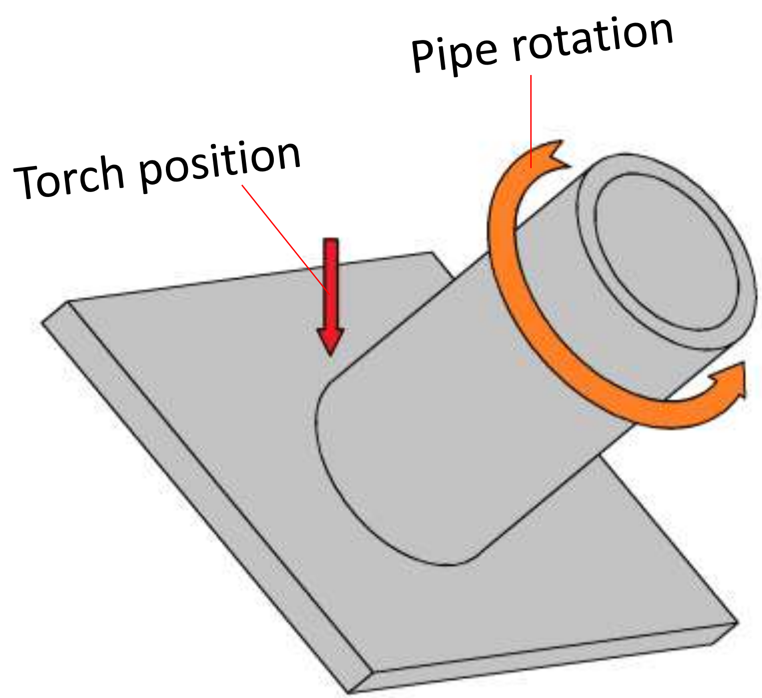
WELDING POSITIONS – SOME EXAMPLES

PA → Flat position - TUBES





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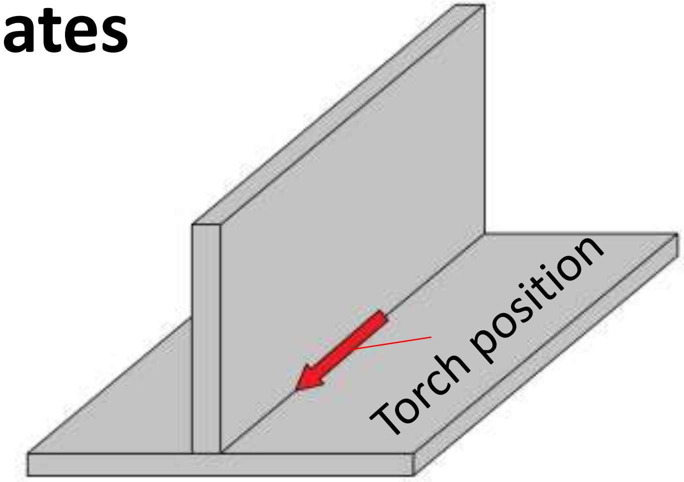
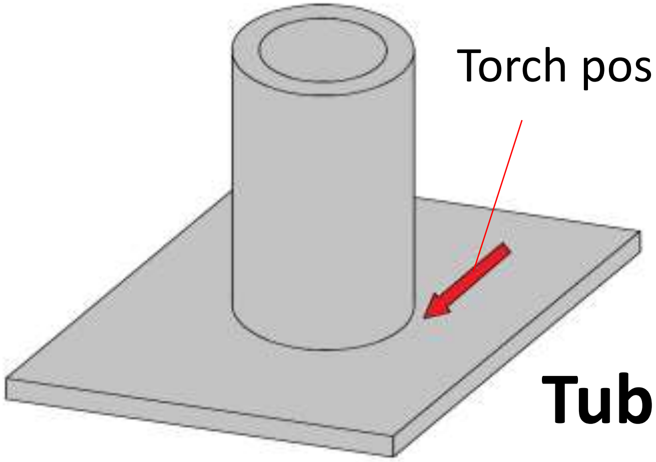
WELDING POSITIONS – SOME EXAMPLES

PB → Horizontal vertical

Plates





Tubes

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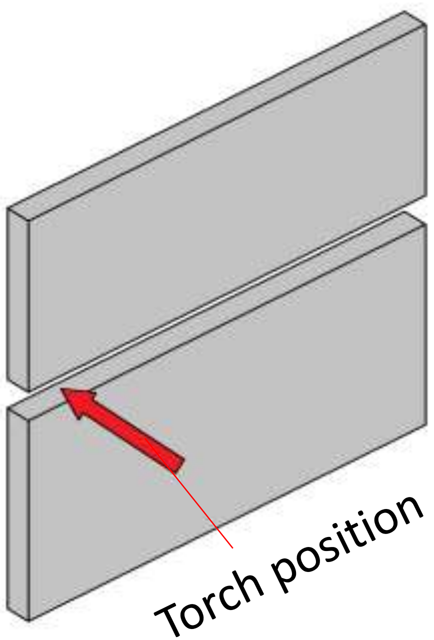
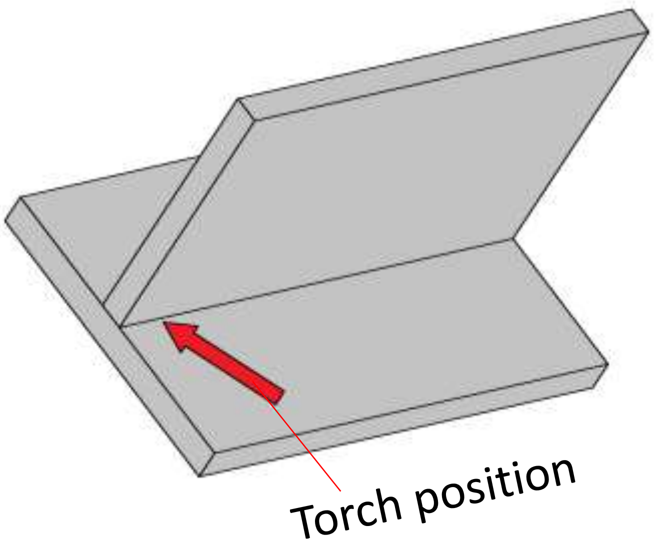
WELDING POSITIONS – EXAMPLES

PC → Horizontal - PLATES





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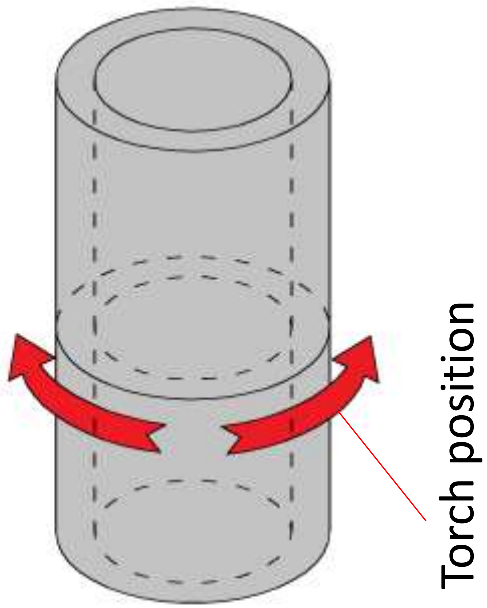
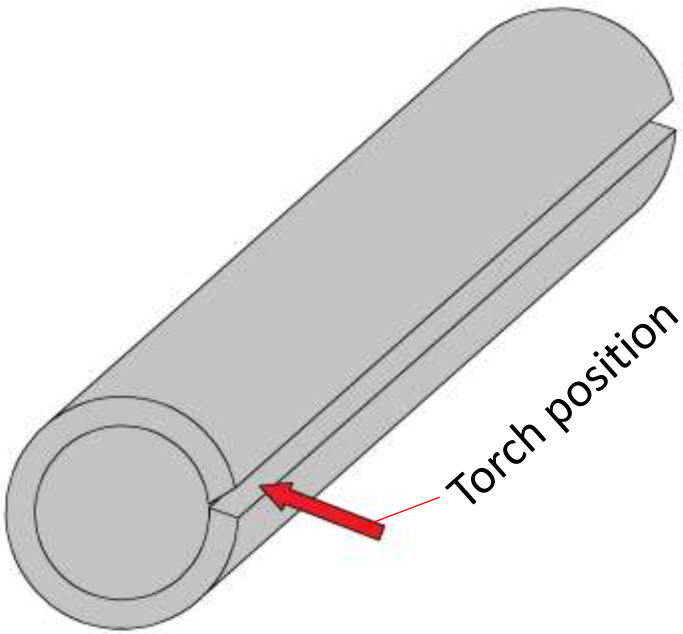
WELDING POSITIONS – EXAMPLES

PC → Horizontal - TUBES





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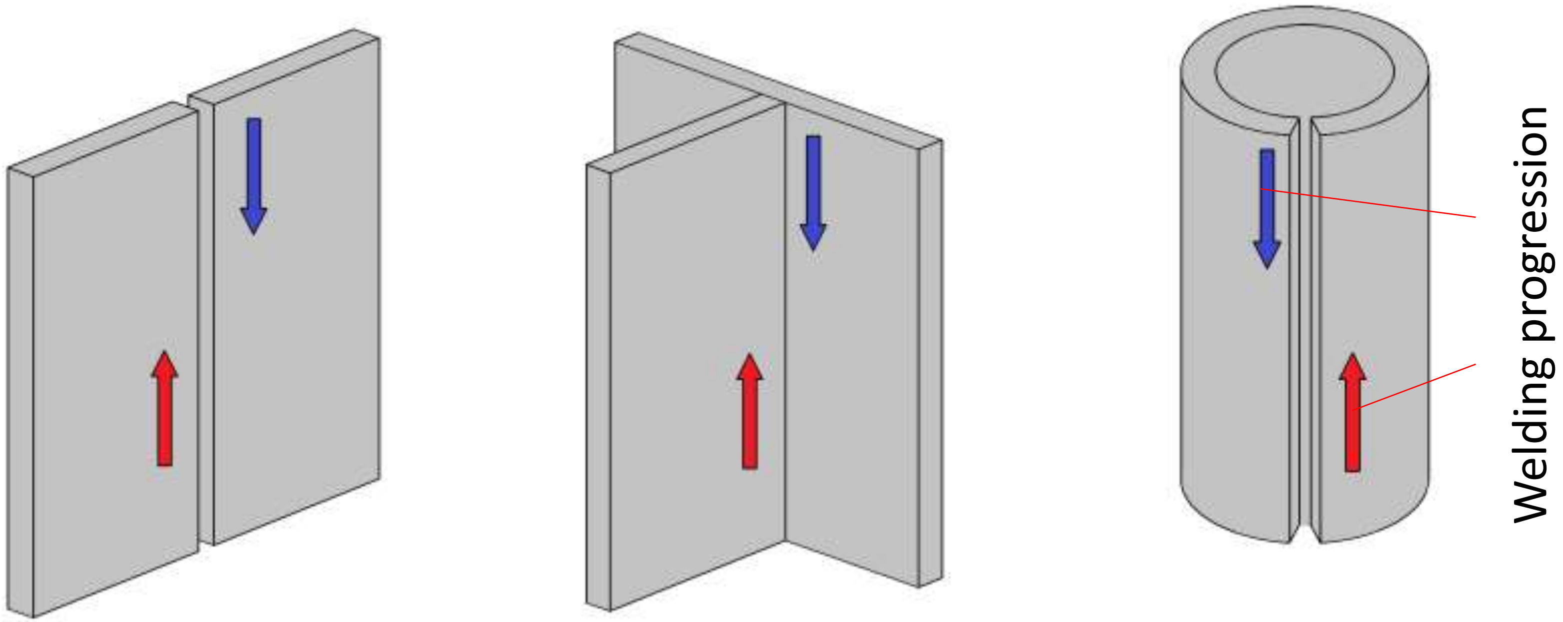
WELDING POSITIONS – EXAMPLES

PF → Vertical up; PG → Vertical down



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Useful Topic Related Links

https://www.youtube.com/watch?v=HAcuPmrFfL0

https://www.youtube.com/watch?v=Gdm23KLTEW0

https://www.youtube.com/watch?v=LlylLsUb6AQ

https://www.youtube.com/watch?v=cL7LcJG7jW8

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PART I (Technology): Basic of welding tehnology

I.1. GENERAL WELDING ASPECTS

1.4. Symbolic representation of joints (EN ISO 2553)

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Aim & Objectives

Module Aim:	Provide basic knowledge for recognizing symbols of welded joints according to EN ISO 2553.
Number of hours:	1 hour
Learning Outcomes:	• Understanding tehnical drawings through weld symbols, • Recognizing different types of welds, • Recognizing different types of joints (EN ISO 9692),
ECVET:	

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Lecture Outline

- This lecture will provide basic knowledge for recognizing symbols of welded joints according to EN ISO 2553.
- This lecture will help to understand tehnical drawings through weld symbols,
- This lecture will help to recognize different types of welds,
- This lecture will help to recognize different types of joints based on EN ISO 9692,

I.1. General welding aspects

I.1.4. Symbolic representation of joints (EN ISO 2553)

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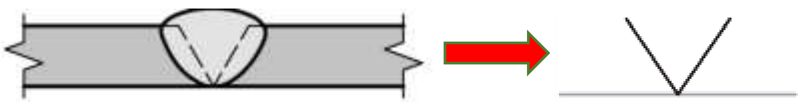
1.4.1 TYPES OF WELDS – Butt weld

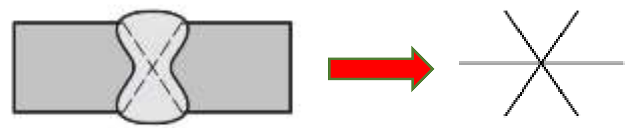
Single- V butt

EN ISO 2553



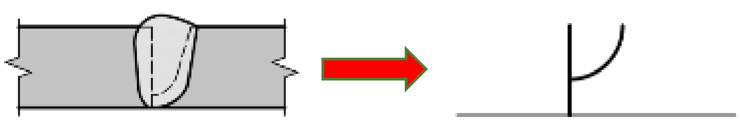
Double -V butt

EN ISO 2553



Single-J butt

EN ISO 2553



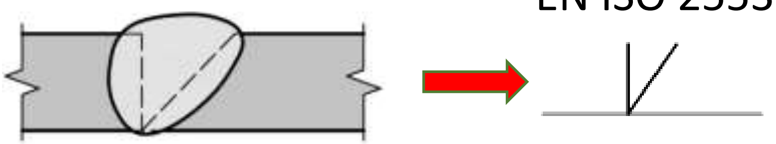
Square butt

EN ISO 2553

1.4.1 TYPES OF WELDS – Butt weld

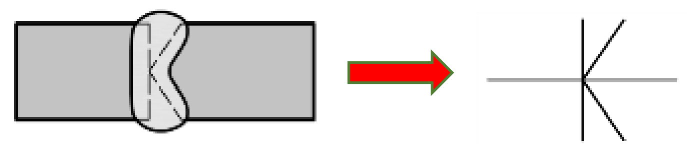
Single-bevel butt

EN ISO 2553



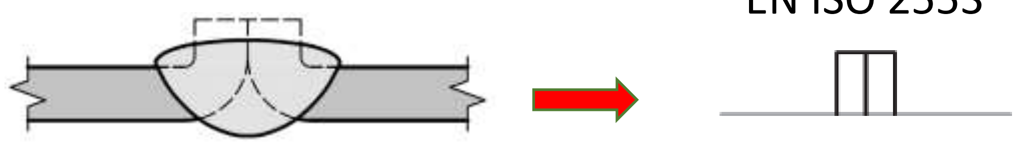
Double bevel butt

EN ISO 2553



Flanged butt / corner weld

EN ISO 2553



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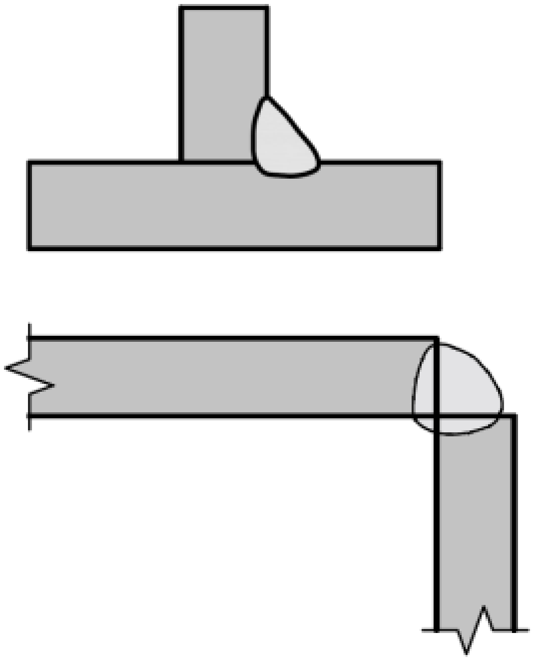
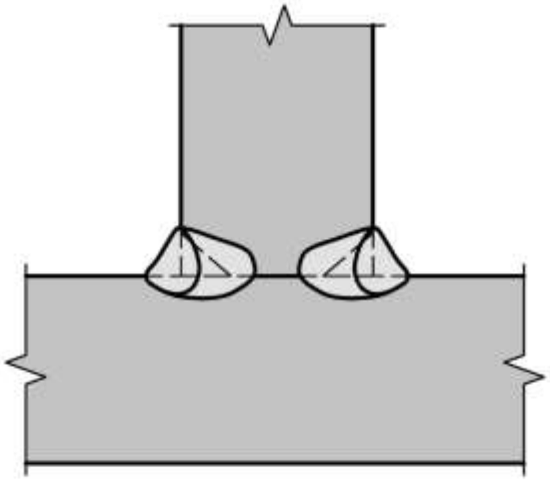
1.4.1 TYPES OF WELDS – Fillet weld





EN ISO 2553

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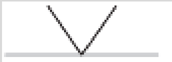
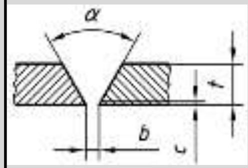
1.4.2 TYPES OF JOINTS PREPARATION (EN ISO 9692 -1)

Single -V butt

Material thickness, t (mm)	Type of preparation	Symbol (EN ISO 2553)	Cross section	Dimensions				Recomended welding process (ISO 4063)	Welding ilustration
				Angle, α, β	Gap, b (mm)	Thickness of root face, c (mm)	Depth of preparation, h (mm)		
3 < t <= 10	Single V			40°<= α <= 60°	<= 4	<= 2	-	3, 111,13, 141	
8 < t <= 12				6°<= α <= 8°	-			52	

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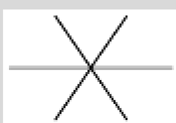
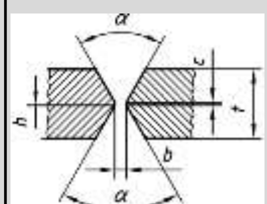
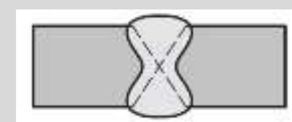
1.4.2 TYPES OF JOINTS PREPARATION (EN ISO 9692 -1)

Double -V butt

Material thickness, t (mm)	Type of preparation	Symbol (EN ISO 2553)	Cross section	Dimensions				Recomended welding process (ISO 4063)	Welding ilustration
				Angle, α, β	Gap, b (mm)	Thickness of root face, c (mm)	Depth of preparation, h (mm)		
> 10	Double V			α ≈ 60°	1 <= b <= 3	<= 2	≈ t/2	111, 141	
				40°<= α <= 60°				13	

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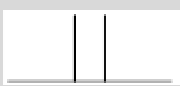
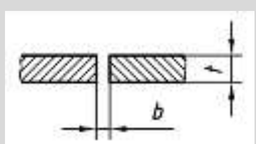
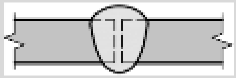
1.4.2 TYPES OF JOINTS PREPARATION (EN ISO 9692 -1)

Square butt

Material thickness, t (mm)	Type of preparation	Symbol (EN ISO 2553)	Cross section	Dimensions: Angle, α, β	Dimensions: Gap, b (mm)	Dimensions: Thickness of root face, c (mm)	Dimensions: Depth of preparation, h (mm)	Recomended welding process (ISO 4063)	Welding ilustration
<= 4	Square			-	≈ t	-	-	3, 111,141	
3 < t <= 8					6 <= b <=8			13	
					≈ t			141	
<= 15					<= 1			52 (filler)	
					0			52	

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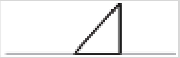
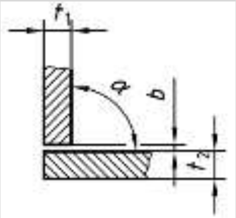
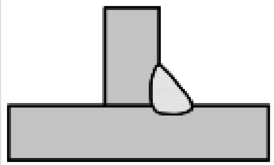
1.4.2 TYPES OF JOINTS PREPARATION (EN ISO 9692 -1)

Fillet – one sided

Material thickness, t (mm)	**Type of preparation**	**Symbol (EN ISO 2553)**	**Cross section**	**Dimensions**		**Recomended welding process (ISO 4063)**	**Welding ilustration**
				Angle, α, β	**Gap, b (mm)**		
$t_1 > 2$ $t_2 > 2$	Square			70°<= α <= 100°	<= 2	3, 111,13, 141 52	

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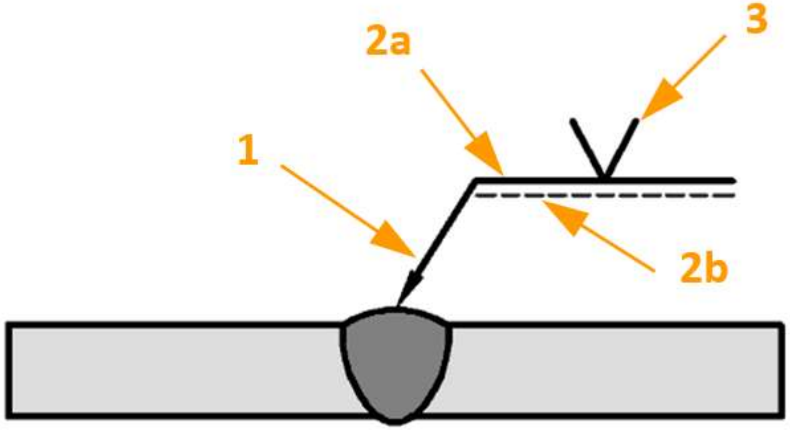
1.4.3 TEHNICAL DRAWING SYMBOLS OF WELD (EN ISO 2553)

Standard EN ISO 2553 predicts two different possibilities of drawing symbols which are system A and system B. In this lecture system A will be presented.



1 – an arrow

2a – reference line (undashed)

2b - indentification line (dashed)

3 – symbol of welded joint

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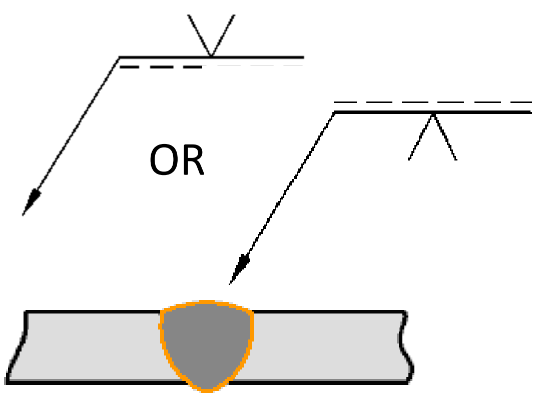
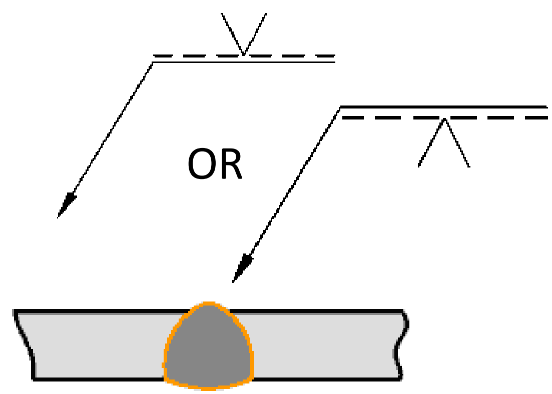
Some practical symbol drawing cases

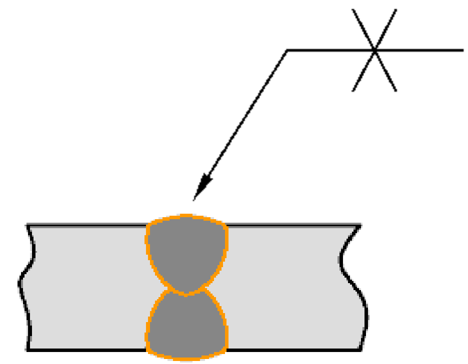
Butt weld (Definition of welding side)



Welded from arow side



Welded on the opposite side of an arow



Welded on both side of an arow

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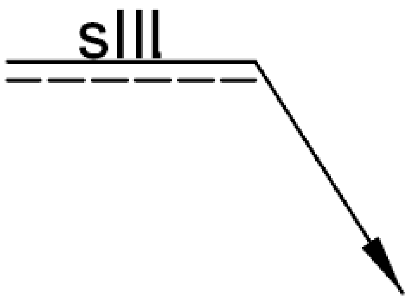
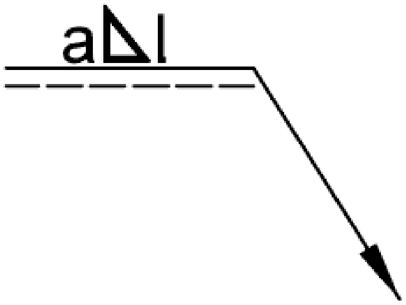
Some practical symbol drawing cases

Dimension designation of welded joint



Square butt weld



Fillet weld

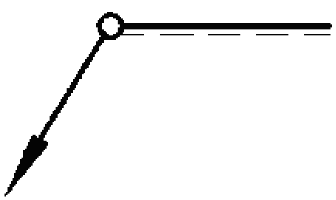
s – dimension of deposit thickness of square butt weld

a – dimension on cross-section of fillet weld

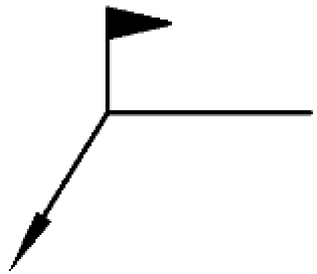
l – weld lenght

Some pratcital symbol drawing cases

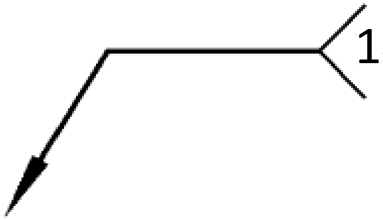
Aditional designations of welded joints



Designation for weld all around



Designation for field weld



Welding process designation and possible other designations (accceptance criteria, welding position, type of filler material etc.

Useful Topic Related Links

BASIC WELDING JOINTS

TYPE OF WELDING JOINTS

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PART I (Technology): Basic of welding tehnology

I.1. GENERAL WELDING ASPECTS

I.1.5 Edge preparation processes

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Aim & Objectives

Module Aim:	Provide basic knowledge about welding edge preparation processes.
Number of hours:	1 hour
Learning Outcomes:	• Understanding suitable cutting processes for different types of steel to achieve suitable cutting surface. • Understanding arc gouging and gas gouging principles • Get basic knowledge of other cutting processes: plasma, laser, mechanical cutting
ECVET:	

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Lecture Outline

- This lecture will provide basic knowledge for suitable cutting processes for different types of steel to achieve suitable cutting surface.
- lecture will help to understand arc gouging and gas gouging principles
- This lecture will provide basic knowledge of other cutting processes: plasma, laser, mechanical cutting

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I.1. General welding aspects

I.1.5 Edge preparation processes

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1.5.1 Suitable cutting processes for different types of steel to achieve a suitable cutting surface

MOST COMMON MECHANICAL CUTTING PROCESSES

1. CUTTING WITH SAWS

- band saw
- circular saw

2. SHEARING

3. MECHANICAL MACHINING

4. GRINDING AND CUTTING WITH MANUAL GRINDERS

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MECHANICAL CUTTING

MECHANICAL MACHINING:

- Turning,
- cutting,
- planing

Mainly used for the preparation of welds that have such a profile that can‘t be made by other cutting operations (e.g. U welds), or have such thickness that they can not be thermally cut.

Grinding and cutting with manual grinders

In many cases grindiders are needed to finalize edge praparation after other cutting process.

This kind of welding edge preparation is common on field welding where other processes are not applicable.

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THERMAL CUTTING AND EDGE PREPARATION

PLASMA CUTTING → All metals that electrically conductivite can be cutted

FLAME CUTTING → The temperature of the metal inflammation must be lower than the melting temperature of the metal.

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1.5.2 Flame cutting: principles and parameters, cutting blow pipes, cutting machines, quality of cut surface (e.g. ISO 9013)

Principle

The metal must burn with oxygen and the resulting oxides must have low viscosity, so they can be easy removed from the cutting slot. Unnaloyed steels burns 50 to 80 % and 20 to 50 % is melted

The temperature of the metal inflammation must be lower than the melting temperature of the metal.
The thermal conductivity of the metal must be as low as possible, and burning process must produce heat as much as possible.

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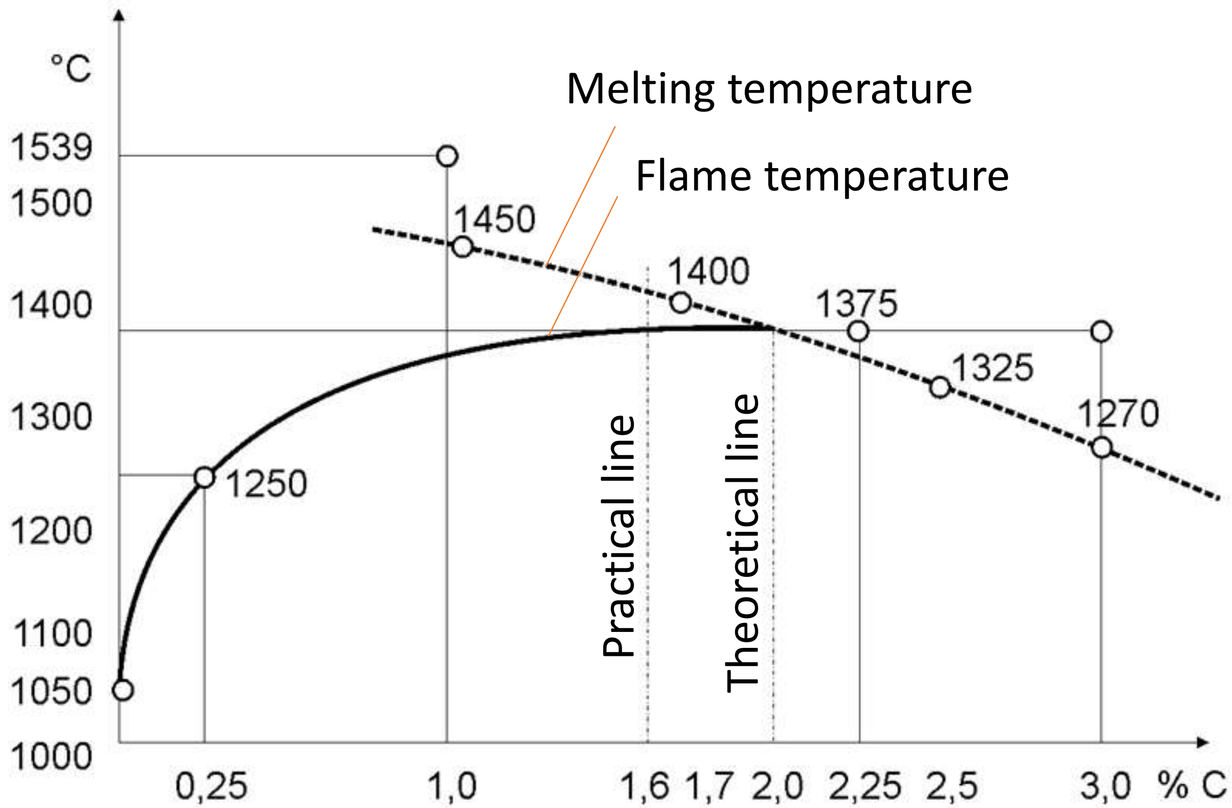
1.5.2 Flame cutting: principles and parameters, cutting blow pipes, cutting machines, quality of cut surface (e.g. ISO 9013)



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1.5.2 Flame cutting: principles and parameters, cutting blow pipes, cutting machines, quality of cut surface (e.g. ISO 9013)

Parameters

Plate thickness (mm)	Nozzle nr.	Cutting oxygen pressure (bar)	Heating oxygen pressure (bar)	Acetylene pressure (bar)	Kerf width (mm)	Cutting speed (mm/min)	Oxygen consumption (m^3/h)	Acetylene consumption (m^3/h)
3	**1**	2,0	2,0	0,2	1,5	730	1,64	0,24
5		2,0	2,0	0,2	1,5	690	1,67	0,27
8		2,5	2,0	0,2	1,5	640	1,92	0,32
10		3,0	2,0	0,2	1,5	600	2,14	0,34
15	**2**	3,0	2,5	0,2	1,8	520	2,67	0,37
20		3,5	2,5	0,2	1,8	450	2,98	0,38
25		4,0	2,5	0,2	1,8	410	3,20	0,40
30	**3**	4,3	2,5	0,2	2,0	380	3,42	0,42
35		4,5	2,5	0,2	2,0	360	3,54	0,44
40		5,0	2,5	0,2	2,0	340	3,85	0,45
50	4	4,5	2,5	0,2	2,2	320	5,39	0,49
60		5,0	2,5	0,2	2,2	310	5,82	0,52
60	**5**	5,0	2,5	0,2	3,5	320	8,56	0,56
80		5,5	2,5	0,2	3,5	280	9,22	0,62
100		6,0	2,5	0,2	4,0	260	9,97	0,67

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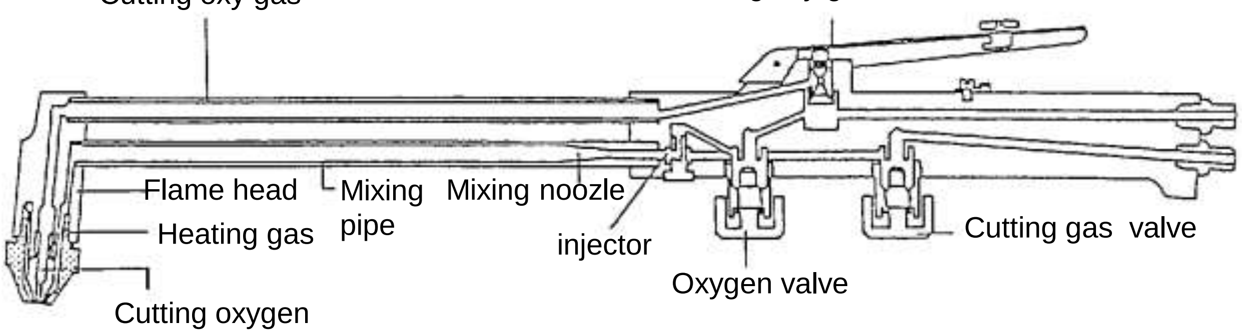
1.5.2 Flame cutting: principles and parameters, cutting blow pipes, cutting machines, quality of cut surface (e.g. ISO 9013)

Cutting blow pipes

Nowadays injector blow pipes are the most common. Combustable gas and oxygen are mixed together in the blow pipe.

Type of flame can be set manualy.



1.5.2 Flame cutting: principles and parameters, cutting blow pipes, cutting machines, quality of cut surface (e.g. ISO 9013)

Quality of cut surfaces

Reference standard -> **EN ISO 9013** - Qualifies ranges of guality of cut surfaces for flame cutting thicknesses 3 – 300 mm.

The quality of the cut area is assessed with the following characteristics:

- tolerance of perpendicularity or angularity,
- mean height of the longitudinal profile Rz5 (roughness of the cutting surface).

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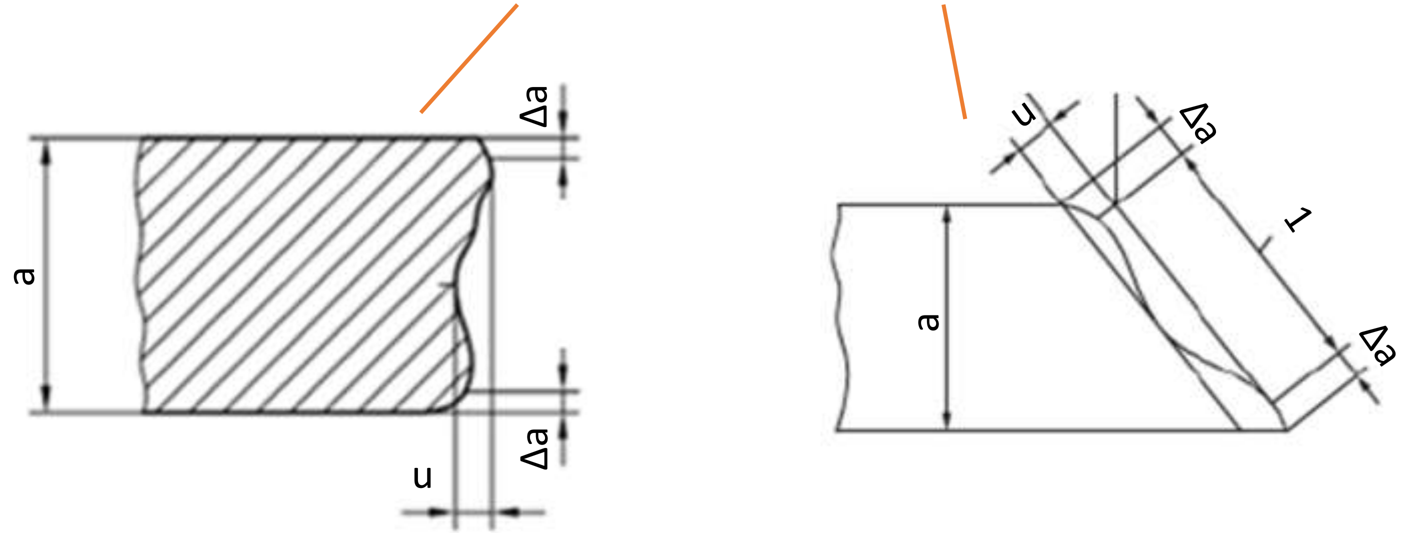
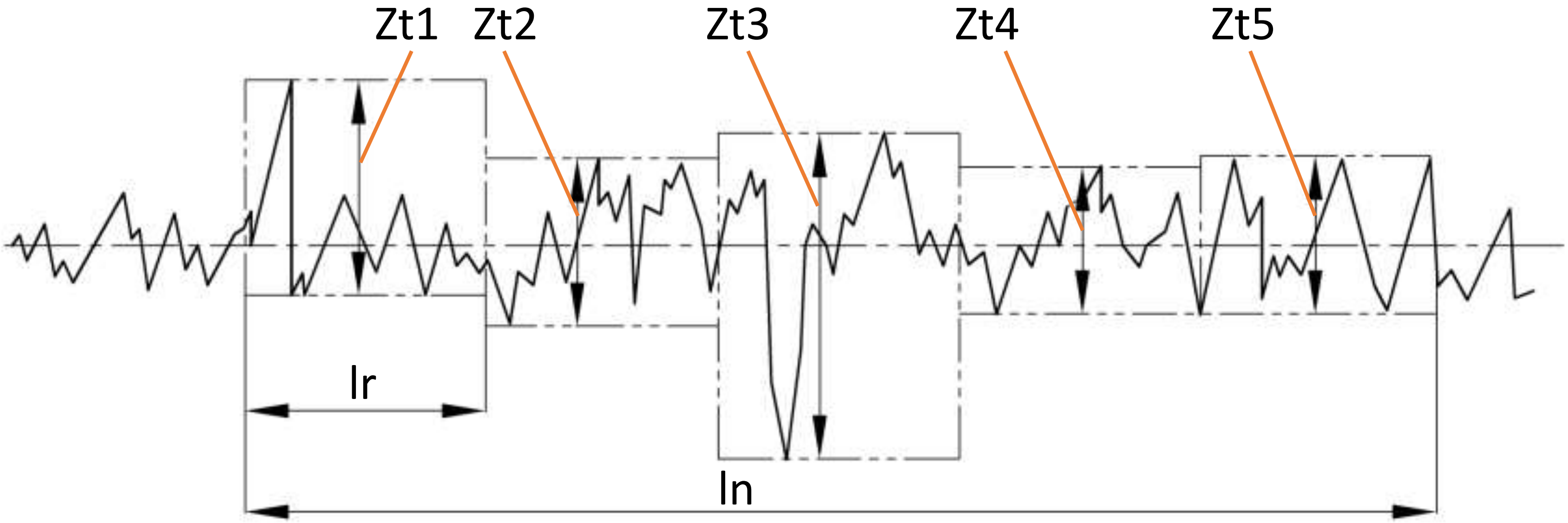
1.5.2 Flame cutting: principles and parameters, cutting blow pipes, cutting machines, quality of cut surface (e.g. ISO 9013)

Tolerance of perpendicularity or angularity



1.5.2 Flame cutting: principles and parameters, cutting blow pipes, cutting machines, quality of cut surface (e.g. ISO 9013)

Mean height of the longitudinal profile Rz5(roughness of the cutting surface).



1.5.2 Flame cutting: principles and parameters, cutting blow pipes, cutting machines, quality of cut surface (e.g. ISO 9013)

Ranges of cutting quality

RANGES	Tolerance of perpendicularity or angularity (mm)
1	0,05 + 0,003·a
2	0,15 + 0,007·a
3	0,4 + 0,01·a
4	0,8 + 0,02·a
5	1,2 + 0,035·a
RANGES	Roughness of the cutting surface) R_{z5} (μm)
1	10 + (0,6·a mm)
2	40 + (0,8·a mm)
3	70 + (1,2·a mm)
4	110 + (1,8·a mm)

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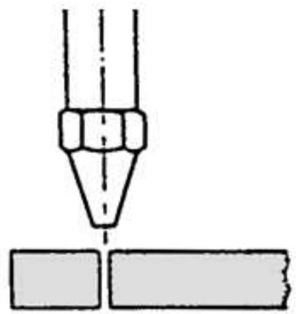
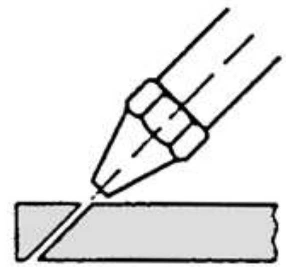
1.5.2 Flame cutting: principles and parameters, cutting blow pipes, cutting machines, quality of cut surface (e.g. ISO 9013)

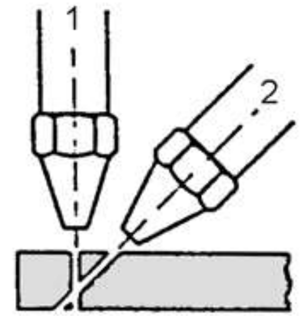
FLAME CUTTING EXAMPLES



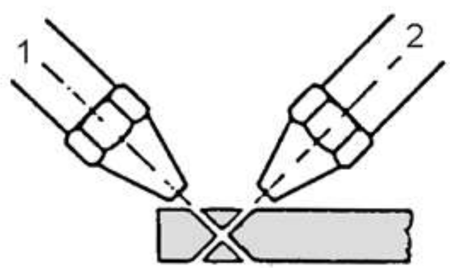
Square



Single-V



Single-bevel



Double-V

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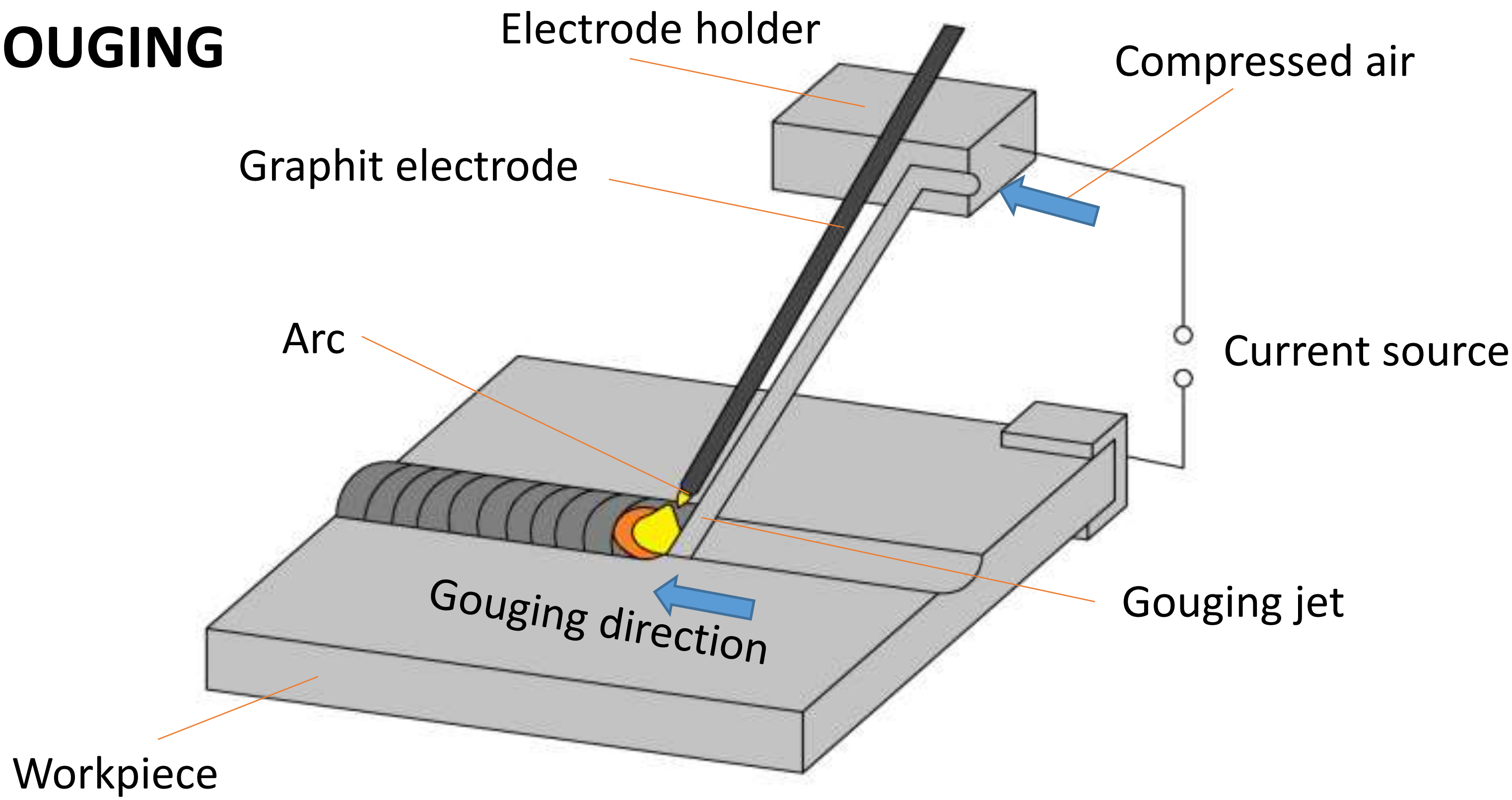
1.5.3 Arc gouging and gas gouging principles

ARC GOUGING



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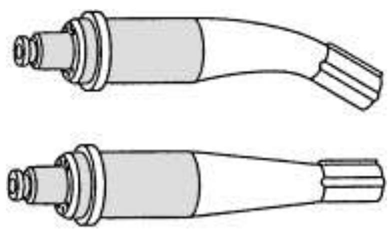
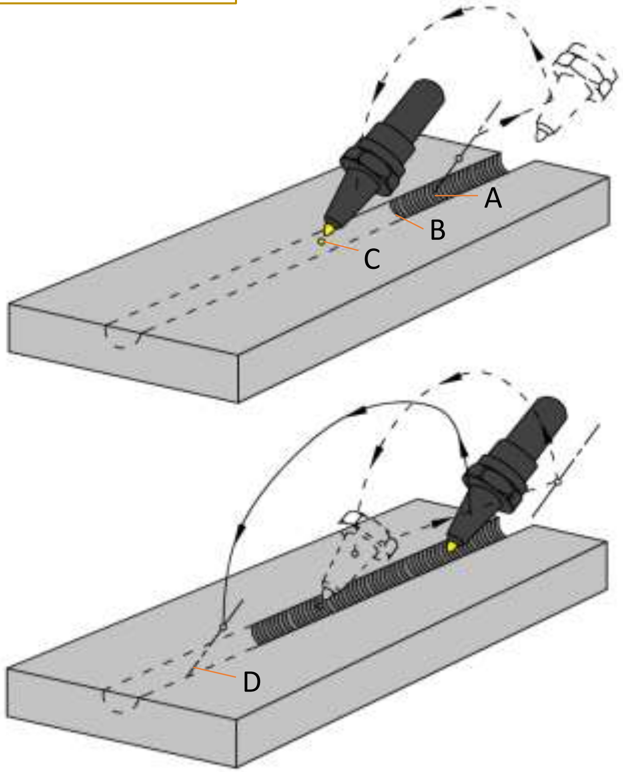
1.5.3 Arc gouging and gas gouging principles

Gas gouging → Similar process as gas cutting

Special cutting blow pipes are produced for gas gouging.





Gouging order A to D.
Less residual stress and deformations

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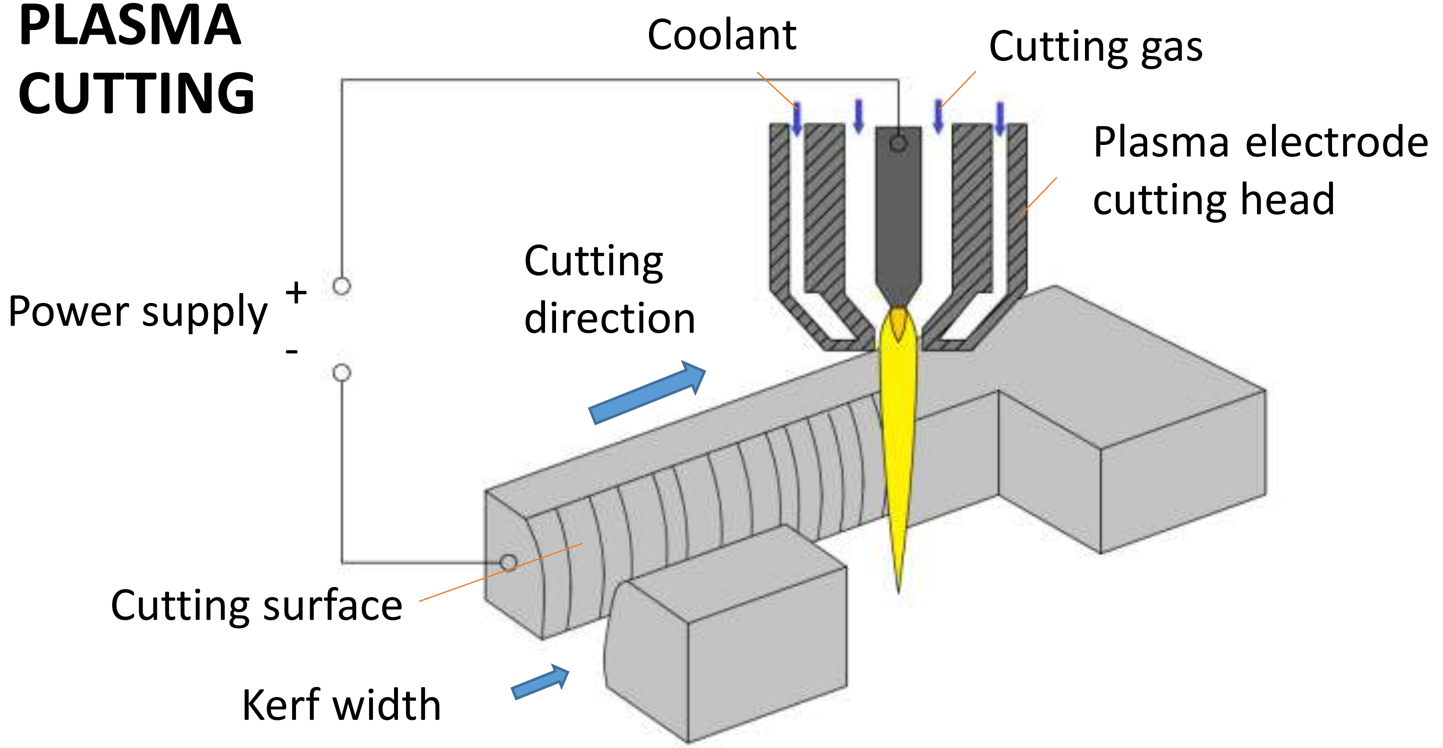
1.5.4 Other cuttting processes as: plasma, laser, mechanical cutting

PLASMA CUTTING



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1.5.4 Other cuttting processes as: plasma, laser, mechanical cutting

LASER CUTTING

Used mostly for cutting high alloyed steels and colored materials. The temperature of the metal inflammation is higher than the melting point.

Gases used for laser cutting: oxigen, nitrogen (N_2), argon (Ar), mixtures Ar/He or air.

Biggest advantage of laser cutting in comparison with flame cutting is significantly better cutting surface quality.

<u>Main laser cutting parameters:</u>

- Cutting velocity [cm/min], Laser gas pressure *p* [bar], Laser power *P* [kW], laser type (CO_2 or Nd:YAG), cutting gas, spot size, pulse frequency, pulse energy

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1.5.4 Other cuttting processes as: plasma, laser, mechanical cutting

MECHANICAL CUTTING

CUTTING WITH SAWS:

- band saw
- circular saw

This kind of cutting is used to preliminary for cutting of long work pieces (hot rolled profiles, pipes, bars…) based on tehnical documentation of welded joints.

SHEARING:

- used for cutting (shearing) of plates and sheets up to 10 mm thickness.
- process is limited to rectangular or polygonal shapes of weld metals.
- Additional grinding needed to achieve apropriate welding edge.

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1.5.4 Other cuttting processes as: plasma, laser, mechanical cutting

MECHANICAL MACHINING:

- Turning,
- cutting,
- planing

→ Mainly used for the preparation of welds that have such a profile that can‘t be made by other cutting operations (e.g. U welds), or have such thickness that they can not be thermally cut.

Grinding and cutting with manual grinders

→ In many cases grindiders are needed to finalize edge praparation after other cutting process. This kind of welding edge preparation is common on field welding where other processes are not applicable.

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Useful Topic Related Links

https://www.youtube.com/watch?v=Zy3g4-D1ZeA

https://www.youtube.com/watch?v=Yjg3ZxMDv_4

https://www.youtube.com/watch?v=qd1L_9nljdg

https://www.youtube.com/watch?v=pa95B_4HbW8

https://www.youtube.com/watch?v=pMSyGOoesfM

Waterjet cutting
https://www.youtube.com/watch?v=XfGkLsUm92Q

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PART I
Basic of welding tehnology

I.1. GENERAL WELDING ASPECTS

I.1.6. Power sources of arc welding

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Aim & Objectives

Module Aim:	Provide basic knowledge about sources for arc welding
Number of hours:	1 hour
Learning Outcomes:	• Understanding electric transformers for AC. • Understanding rectifiers for DC. • Understanding inverters for AC/DC.
ECVET:	

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Lecture Outline

- This lecture will provide basic knowledge obout electric transformers for Alternative Current (AC).
- Lecture will help to understand rectifiers principles for Direct Current (DC)
- Lecture will help to understand inverters principles for Alternative (AC) and Direct Current (DC)

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I.1. General welding aspects

I.1.6. Power sources of arc welding

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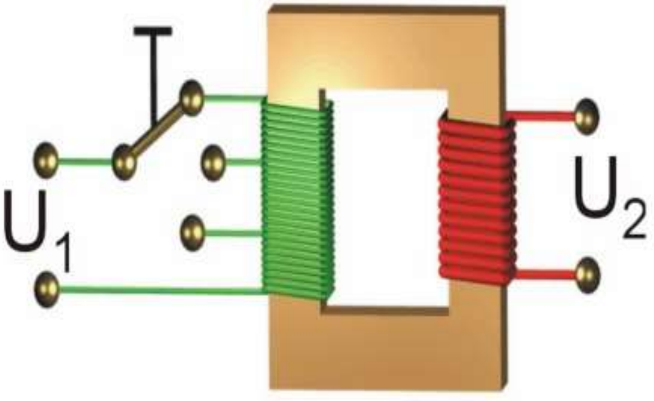
1.6.1 Transformers use of AC

Transformer is assembled from primary and secundary winding and laminated iron core. Side with more windings is made from thinner wire than side with less windings.

WORKING PRINCIPLE:

Transformer changes electric voltage and current from primary side to secondary side. Transformer works based on magnetic induction principle. This means that only alternative voltage and current can be transformed.



Electrical power is same on both side if losses are neglected.

Higher voltage on primary side means that current is smaller on same side. On the secundary side values are inversed.

$U_1 / U_2 = N_1 / N_2$ -> U = electric voltage; N = number of windings

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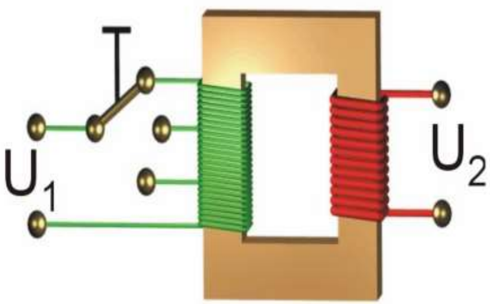
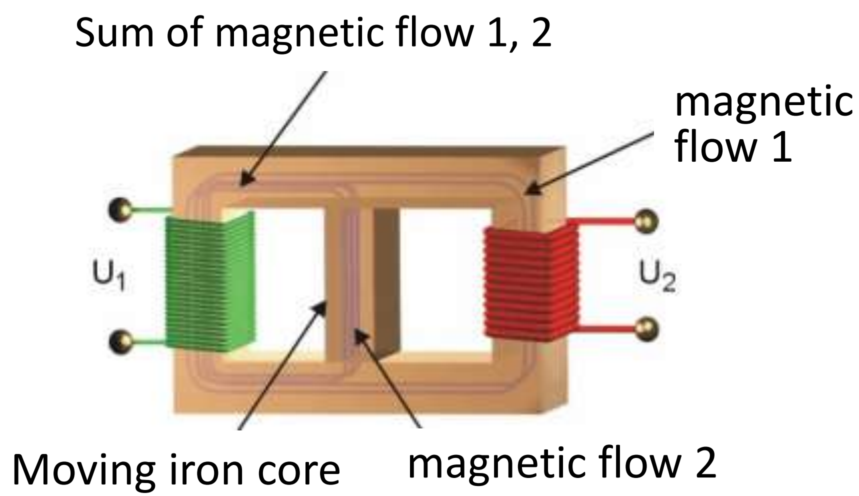
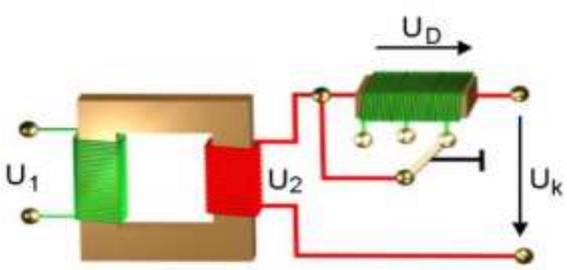
1.6.1 Transformers use of AC

Different transformers variants:



Regulation with switch



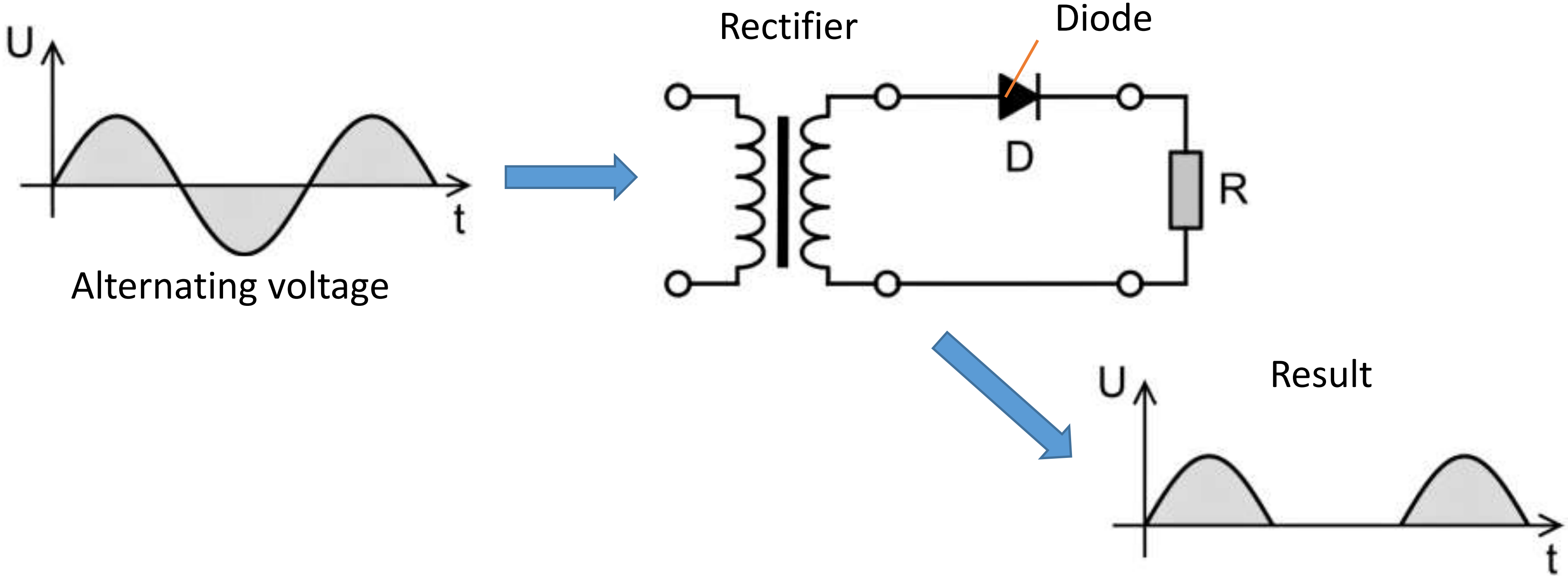


Regulation with inductive ballast

1.6.2 Rectifiers use of AC

Rectifier is an electrical device which converts an alternating current into a direct current by allowing a current to flow through it in one direction only.

Half-wave rectification



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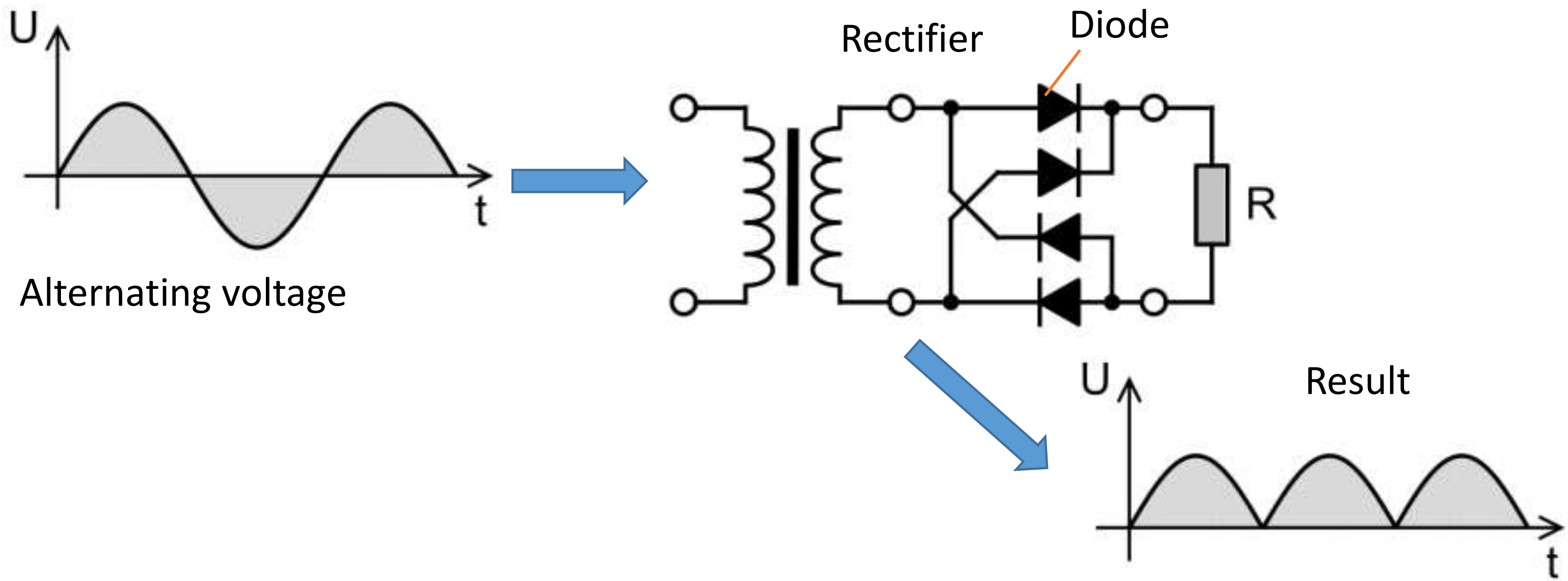
1.6.2 Rectifiers use of AC

Rectifier is an electrical device which converts an alternating current into a direct current by allowing a current to flow through it in one direction only.

Full-wave rectification



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1.6.2 Inverters for AC/DC

Inverters are electric devices, that are significantly smaller and have also significant smaller mass in comparison to transformers.

Alternating current is first directed and then transformed into significantly higher alternate frequences (up to 100kHz) and then transformed into high frequency current with high frequency transformer.

Welding current can be high frequency AC or directed DC.

Inverters are safer to use in comparison to transformers due to the „skin effect“*.

*For more information obout skin effect please see link at the end of presentation!

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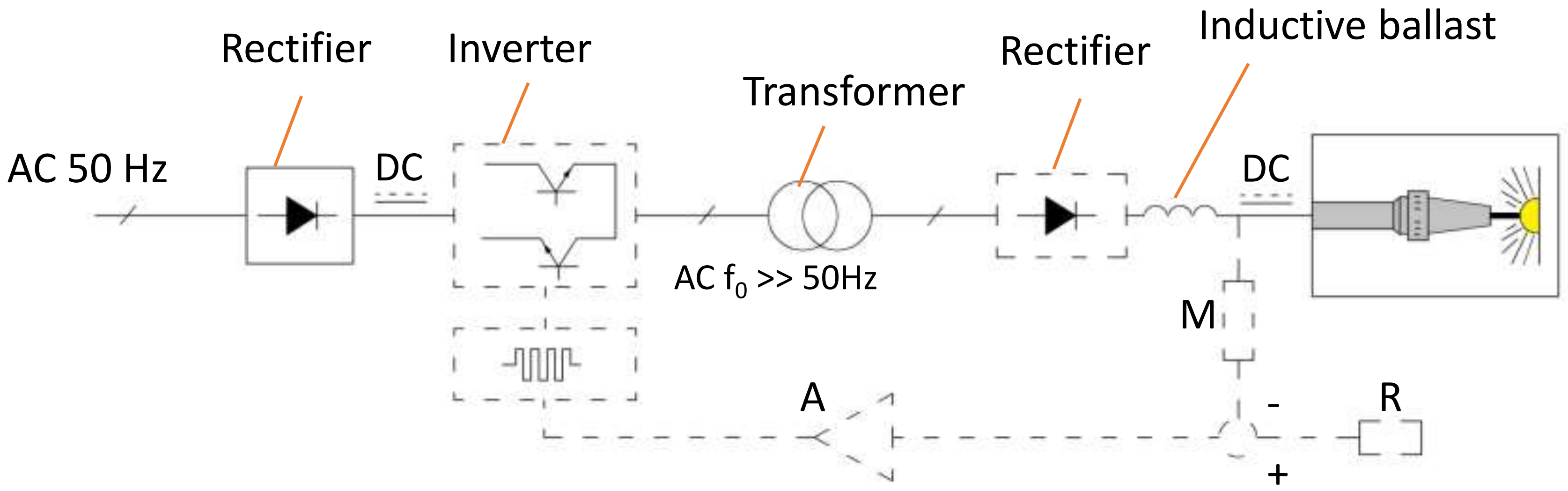
1.6.2 Inverters for AC/DC

WELDING INVERTER SCHEME



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Useful Topic Related Links

TRANSFORMER

RECTIFIER

INVERTER

SKIN EFFECT

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I.2. Materials used in fusion welding

2.1. Metallic materials

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Aim & Objectives

Module Aim:	Basic knowledge about the basic properties of metallic materials
Number of hours:	e-learning: 4h, self-study: 4h
Learning Outcomes:	• Knowing the properties of the materials used in fusion welding processes • Identification of the base materials used in fusion welding processes
ECVET:	4

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Lecture Outline

- Properties of metallic materials lecture deals with the basic mechanical properties of metals
- Classification of steels lecture will help to identify the different steel groups according to their main alloying elements and their main properties. The standardized steel grades for qualification of welding personal and welding procedures are neccessary and also discussed in his lecture.

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Lecture Outline

- Aluminum and aluminum alloys lecture will help to identify and classify the different groups of these metals and alloys according to their main alloying elements. Standardized aluminum grades for qualification of welding personal and welding procedures are neccessary.

- Titanium, nickel, copper and other metals and alloys lecture deals with the classification of this metals and alloys. Also in case of these materials Standardized alloy grades for certification of welding personal and welding procedures are neccessary (according ISO/TR 15608:2017).

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I-2.1. Properties of metallic materials

Physical and mechanical properties

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Main physical properties

- Valence electrons move freely between atomic cores → electron cloud → primer, strong metallic bond between atoms causing generally:
- → Thermal and electric properties:
  - Good electric conductivity and small electric resistance
  - Good thermal conductivity
  - High thermal expansion
  - Moderate to very high melting point

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Main physical properties

- → Mechanical properties:
  - Moderate to very high hardness
  - Moderate to very high mechanical strength
  - Good plasticity and
  - Good ductility

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Hardness

- The hardness of metals is measured mostly on even surface and can be interpreted as a resistance against a very hard (hard metal or diamond) indenter at given load.
- Hardness of the metals is directly proportional with other mechanical properties like tensile strength and ductility.
- The hardness can also indicate brittle not allowed phases in the welded joint → hardness in the welded joint is limited (~max e.g. 350HV10)

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Hardness

- Common hardness measurement units used to measure base metal and weldment hardness are:
  - **Vickers** hardness (HV) (diamond pyramid indenter)
  - **Brinell** hardness (HB) (hard metal sphere indenter)
  - **Rockwell B** hardness (HRB) (hard metal sphere indenter)
  - **Rockwell C** hardness (HRC) (diamond cone indenter)

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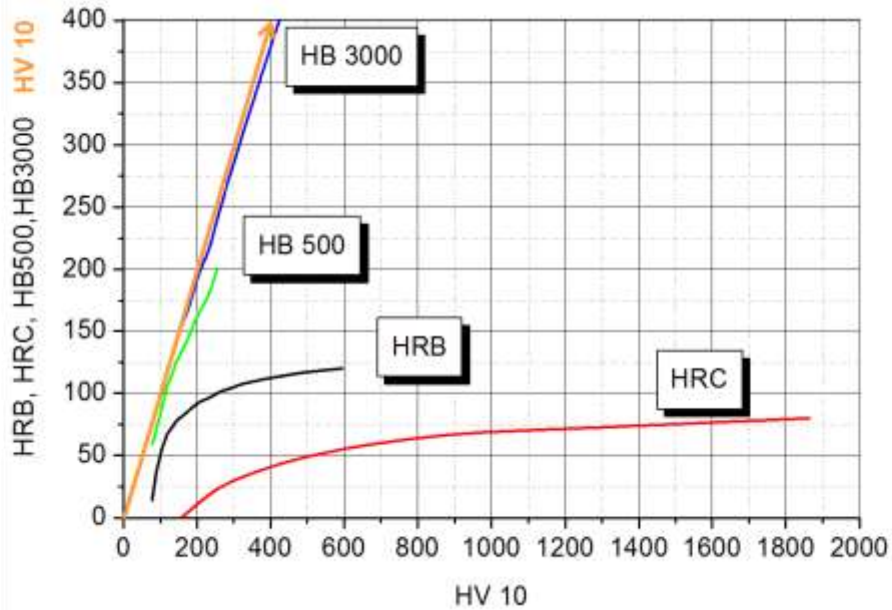
Hardness conversion

- Different hardness values can be converted into each other see diagram.



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Tensile properties

- Tensile testing is made to determine the mechanical strength of materials against tensile loading
- The following main parameters are determined due to testing:

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Tensile properties

- E-modulus is the elastic modulus (Young's modulus) is he initial slope of the stress-strain curve obtained due tensile testing, shows the elastic behavior according to Hooks law:

$$\sigma\left(\frac{N}{mm^2}\right)=E\left(\frac{N}{mm^2}\right)\times\varepsilon(-)$$

- where σ is the stress in the test coupon (applied force on the cross section with the dimension N/mm^2 or MPa) and ε is the strain (longitudinal elongation of the test coupon divided with the initial length with the dimension - or in %)

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Tensile properties

- Yield strength (YS or $R_{p0,2}$) in MPa is the boundary between reversible elastic and irreversible plastic deformation of the material. If the stress in given material is greater than its YS it will suffer permanent plastic deformation.
- Ultimate tensile strength (UTS or R_m) in MPa is the greatest stress the material can have before fracture. NOTE: UTS is calculated using the initial cross section area of the test specimen.
- Fracture elongation (%) A is the length difference of the fractured and initial test coupon divided by the initial length ×100

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Tensile properties

- A_5, A_{10} means the fracture elongation of a cylindrical probe were the initial length is five or ten times the diameter of the probe respectively.
- $A_{5,56}$, $A_{11,3}$ means the fracture elongation of a sheet probe were the initial length is five or ten times the equivalent diameter of the probe respectively.
- Z is the necking (%) of the probe the difference in cross section (at the fracture) divided by the original cross section of the probe ×100.

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Tensile properties

- The greater **A** and **Z** the more ductile the metals behave which is favorable at welding mostly if you weld great wall thicknesses.
- Generally good weldable steels have A>15% and Z > 10%.

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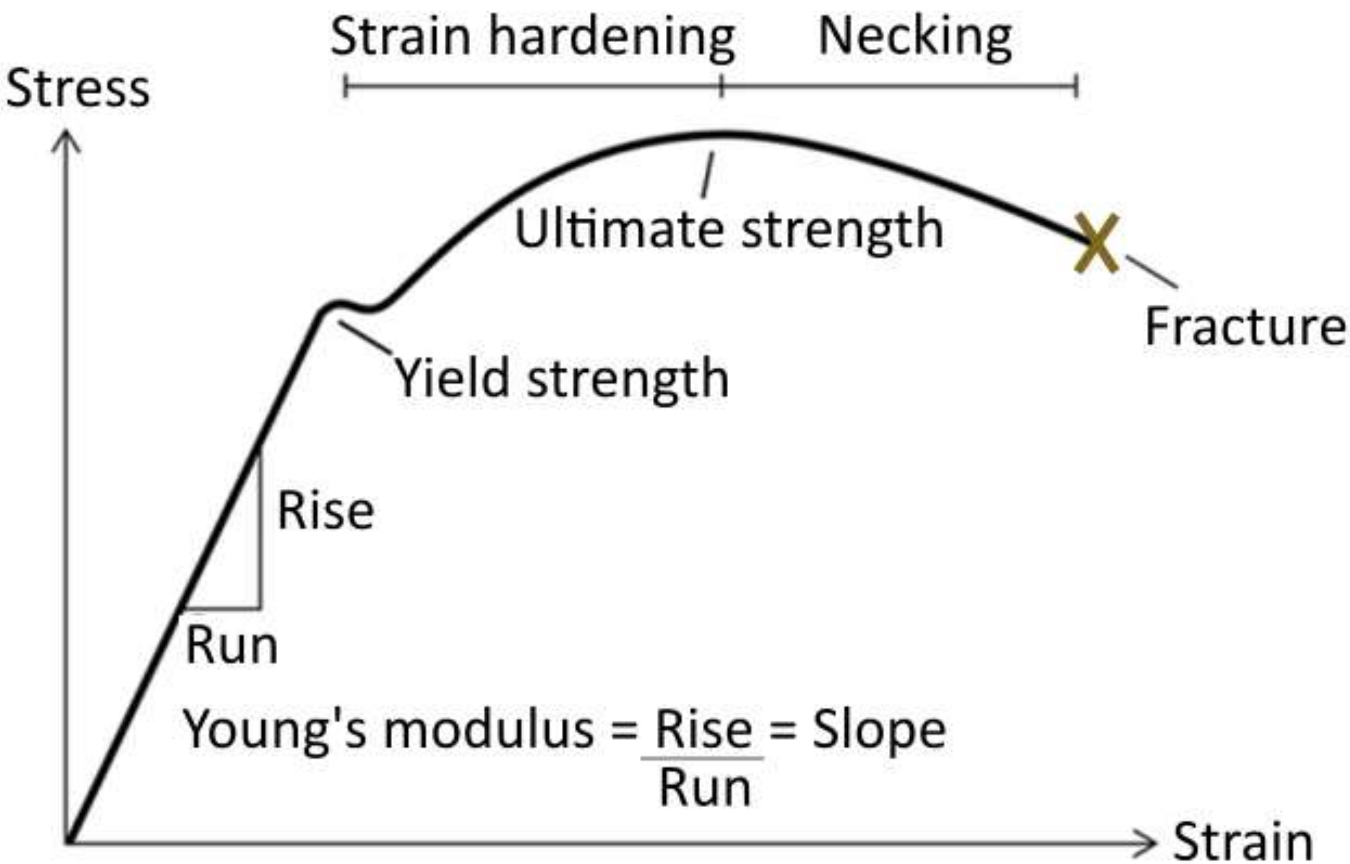
Stress vs. strain plot of a steel specimen



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Influence of the temperature

- For all the materials their strength increases but their ductility decreases with:
  - smaller temperature
  - faster loading
  - and multiaxial tensile stress
- To avoid brittle fracture of the welded construction the base material and the weld material is tested by Charpy impact test, (Charpy V-notch test)

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Charpy V-notch test

- A pendulum acting as a hammer breaks a standardized specimen with a V-shaped notch. During the breaking of the specimen the amount of energy is determined which absorbed by a material during fracture.
- To avoid brittle fracture at least 27 J fracture energy is needed at given temperature, sometimes higher level of safety is needed 40 J or 60 J energy is expected from the weldment

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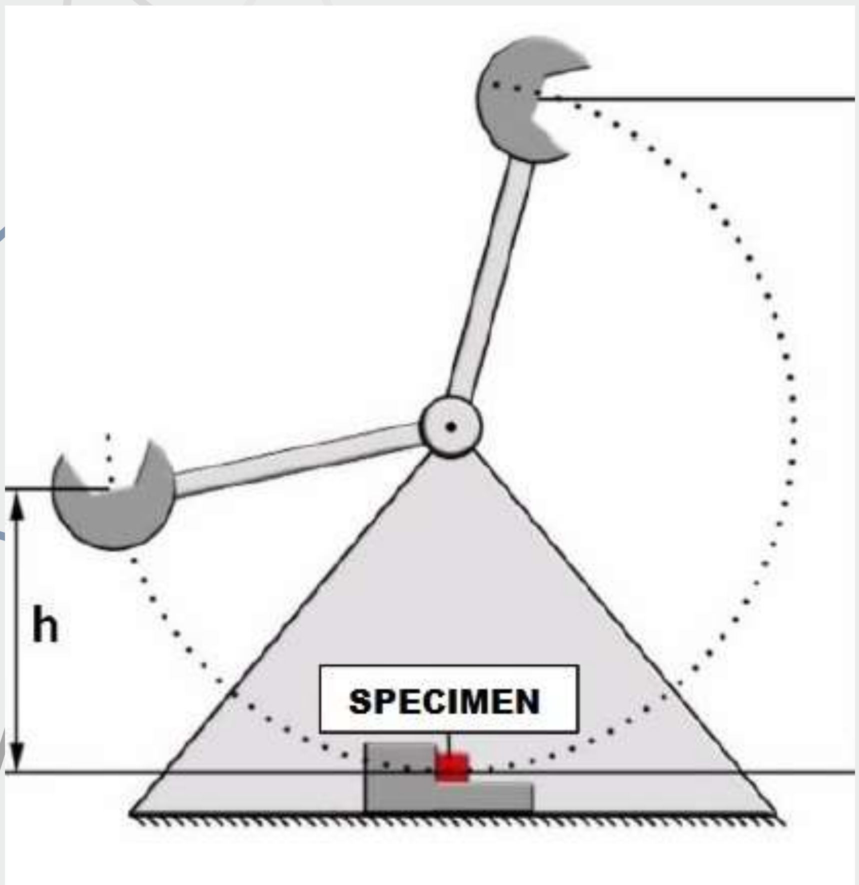
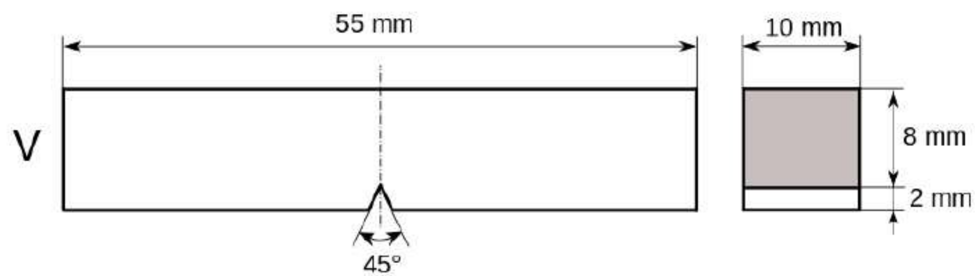
Charpy V-notch test



- The schematic sketch of the Charpy pendulum and the geometry of the specimen is on the image



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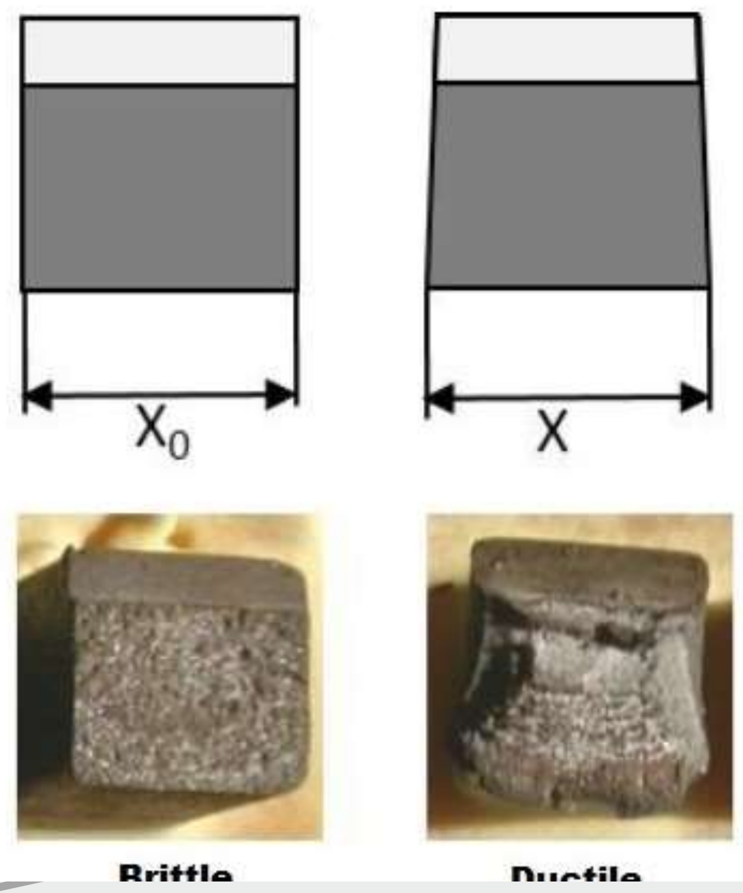
Charpy V-notch test



- A brittle fractured (small deformation) and a ductile fractured (large expansion) Charpy-V specimen is on the image
- For critical applications e.g. pressure vessels a certain expansion (e>10%) is also expected from the weldment
- expansion: $e = \frac{l - l_0}{l_0} \times 100 \ (\%)$

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Charpy V-notch test

- To determine the absorbed energy vs. temperature Charpy-v tests can be made at different temperatures see figure.
- The steel grade with the purple courve can be used at lower temperature as he blue one
- The steel grade with the yellow courve can be used at the lowest temperature it is typical for austenitic steels

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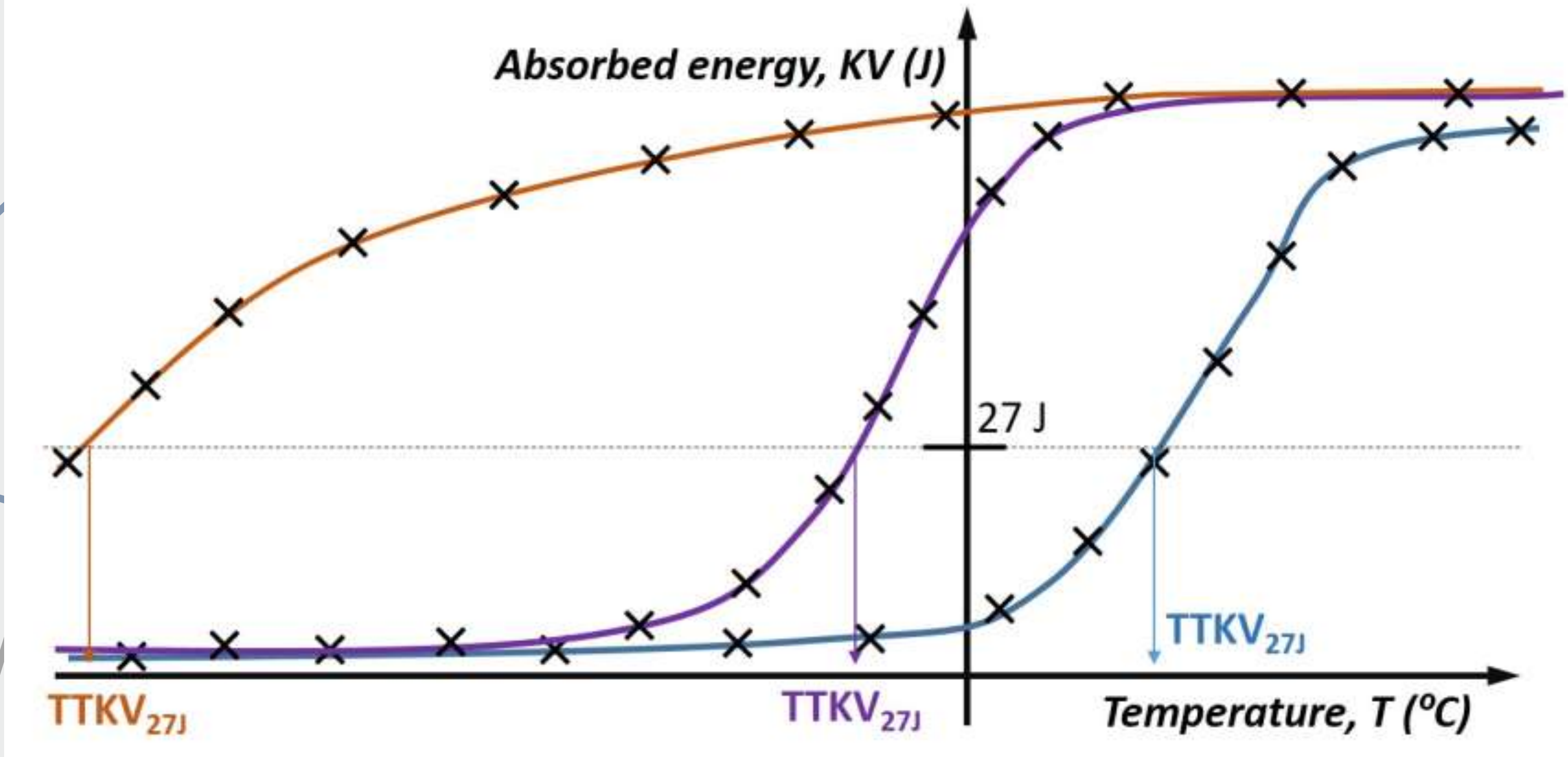
Charpy V-notch test



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Useful Topic Related Links

[Electrical resistance and conductance](https://en.wikipedia.org/wiki/Electrical_resistance_and_conductance)

https://en.wikipedia.org/wiki/Electrical_resistance_and_conductance

Thermal conductivity

https://en.wikipedia.org/wiki/Thermal_conductivity

Thermal expansion

https://en.wikipedia.org/wiki/Thermal_expansion

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Useful Topic Related Links

Hardness testing

https://en.wikipedia.org/wiki/Hardness

Vickers hardness

https://en.wikipedia.org/wiki/Vickers_hardness_test

Brinell hardness

https://en.wikipedia.org/wiki/Brinell_scale

Rockwell hardness

https://en.wikipedia.org/wiki/Rockwell_scale

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Useful Topic Related Links

Hardness conversion

https://en.wikipedia.org/wiki/Hardness_comparison

Tensile testing

https://en.wikipedia.org/wiki/Tensile_testing

Charpy impact testing

https://en.wikipedia.org/wiki/Charpy_impact_test

Link 3

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I.2. Materials used in fusion welding

2.2. Classification of steels terials

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Aim & Objectives

Module Aim:	Basic knowledge about the basic properties of metallic materials
Number of hours:	e-learning: 4h, self-study: 4h
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I-2.2. Classification of steels

Main steel types

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About steels

- Steels are basically iron based alloys with carbon as main alloying element. Generally Fe + max. 2wt% C.
- Fe based alloys with C > 2wt% are cast irons.
- The easiest weldable steels have generally less carbon content than 0,4 wt%.
- The modern steel making processes allow low carbon content. Also low hydrogen, nitrogen, oxygen, sulfur and phosphorus impurities can be reached which is good for the preventing the different types of welding flaws and cracks.

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Classification of steels

- According to ISO/TR 15608:2017 standard steels are grouped from 1-11 according their alloying element content and main tensile properties.

- Rule of thumb the less alloying elements the easier to weld the steel.

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Group 1 (according ISO/TR 15608:2017)

Group	Sub-group	Type of steel
1		Steels with a specified minimum yield strength $R_{eH} \leq 460$ MPa and Unalloyed steel contains the following components beyond the iron: C≤0.25%, Si≤0.6, Mn≤1.7, Mo≤0,07 Cu≤0.4, Ni≤0.5, Cr≤0.3 (0.4 for castings), Nb≤0.05, V≤0.12, Ti≤0.05 S≤0.045, P≤0.045
	1.1	Steels with a specified minimum yield strength $R_{eH} \leq 275$ MPa
	1.2	Steels with a specified minimum yield strength 275 MPa $\leq R_{eH} \leq 360$ MPa
	1.3	Steels with a specified minimum yield strength $R_{eH} > 360$ MPa
	1.4	Steels with improved atmospheric corrosion resistance whose analysis exceed the requirements for the single elements indicated above (mostly additional Cu alloy is applied to improve atmospheric corrosion resistance)

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Group 2 (according ISO/TR 15608:2017)

- To improve mechanical properties like R_{eH}, R_m, A, Z, TTKV thermomechanical treatment during production is applied instead of increasing alloy content. Therefore these steels are not much harder to weld but special care must be taken to control heat input. Note that grain refinement can increase both toughness and mechanical strength!

Group	Sub-group	Type of steel
2	2.1	Thermomechanically treated fine grained steels and cast steels with a specified minimum yield strength 360 MPa ≤ R_{eH} ≤ 460 MPa
	2.2	Thermomechanically treated fine grained steels and cast steels with a specified minimum yield strength R_{eH} > 460 MPa

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Group 3 (according ISO/TR 15608:2017)

- Quenching is a heat treatment with a heating and subsequent high cooling rate. Its goal is to produce martensitic structure in the steel. Martensite has a very high strength but it is very brittle, therefore it must be tempered. During tempering the steel will be heated to a lower temperature so the strength slightly decreases but the toughness increases significantly.
- This steels can form martensite during welding which is not good (brittle) therefore special care must be taken to control heat input, and may preheating and post weld heat treatment must be applied.

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Group 3 (according ISO/TR 15608:2017)

Group	Sub-group	Type of steel
3		Quenched and tempered steels and precipitation hardened steels except stainless steels with a specified minimum yield strength R_{eH} > 360 MPa.
	3.1	Quenched and tempered steels with a specified minimum yield strength 360 MPa ≤ R_{eH} ≤ 690 MPa .
	3.2	Quenched and tempered steels with a specified minimum yield strength R_{eH} > 690 MPa
	3.3	Precipitation hardened steels except stainless steels

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Group 4-6 (according ISO/TR 15608:2017)

Group	Sub-group	Type of steel
4		Low vanadium alloyed Cr-Mo-(Ni) steels with Mo ≤ 0.7% and V≤ 0.1%
	4.1	Steels with Cr ≤ 0.3% and Ni ≤ 0.7%
	4.2	Steels with Cr ≤ 0.7% and Ni ≤ 1.5%
5		Cr-Mo steels free of vanadium with C ≤ 0.35%
	5.1	Steels with 0.75% ≤ Cr ≤ 1.5% and Mo ≤ 0.7%
	5.2	Steels with 1.5% ≤ Cr ≤ 3.5% and 0.7% ≤ Mo ≤ 1.2%
	5.3	Steels with 3.5% ≤ Cr ≤ 7.0% and 0.4% ≤ Mo ≤ 0.7%
	5.4	Steels with 7.0% ≤ Cr ≤ 10.0% and 0.7% ≤ Mo ≤ 1.2%
6		High vanadium alloyed Cr-Mo-(Ni) steels
	6.1	Steels with 0.3% ≤ Cr ≤ 0.75% and Mo ≤ 0.7% and V ≤ 0.35%
	6.2	Steels with 0.75% ≤ Cr ≤ 3.5% and 0.7% ≤ Mo ≤ 1.2% and V ≤ 0.35%
	6.3	Steels with 3.5% ≤ Cr ≤ 7.0% and Mo ≤ 0.7% and 0.45% ≤ V ≤ 0.55%
	6.4	Steels with 7.0% ≤ Cr ≤ 12.5% and 0.7% ≤ Mo ≤ 1.2% and V ≤ 0.35%

Group 7-10 (according ISO/TR 15608:2017)

- Stainless steels are high alloy steels, they can be grouped according to their microstructure (seen in microscope).
- They can be grouped into: ferritic, austenitic, martensitic, and duplex stainless steels. They have different corrosion resistance and mechanical strength for different applications.
- To different stainless steel type different weld material must be used.
- According the chemical composition of the steel the microstructure of the weld metal can be determined via Schaeffler diagram where the two axes are the nickel and chrome equivalent.

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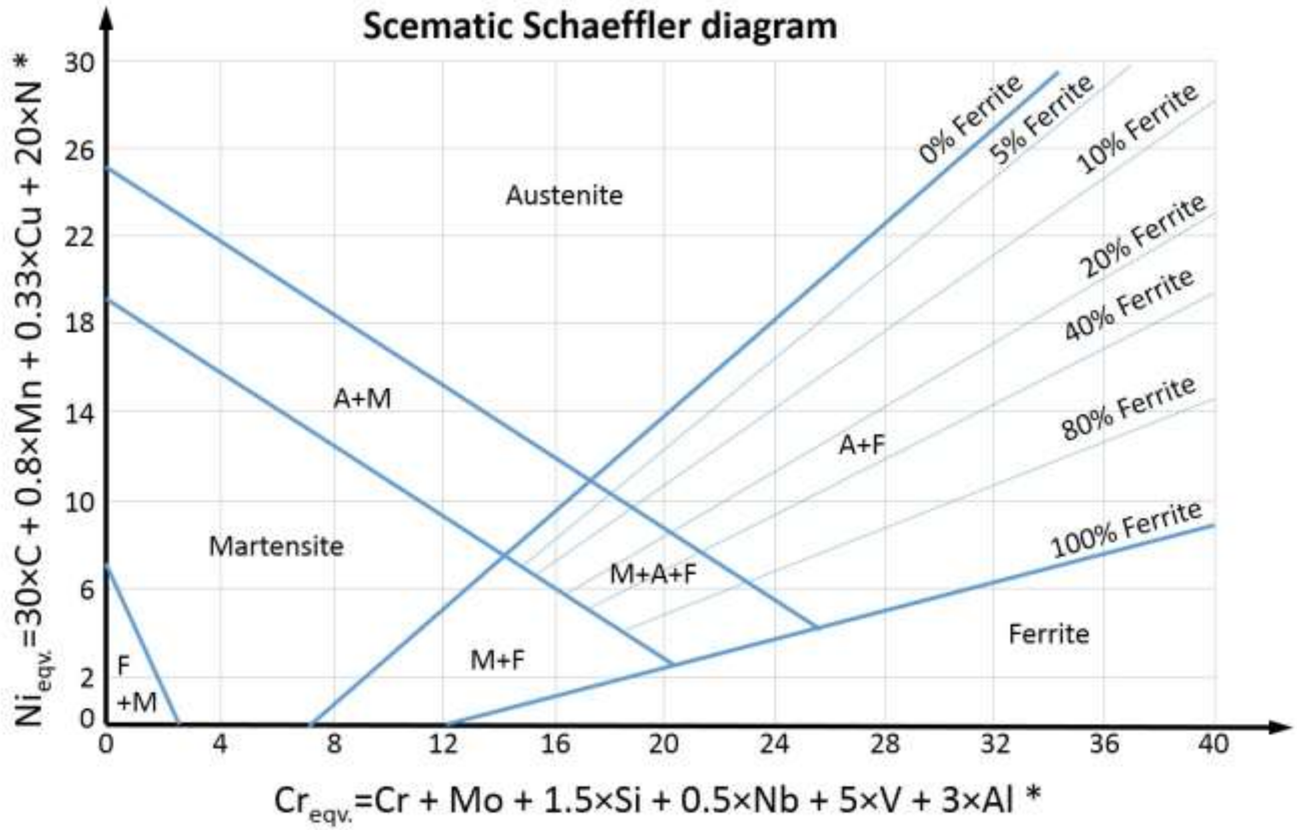
Group 7-10 (according ISO/TR 15608:2017)



* Alloying elements in weight %

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Group 7-10 (according ISO/TR 15608:2017)

Group	Sub-group	Type of steel
7		Ferritic, martensitic or precipitation hardened stainless steels with C ≤ 0.35% and 10.5% ≤ Cr ≤ 30%
	7.1	Ferritic stainless steels
	7.2	Martensitic stainless steels
	7.3	Precipitation hardened stainless steels
8		Austenitic stainless steels
	8.1	Austenitic stainless steels with Cr ≤ 19%
	8.2	Austenitic stainless steels with Cr > 19%
	8.3	Manganese austenitic stainless steels with 4.0% < Mn ≤ 12%

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Group 7-10 (according ISO/TR 15608:2017)

Group	Sub-group	Type of steel
9		Nickel alloy steels with Ni ≤ 10.0%
	9.1	Nickel alloy steels with Ni ≤ 3.0%
	9.2	Nickel alloy steels with 3.0% < Ni ≤ 8.0%
	9.3	Nickel alloy steels with 8.0% < Ni ≤ 10.0%
10		Austenitic ferritic stainless steels (duplex)
	10.1	Austenitic ferritic stainless steels with Cr ≤ 24%
	10.2	Austenitic ferritic stainless steels with Cr > 24%

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Group 11 (according ISO/TR 15608:2017)

Group	Sub-group	Type of steel
11		Steels covered by group 1 except 0.25% < C ≤ 0.5%
	11.1	Steels indicated under 11 with 0.25% < C ≤ 0.35%
	11.2	Steels indicated under 11 with 0.35% < C ≤ 0.5%

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How to identify the composition?

The steel name can be of assistance, if it is given for chemical composition e.g.:

- For unalloyed steels if Mn < 1 wt.%
  - C45 → C × 100 (wt.%) (C = 0,45 %) (mid. value)

- If Mn > 1 wt.% and sum of the alloying elements is < 10 wt.%
  - 42CrMo4

42: C × 100 (wt%) (C=0,42 %)

CrMo: Alloying elements from highest to lowest amount

4: Alloying elements from highest to lowest amount Cr × 4; Mo × 10 (under 1% no number)

How to identify the composition?

- 37CrMo6

C × 100 (wt%) (C=0,37 %)

Alloying elements from highest to lowest amount

Alloying elements from highest to lowest amount Cr × 4; Mo × 10
Cr=1.5 %
Mo≤1%

- Multiplication factors for the different alloying elements are listed in the table

Cr, Co, Mn, Ni, Si, W	Al, Be, Cu, Mo, Nb, Pb, Ta, Ti, V, Zr	Ce, N, P, S	B
4	10	100	1000

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How to identify the composition?

- For high alloyed steels if sum of the alloying elements is > 10 wt%

X6CrNi18-10

C × 100
(C=0,06 wt%)

Alloying elements from highest to lowest amount

Alloying elements from highest to lowest amount **NO multiplication factors**
Cr=18%
Ni=10%

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How to identify the steel?

- Steel names maybe are given in their short name **for application** according EN 10027 -1 standard, in that case not the chemical composition but some main properties are given! For example:

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How to identify the steel?

- Example for short name according to EN 10027 -1:

G S 355 J2 G2 W Cu5

Cu × 10 (m%)

only for cast material letter **G**

Application symbol Structure steel letter **S**

Main property R_{eH}=355 MPa

Additional sign:
J2 – 27J -20 ºC
M – Thermomechanically treated
N – Normalized
Q – Quenched and tempered

Additional property:
W – improved atmospheric corrosion resistance
G2 – killed

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Main application symbols

Application symbol	Meaning	Mechanical Property
S	Structural steel	Minimum Yield Strength
P	Steel for pressure lines and vessels	Minimum Yield Strength
L	Steel for pipe and tube	Minimum Yield Strength
E	Engineering steels	Minimum Yield Strength
B	Steel for reinforced concrete	Characteristic Yield Case
R	Steel for rail use	Minimum Yield Case
H	High Strength Cold Rolled	Minimum Yield Case
D	Flat Products for Cold Forming	
T	Tinmill Products	Nominal Yield Case
M	Electrical Steel	

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Useful Topic Related Links

Steelmaking

https://en.wikipedia.org/wiki/Steelmaking

AOD steel manufacturing

https://en.wikipedia.org/wiki/Argon_oxygen_decarburization

Thermomechanical processing

https://en.wikipedia.org/wiki/Thermomechanical_processing

Steel grades

https://en.wikipedia.org/wiki/Steel_grades

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I-2. Materials used in fusion welding

2.3. Aluminium and aluminium alloys

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Aim & Objectives

Module Aim:	Basic knowledge about the basic properties of metallic materials
Number of hours:	e-learning: 4h, self-study: 4h
Learning Outcomes:	• Knowing the properties of the materials used in fusion welding processes • Identification of the base materials used in fusion welding processes
ECVET:	4

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I-2.3. Aluminium and aluminium alloys

Main aluminum types, classification of aluminum alloys

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About aluminum

- Aluminum (or aluminum) is a light metal with very low density ~2.7 g/cm^3 (iron and steel ~ 7.6 g/cm^3) → good for lightweight constructions
- Aluminum has a relative good corrosion resistance
- Aluminum alloys have low to high strength 70 MPa $\leq R_m \leq$ 700 MPa.
- Young modulus of aluminum is low E = 70-75 GPa (Young modulus of steel 190-210 GPa) → to achieve the same stiffness as steel greater sheet thickness is needed

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Classification of aluminum

- According to ISO/TR 15608:2017 standard aluminum alloys are grouped from 21-25 according their alloying element type and content.
- The alumina (oxide layer) on the surface of every aluminum alloy makes the welding difficult, due to the large difference in their melting point.
- Rule of thumb the welding of heat treated and high strength aluminum alloy is tricky, the mechanical properties of the weld will likely to be inferior to the base material.

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Group 21-23 (according ISO/TR 15608:2017)

- Groups 21-23 are generally for wrought materials

Group	Sub-group	Type of aluminum and aluminum alloy
21		Pure aluminum ≤ 1% impurities or alloy content
22		Non heat treatable alloys
	22.1	Aluminum-manganese alloys
	22.2	Aluminum-magnesium alloys with Mg ≤ 1.5 %
	22.3	Aluminum-magnesium alloys with 1.5 % < Mg ≤ 3.5 %
	22.4	Aluminum-magnesium alloys with Mg > 3.5 %
23		Heat treatable alloys
	23.1	Aluminum-magnesium-silicon alloys
	23.2	Aluminum-zinc-magnesium alloys

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Group 24-26 (according ISO/TR 15608:2017)

- Groups 24-26 are generally for cast materials

Group	Sub-group	Type of aluminum and aluminum alloy
24		Aluminum-silicon alloys with Cu ≤ 1 %
	24.1	Aluminum-silicon alloys with Cu ≤ 1 % and 5% < Si ≤ 15 %
	24.2	Aluminum-silicon alloys with Cu ≤ 1 % and 5% < Si ≤ 15 % and 0.1 % < Mg ≤ 0.8 %
25		Aluminum-silicon-copper alloys with 5% < Si ≤ 14 % and 1.0 < Cu ≤ 5.0 % and Mg ≤ 0.8 %
26		Aluminum-copper alloys with 2 % < Cu ≤ 6 %

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Aluminum alloy designation system

Name (series)	Type of aluminum and aluminum alloy
1000	pure aluminum with a minimum 99% aluminum content wt.% can be work hardened
2000	alloyed with copper can be precipitation hardened to tensile strengths comparable to steel.
3000	alloyed with manganese can be work hardened
4000	are alloyed with silicon mostly intended for casting
5000	are alloyed with magnesium outstanding corrosion resistance

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Aluminum alloy designation system

Name (series)	Type of aluminum and aluminum alloy
6000	alloyed with magnesium and silicon they are easy to machine, are good weldable they can be precipitation hardened, but not to the high strengths that 2000 and 7000 can reach
7000	alloyed with zinc, can be precipitation hardened to the highest strengths of any aluminum alloy (R_m up to 700 MPa for the 7068 alloy).
8000	alloyed with other elements which are not covered by other series

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Useful Topic Related Links

Aluminum

https://en.wikipedia.org/wiki/Aluminium

Aluminum alloys

https://en.wikipedia.org/wiki/Aluminium_alloy

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I.2. Materials used in fusion welding

2.4. Titanium, nickel, copper and other metals and alloys

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Aim & Objectives

Module Aim:	Basic knowledge about the basic properties of metallic materials
Number of hours:	e-learning: 4h, self-study: 4h
Learning Outcomes:	• Knowing the properties of the materials used in fusion welding processes • Identification of the base materials used in fusion welding processes
ECVET:	4

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I-2.4. Titanium, nickel, copper and other metals and alloys

Classification of copper, nickel, titanium, zirconium and their alloys and cast iron

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About copper

- Copper has density ~8.96 g/cm^3
- It is and ductile metal and has good cold formability
- It has very high thermal electrical therefore resistance spot welding needs has some difficulties.
- It has very high thermal conductivity therefore oxy-fuel welding has difficulties.
- Tensile strength of Cu-alloys can be up to high as steels, Young's modulus E= 110–128 GPa
- Soldering and brazing of copper is relatively easy, Cu is also main component of different braze materials

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Classification of copper

- According to the ISO/TR 15608:2017 standard copper and copper alloys are grouped from 31-38 according their alloying element type.
- For other copper alloys also see

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Group 31-38 (according ISO/TR 15608:2017)

Group	Sub-group	Type of copper and copper alloys
31		Pure copper
32		Copper-zinc alloys
	32.1	Copper-zinc alloys, binary
	32.2	Copper-zinc alloys, complex
33		Copper-tin alloys
34		Copper-nickel alloys
35		Copper-aluminum alloys
36		Copper-nickel-zinc alloys
37		Copper alloys low alloyed (<5% other elements) not covered by groups 31-36
38		Other copper alloys (≥5% other elements) not covered by groups 31-36

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About nickel

- Nickel has density ~8.9 g/cm^3
- It is a transition metals and is hard and ductile.
- Under standard conditions because (oxide layer on the surface) corrosion resistant
- Also a main alloy element of stainless steels
- Young's modulus E= 200 GPa
- According to the ISO/TR 15608:2017 standard nickel and nickel alloys are grouped from 41-48 according their alloying element type.

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Group 41-48 (according ISO/TR 15608:2017)

Group	Sub-group	Type of nickel and nickel alloys
41		Pure nickel
42		Nickel-copper alloys (Ni-Cu) Ni ≥ 45% and Cu ≥ 10%
43		Nickel-chromium alloys (Ni-Cr-Fe-Mo) Ni ≥ 40%
44		Nickel-molybdenum alloys (Ni-Mo) Ni ≥ 45% and Mo≤ 32%
45		Nickel-iron-chromium alloys (Ni-Fe-Cr) Ni ≥ 30%
46		Nickel-chromium-cobalt alloys (Ni-Cr-Co) Ni ≥ 45% and Co ≥ 10%
47		Nickel-iron-chromium-copper alloys (Ni-Fe-Cr-Cu) Ni ≥ 45%
48		Nickel-iron-cobalt alloys (Ni-Fe-Co-Mo-Cu) 25% ≤ Ni ≤ 45% and Fe ≥ 20%

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About titanium

- Titanium has relative moderate density ~4.5 g/cm^3
- Ti is a transition metal with a silver color,
- It has high strength 400 MPa < R_m < 1400 MPa but moderate Young's modulus E= 116 GPa
- Titanium is resistant to corrosion in sea water, aqua regia, and chlorine.
- Titanium is often sorted into Grades 1-38 (ASTM standard) according to their chemical composition.
- According to the ISO/TR 15608:2017 standard titanium and titanium alloys are grouped from 51-54 according their alloying element type.

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Group 51-54 (according ISO/TR 15608:2017)

Group	Sub-group	Type of titanium and titanium alloys
51		Pure titanium
	51.1	Titanium with $O_2 < 0.20\%$
	51.2	Titanium with $0.20\% < O_2 \leq 0.25\%$
	51.3	Titanium with $0.25\% < O_2 \leq 0.35\%$
	51.4	Titanium with $0.35\% < O_2 \leq 0.40\%$
52		Alpha alloys e.g.: Ti-0.2Pd, Ti-2.5Cu, Ti-8Al-1Mo-1V, Ti-6Al-2Sn-4Zr-2Mo, Ti-6Al-2Nb-1Ta-0.8Mo
53		Alpha-beta alloys e.g.: Ti-3Al-2.5V, Ti-6Al-4V, Ti-6Al-6V-2Sn, Ti-7Al-4Mo
54		Near beta and beta alloys e.g.: Ti-10V-2Fe-3Al, Ti-13V-11Cr-3Al, Ti-11.5Mo-6Zr-4.5Sn, Ti-3Al-8V-6Cr-4Zr-4Mo

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About zirconium

- Zirconium has a density ~6.5 g/cm^3
- Zirconium is mainly used as refractory, opaficer, alloy element and in nuclear industry.
- It has a moderate Young's modulus E= 86 GPa
- According to the ISO/TR 15608:2017 standard zirconium and zirconium alloys are grouped from 61-62 according their alloying element type.

Group	Sub-group	Type of zirconium and zirconium alloys according ISO/TR 15608:2017
61		Pure zirconium
62		Zirconium with 2.5% Nb

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About cast irons

- Cast irons are iron based alloys with more than 2% carbon content
- It can be grouped according the microstructure and graphite type.
- Generally cast irons are very hard to weld, need high temperature preheating and special very ductile filler metals. The danger of cracking while preheating and welding is high.
- According to the ISO/TR 15608:2017 standard cast irons are grouped from 71-76 according their alloying element type.

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Group 71-73 (according ISO/TR 15608:2017)

Group	Sub-group	Type of cast iron
71		Grey cast iron with specified tensile strength or Brinell hardness
72		Spheroidal graphite cast irons with specified mechanical properties
	72.1	Spheroidal graphite cast irons with specified tensile strength, 0.2% proof stress and elongation or specified Brinell hardness
	72.2	Spheroidal graphite cast irons (like 72.1) with specified impact resistance value
73		Malleable cast irons
	73.1	Whiteheart Malleable (decarburized) cast irons most suitable for welding
	73.2	Whiteheart Malleable (decarburized) cast irons
	73.3	Blackheart Malleable (non-decarburized) cast irons

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Group 74-76 (according ISO/TR 15608:2017)

Group	Sub-group	Type of cast iron
74		Austempered ductile cast irons
75	75.1	Austenitic spheroidal graphite cast irons with specified element content
	75.2	Austenitic spheroidal graphite cast irons
	75.3	Austenitic grey cast irons
76		Cast irons excepting 71-75
	76.1	Abrasion resistant cast irons

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Useful Topic Related Links

Copper

https://en.wikipedia.org/wiki/Copper

Copper alloy

https://en.wikipedia.org/wiki/List_of_copper_alloys

Nickel

https://en.wikipedia.org/wiki/Nickel

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Useful Topic Related Links

Titanium

https://en.wikipedia.org/wiki/Titanium

Titanium alloy

https://en.wikipedia.org/wiki/Titanium_alloy

Zirconium

https://en.wikipedia.org/wiki/Zirconium

Cast iron

https://en.wikipedia.org/wiki/Cast_iron#Allo
ying_elements

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I.3. Materials weldability and heat treatment

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Aim & Objectives

Module Aim:	Knowing different aspects concerning weldability, heat treatment, residual stress and distortion.
Number of hours:	4 hours e-learning, 4 hours self-study
Learning Outcomes:	• Knowing different theoretical and practical aspects concerning the materials weldability. • Knowing the main heat treatments applied for the materials used for welded structures • Explain fully the origin, influencing factors and magnitude of residual stress and distortion in welded fabrication. • Detailed procedures on how to minimize distortion and stress.
ECVET:	4

Lecture Outline

- Definition of weldability
- Metallurgical weldability
  - Chemical composition
  - Metallurgical properties
  - Physical Properties
- Constructional weldability
  - Design, loading
- Operational weldability
  - Preparation, procedure, heat treatment

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I.3.1. Materials weldability

Behaviour of structural steels in fusion welding

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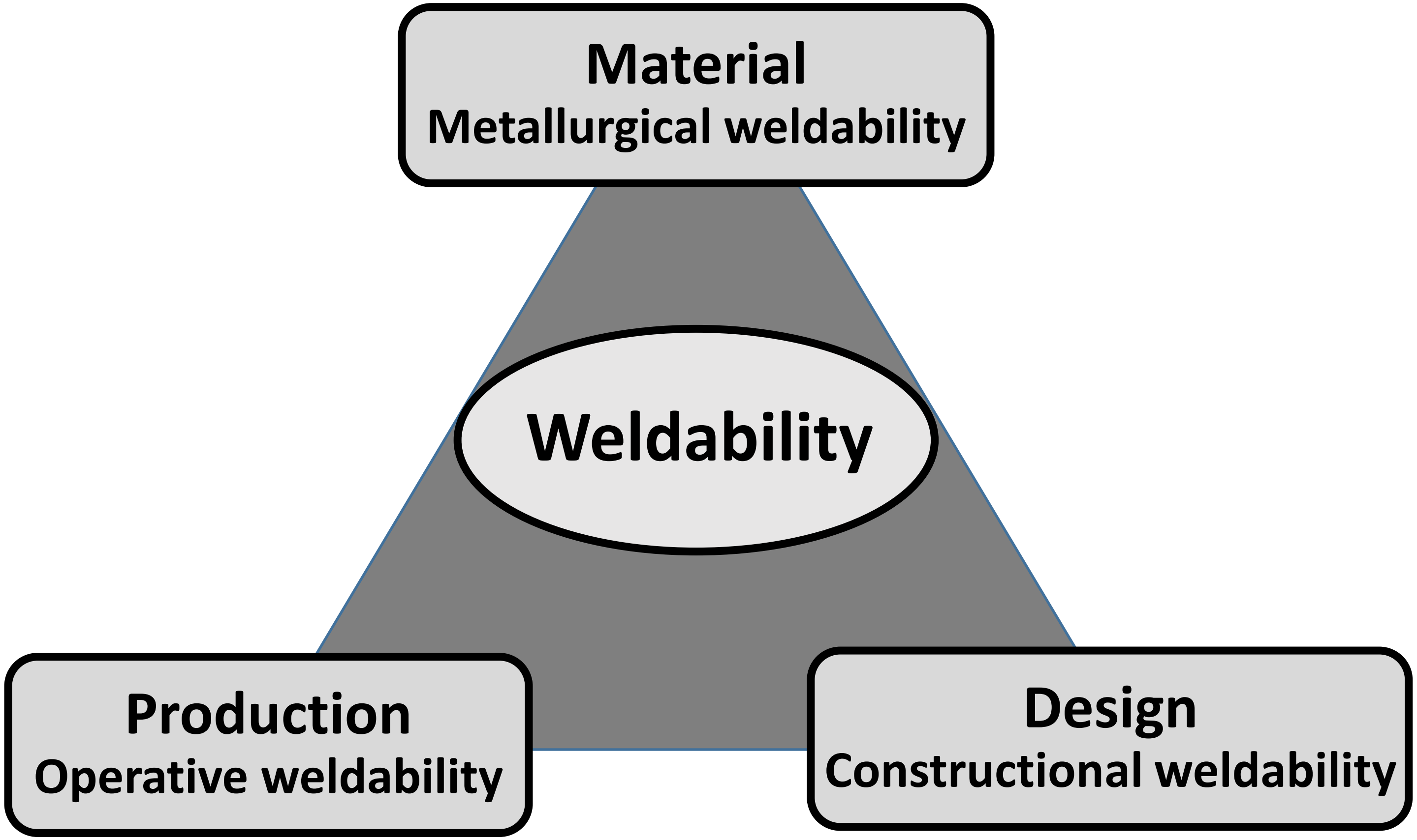
Definition of Weldability (ISO/TR 581)

- A component consisting of metallic material is considered to be weldable by a given process when **metallic continuity** can be obtained by welding using a **suitable welding procedure**. At the same time, the welds shall comply with the requirements specified in regard to both their **metallurgical** and **mechanical properties** and their influence on the **construction** of which they form a part. Weldability is governed by three factors, namely **material, design and production**.

Definition of Weldability (ISO/TR 581)



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Definition of Weldability (ISO/TR 581)

Material, design and production is associated with different properties:

- Metallurgical weldability: material properties
  - These are influenced primarily by production and to a minor extent by the design.
- Constructional weldability: design properties
  - These are influenced primarily by the material and to a minor extent by production.
- Operative weldability: production properties
  - These are influenced primarily by the design and to minor extent by the material.

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Metallurgical Weldability

Chemical composition

- Tendency for brittle fracture, ageing, hardening, hot cracking, behaviour of molten pool, vaporization, melting temperature range

Metallurgical properties

- Segregations, inclusions, anisotropy, grain size, crystalline structure.

Physical properties

- Expansion, thermal properties, melting point, mechanical properties.

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Constructional Weldability

Design of the construction

- Distribution of forces in the component, arrangement of welds, workpiece thickness, notch effect, differences in stiffness.

Conditions regarding loading

- Type and magnitude of stresses in the component, dimensional extent of stresses, speed of stressing, temperatures, corrosion.

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Operative Weldability

Preparation for welding

- Type of joint, shape of joint.

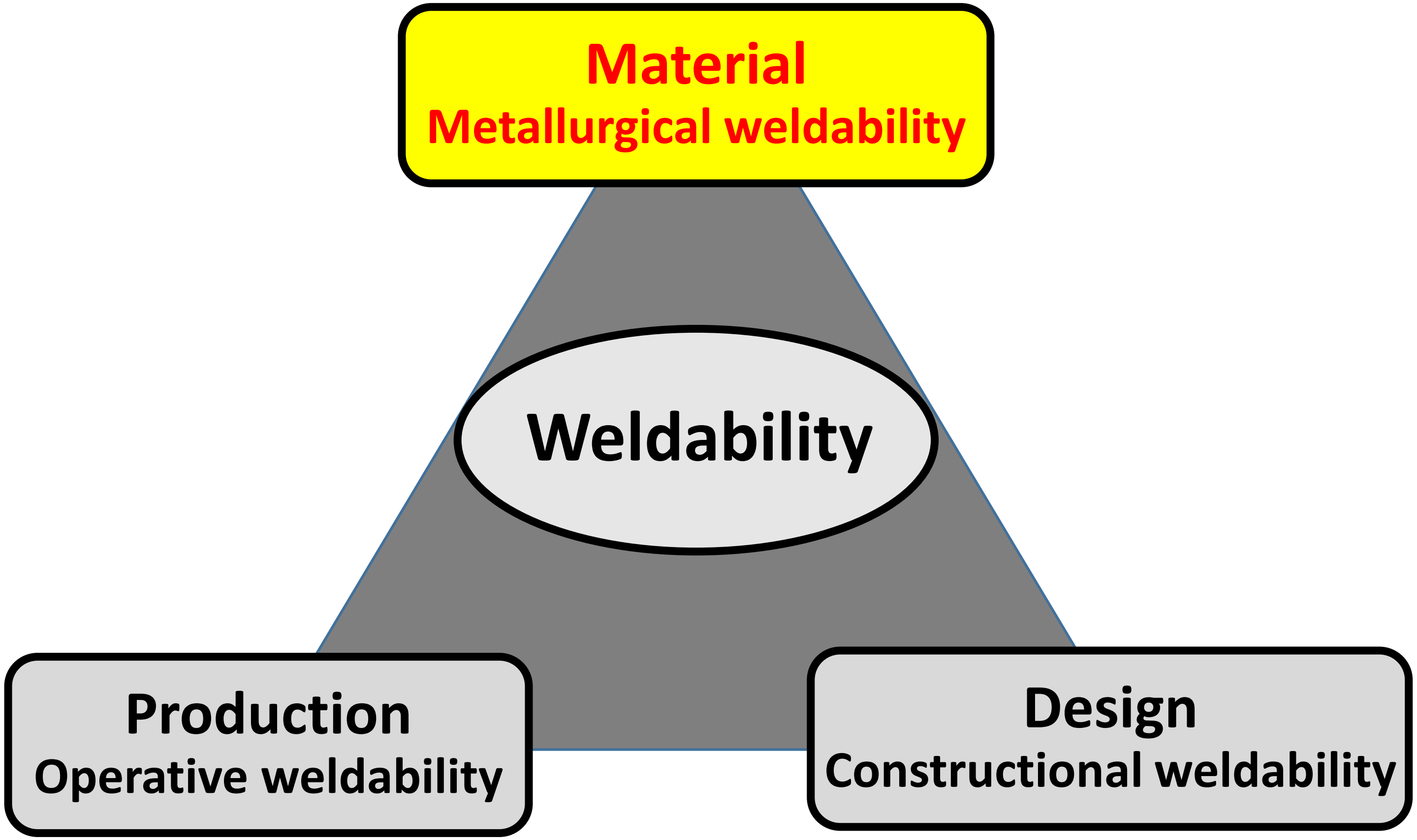
Welding procedure(s)

- Welding process(es), types of filler materials/welding consumables, welding parameters, welding sequence, preheating, welding position(s), precautions taken with respect to unfavourable weather conditions.

Pre- and post-treatment

- Post-weld heat treatment, mechanical treatment (e.g. grinding, machining, peening), chemical treatment (e.g. pickling).

Metallurgical Weldability



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Metallurgical Weldability

A material possesses **metallurgical weldability** if, in the course of the procedure adopted, the chemical, metallurgical and physical properties inherent in the material allow a weld to be made which satisfies the requirements of the application.

The less the factors governed by the material have to be taken into account when determining the welding procedure for a given construction, the better is the Metallurgical Weldability of a material within a material group.

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Metallurgical Weldability - Factors

- Chemical composition
  - Tendency to: brittle fracture, ageing, hardening, hot cracking, behavior of molten pool, vaporization temperature, melting range.
- Production methods
  - Segregation, inclusion, anisotropy, grain size, crystalline structure
- Physical properties
  - Expansion, thermal conductivity, melting point, mechanical strength and toughness

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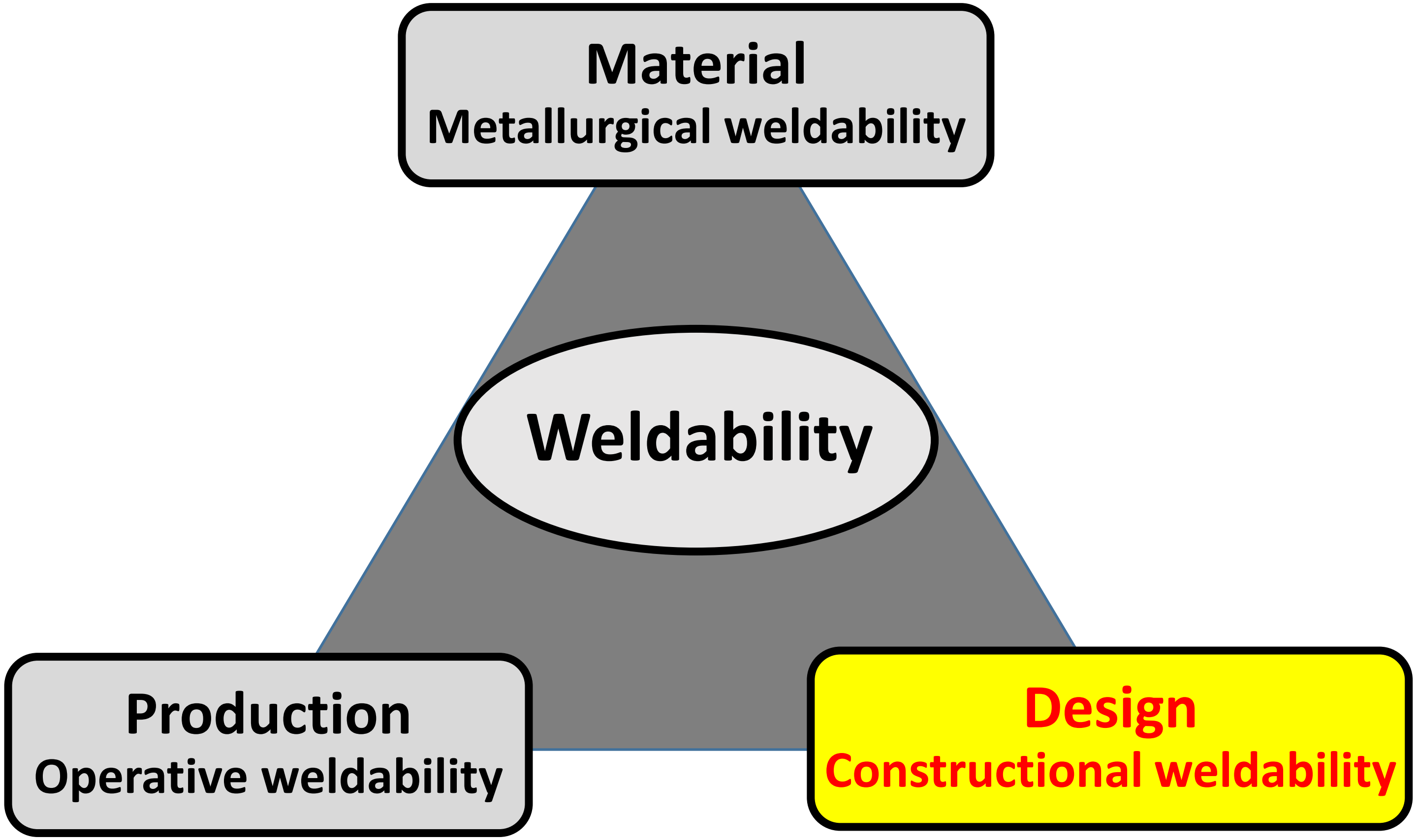
Constructional Weldability



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Constructional Weldability

Constructional weldability exists in a construction if, using the material concerned, the component remains capable of functioning under the envisaged operating conditions by virtue of its design.

The less the factors governed by the design have to be taken into account when selecting the material for a specific welding procedure, the greater is the constructional weldability of a specific structure or component.

Constructional Weldability - Factors

- Design
  - Distribution of forces, arrangement of welds, workpiece thickness, notch effect, differences in stiffness.
- Conditions regarding loading
  - Type and magnitude of stresses, dimensional extent of stresses, speed of stressing, temperatures, corrosion.

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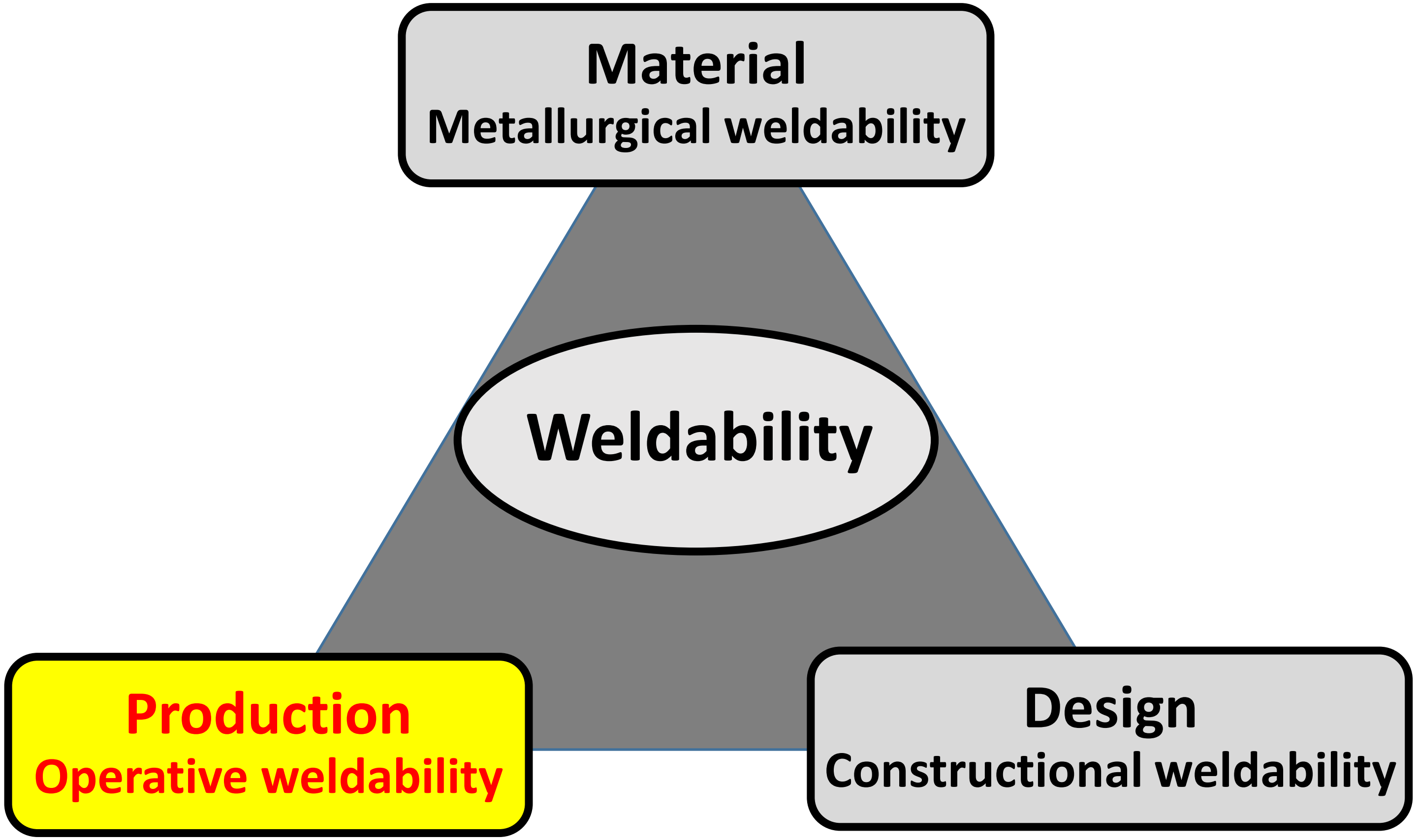
Operative Weldability



Operative Weldability

Operative weldability exists for a welding procedure if the welds envisaged for a particular construction can be made properly under the chosen conditions of production.

The less the factors governed by the welding procedure have to be taken into account in designing a construction for a specific material, the better is the operative weldability of a procedure intended for a specific structure or component

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Operative Weldability - Factors

- Preparation
  - Type and shape of joint
- Welding procedure
  - Process, types of filler, parameters, sequence, preheating, positions, unfavorable weather conditions etc.
- Pre -, post treatment
  - Heat treatment, mechanical treatment, chemical treatment

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Useful Topic Related Links

Weldability

I.3. Materials weldability and heat treatment

I.3.2. Effects of composition, thickness and temperature (preheat and interpass temperaures)

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Aim & Objectives

Module Aim:	Knowing different aspects concerning weldability, heat treatment, residual stress and distortion.
Number of hours:	e-learning – 4 h, self-study – 4 h
Learning Outcomes:	• Knowing different theoretical and practical aspects concerning the materials weldability. • Knowing the main heat treatments applied for the materials used for welded structures • Explain fully the origin, influencing factors and magnitude of residual stress and distortion in welded fabrication. • Detailed procedures on how to minimize distortion and stress.
ECVET:	4

Lecture Outline

- Parts of weld
- Types of cracks in weld metal and heat affected zone
- Solidification cracking
- Hydrogen induced cracking
- Lamellar tearing

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Effects of composition, thickness and temperature

Preheat and interpass

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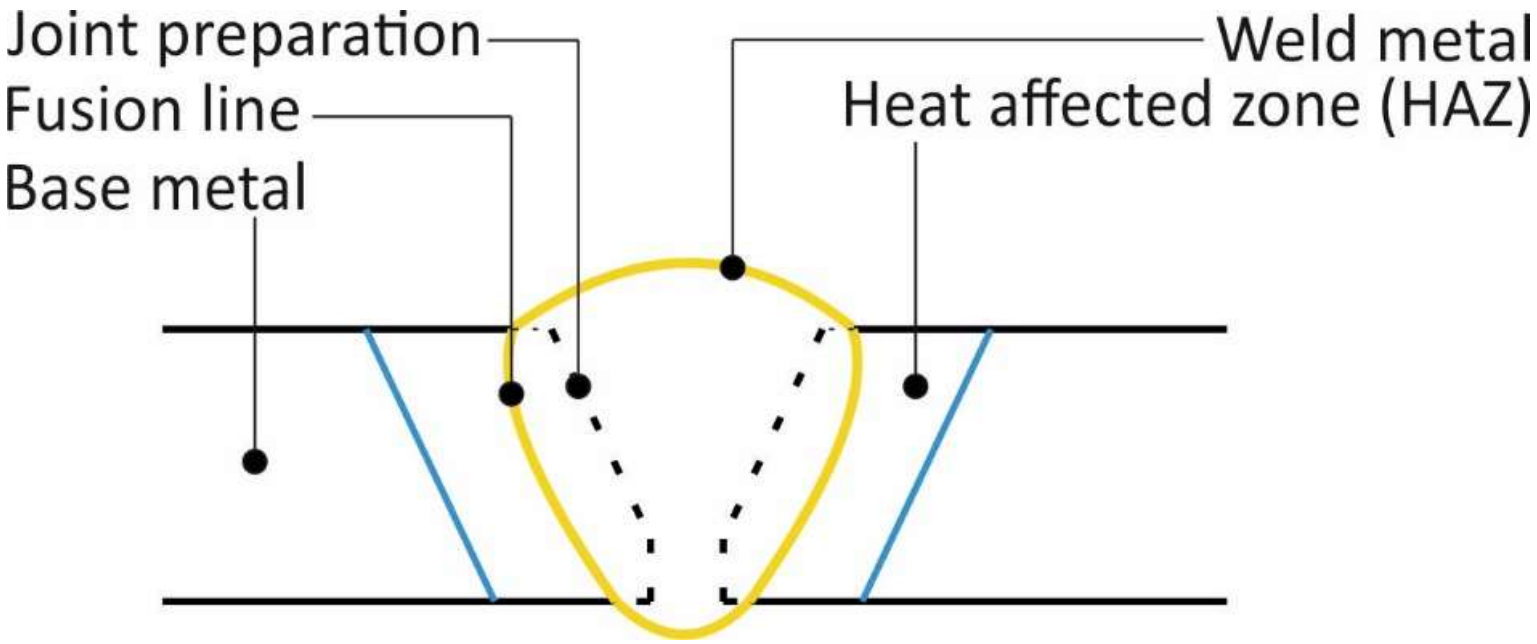
Parts of weld



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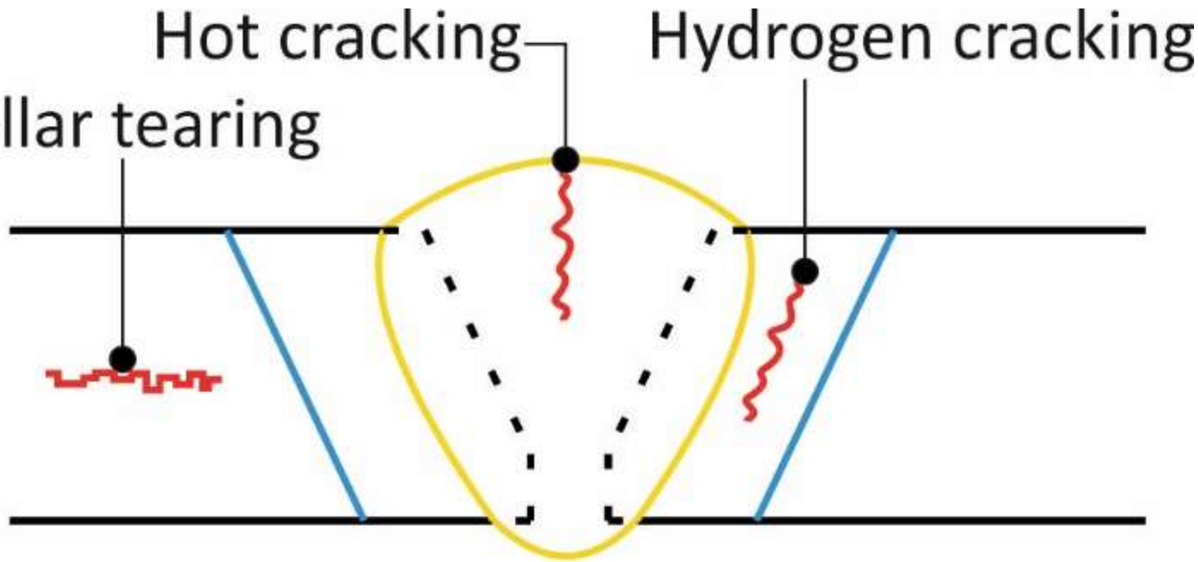
Types of cracks



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Solidification cracking (hot cracking)

- Occurs in fusion zone prior to complete solidification
- Normally appear along the centreline of the weld bead
- Associated with liquid films along solidification boundary
- The cracks are often open to the surface

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Solidification cracking

Prevention

- Control weld metal composition
  - Manganese and silicon alloying to prevent last liquid to solidify sulfur film
- Reduce stresses in weld metal
  - Use proper joint preparation
- Control solidification pattern
  - Use proper welding speed

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Hydrogen cracking (cold cracking)

- Generally occurs below 100°C (ambient temperature, hours after solidification)
- Caused by dissolved entrapped hydrogen
- Generally occurs in the heat affected zone (HAZ)
- Associated with three conditions
  - Presence of hydrogen
  - Martensitic microstructure
  - Tensile stress at the sensitive location

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Hydrogen cracking

Causes

Sources of hydrogen in the weldment:

- Filler metal, moisture in the electrode covering, welding flux, shielding gas, contamination.
- Parent metal susceptibility to form hard phases (martensite, bainite) → Carbon Equivalent (CE)

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Avoidance of cracking

Chemical composition

- Carbon Equivalent (CE)

$$CE_{IIW} = C\% + \frac{Mn\%}{6} + \frac{Cr\% + Mo\% + V\%}{5} + \frac{Ni\% + Cu\%}{15}$$

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Hydrogen cracking

Prevention

- Minimize sources of hydrogen
  - Drying covered electrodes (100-300°C for 1-3 hours, specified by the manufacturers)
  - Clean, degrease surfaces with cleaning fluids that contains no hydrogen
  - Use low hydrogen filler metals
  - Use proper shielding

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Hydrogen cracking

Prevention

- Reduce martensitic phase transformation
  - Reduce weld metal cooling rate
  - Increase heat input
  - Preheat according to base metal's CE
- Reduce tensile stress

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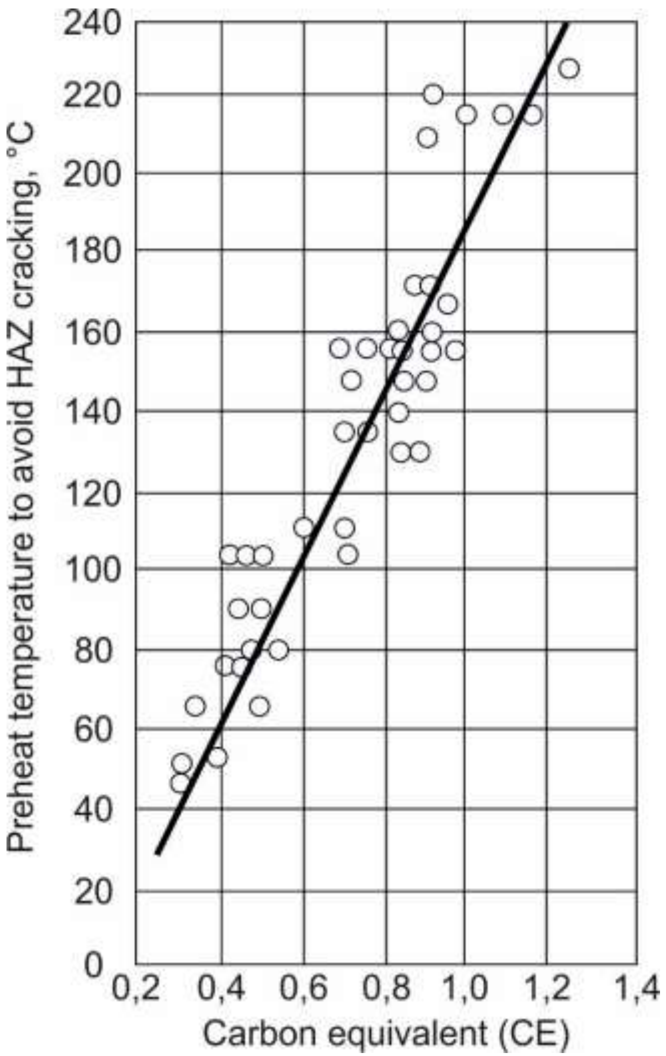
Hydrogen cracking

Preheat temperature

- According to ASM Metals Handbook vol. 6



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Lamellar tearing

- Generally in cases of, fillet welds in corner or T joints
- Only encountered in hot rolled thick plates
- Observed in the base metal parallel to the weld fusion line and the plate surface
- Inclusions present in the centerline of the rolled plate
- May or may not propagate to the surface

Lamellar tearing

Prevention

- Reduce base metal inclusions
    - Minimize sulfur and oxygen content
- Higher strength material is more susceptible
- Reduce plate thickness (< 25 mm)
- Use proper joint design

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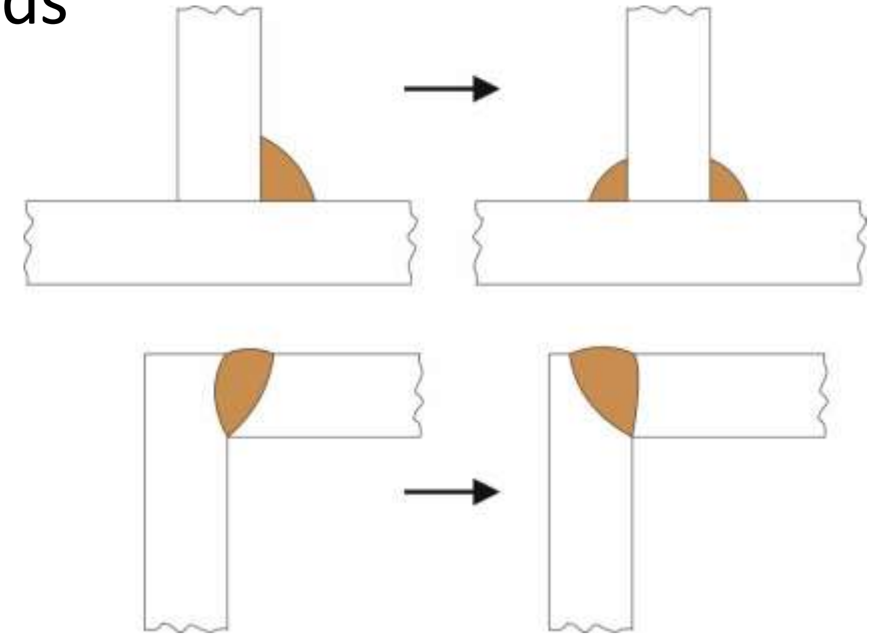
Lamellar tearing

Joint configuration

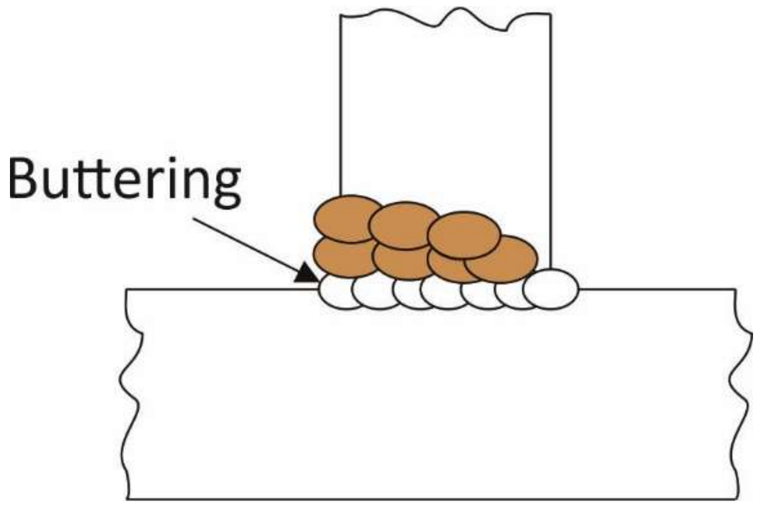
- Use butt joints
- In case of T joints, large single-fillet welds: use double-sided welds



Lamellar tearing

Buttering

- Buttering susceptible plate with low-strength weld metal
- The surface of the plate should be grooved, the butter layer length is 15 to 25 mm and 5 to 10 mm thick



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Lamellar tearing

Steel products with improved deformation

- Improved deformation properties perpendicularly to the surface: standard EN 10164
- Minimum reduction area for different classes
- $Z(\%) = \left(\frac{S_0 - S_u}{S_0}\right) \times 100$

Quality Class	Reduction of area in %	
	Min. average value of three tests	Min. individual value
Z15	15	10
Z25	25	15
Z35	35	25

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Useful Topic Related Links

[Welding defects](#)

[Hot cracking lecture](#)

[Cold cracking lecture](#)

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I.3. Materials weldability and heat treatment

I.3.3. Heat treatment of base materials and welded joints

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Aim & Objectives

Module Aim:	Knowing different aspects concerning weldability, heat treatment, residual stress and distortion.
Number of hours:	e-learning – 4 h, self-study – 4 h
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Lecture Outline

- Definition of heat treatment
- Conventional processes
  - Annealing
  - Normalizing
  - Quenching
  - Tempering
- Special processes
  - Flame hardening
  - Case hardening

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Heat treatment of base materials and welded joints

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Definition of heat treatment

Heat treatment can be defined as an operation or combination of operations including heating and cooling in solid state.

Basically, heat treatment consists of three-steps:

1. Heating to a specific temperature
2. Maintaining at temperature
3. Cooling at a specific rate

With heat treatment the full advantage of a steel product can be taken: can be made strong and hard or soft and ductile.

Main categories

Heat treatment can be divided into two categories:

1. Conventional heat treatments
    1. Annealing
    2. Normalizing
    3. Quenching
    4. Tempering
    5. Stress relieving
2. Special heat treatmens
    1. Flame or induction hardening
    2. Case hardening

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Annealing

- Annealing is most often a hardness reducing process.
- In annealing a sufficient time (1 hour per 25 mm thickness) has to be allowed at elevated temperature to reach fully austenitic state.
- Slow uniform heating and cooling are desirable.
- Furnace cooling is typically used.
- Typically used before forming processes.

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Normalizing

- Similar to annealing, except the higher rate of cooling by cooling on air.
- Normalizing is typically used to lessen grain size and stress relieving.
- Normalized steels are harder and have higher strength than annealed.
- Typically used before CNC machining.

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Quenching

- Quenching can be described as an operation that provides rapid cooling of steel from fully austenitic state.
- Different rates of cooling can be obtained: air, water, oil, molten salts.
- The maximum hardness is accompanied by brittleness.
- Subsequent heat treatment is needed: tempering.

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Tempering

- Tempering is used to modify the steel properties after quenching.
- Tempering is a reheating process and always done at a temperature, where no structural changes occurs.
- The purpose is to reduce brittleness and increase toughness.

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Stress relieving

- Heating under transformation temperature as in case of tempering.
- The purpose is to relief stresses, prevent distorting and cracking during machining.
- After welding residual stresses can built up, which can be reduced by stress relieving process.

Flame hardening

- Surface hardening process.
- Heat is applied to the part being hardened by oxy-acetylene or similar flame.
- After heating the heated area is quenched with water.
- The result is a hardened surface which provides excellent wear resistance and hardness.

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Case hardening

- The conventional methods of case hardening are: carburizing and nitriding.
- The result is similar to flame hardening, but happens due to chemical and thermal processes together.
- Very high hardnesses (> 65 HRc) could be reached by case hardening, which provides excellent wear resistance.

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Useful Topic Related Links

[Heat treating](#)

[Heat treatment of steels - Lecture](#)

I.3. Materials weldability and heat treatment

I.3.4. Development of residual stress due solidification, cooling and shrinkage

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Aim & Objectives

Module Aim:	Knowing different aspects concerning weldability, heat treatment, residual stress and distortion.
Number of hours:	e-learning – 4 h, self-study – 4 h
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Lecture Outline

- Definition of residual stress
- Thermal processes
- Residual stress in arc welding
  - Development of longitudinal stresses
  - Development of transversal stresses
  - Welding sequence

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Development of residual stress due solidification, cooling and shrinkage

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Residual stress - Definiton

- Residual stress is the internal stress, which remains in the metal after the manufacturing processes are completed.
- Can form after thermal cutting, welding, forming, heat treating.

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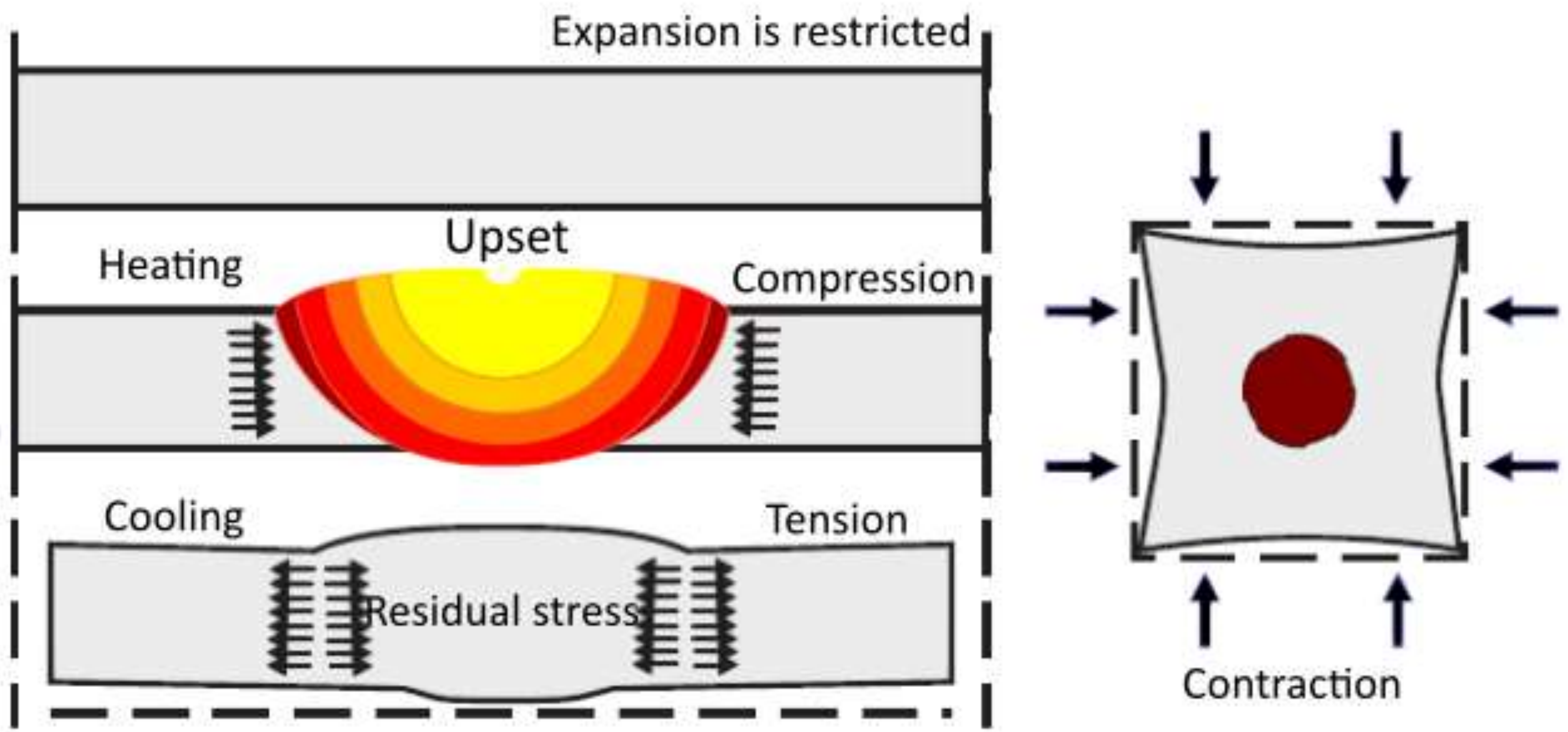
Residual stress by thermal process

- Stresses may be set up when expansion and contraction is restricted.
- At the heated area the metal becomes upset due to restricted expansion by the relatively cold surrounding.
- After cooling the upset induces tension around the heated area → residual stress.

Residual stress by thermal process



Residual stress in arc welding

- The molten pool is going through thermal expansion.
- The surrounding is are relatively cool and do not expand at the same rate → the expansion is restricted by the plates itself.
- During cooling the welded area goes through restricted contraction and sets up high tensile stresses.
- This high residual stress stays inside the plate after welding if nothing else is done.

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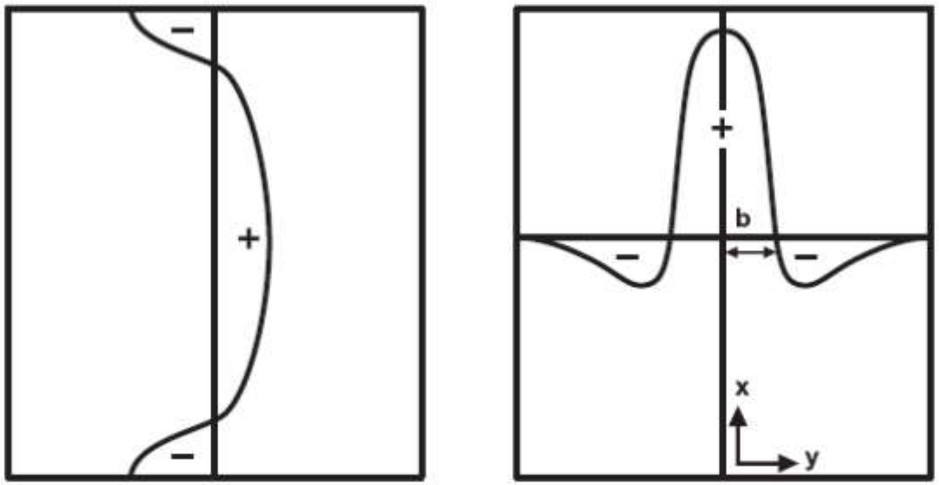
Residual stress in arc welding

- Transverse stresses are not high, except at the edge of the plates.
- Longitudinal stresses in the center line are the highest and can reach yield strength.



Transverse residual stress   Longitudinal residual stress

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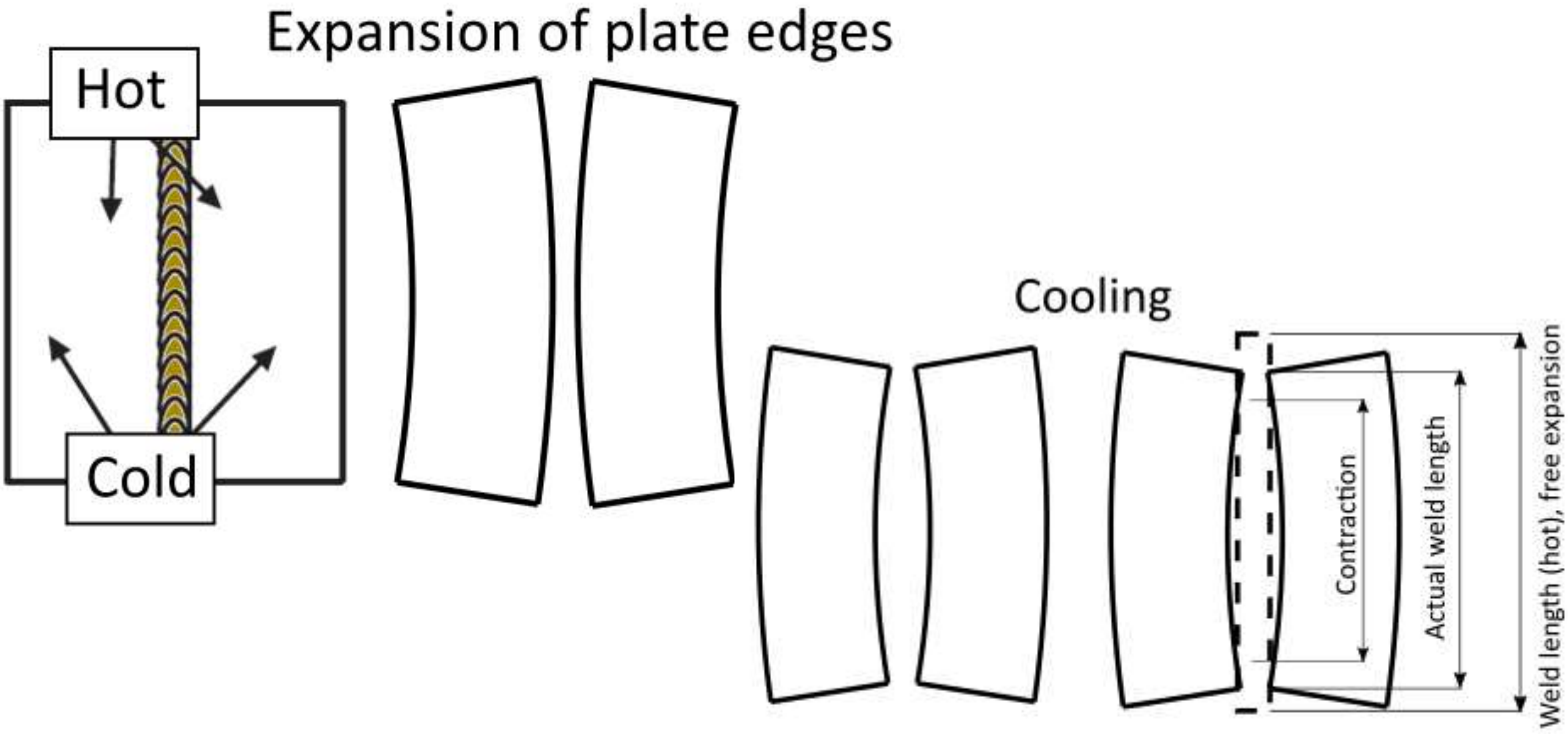
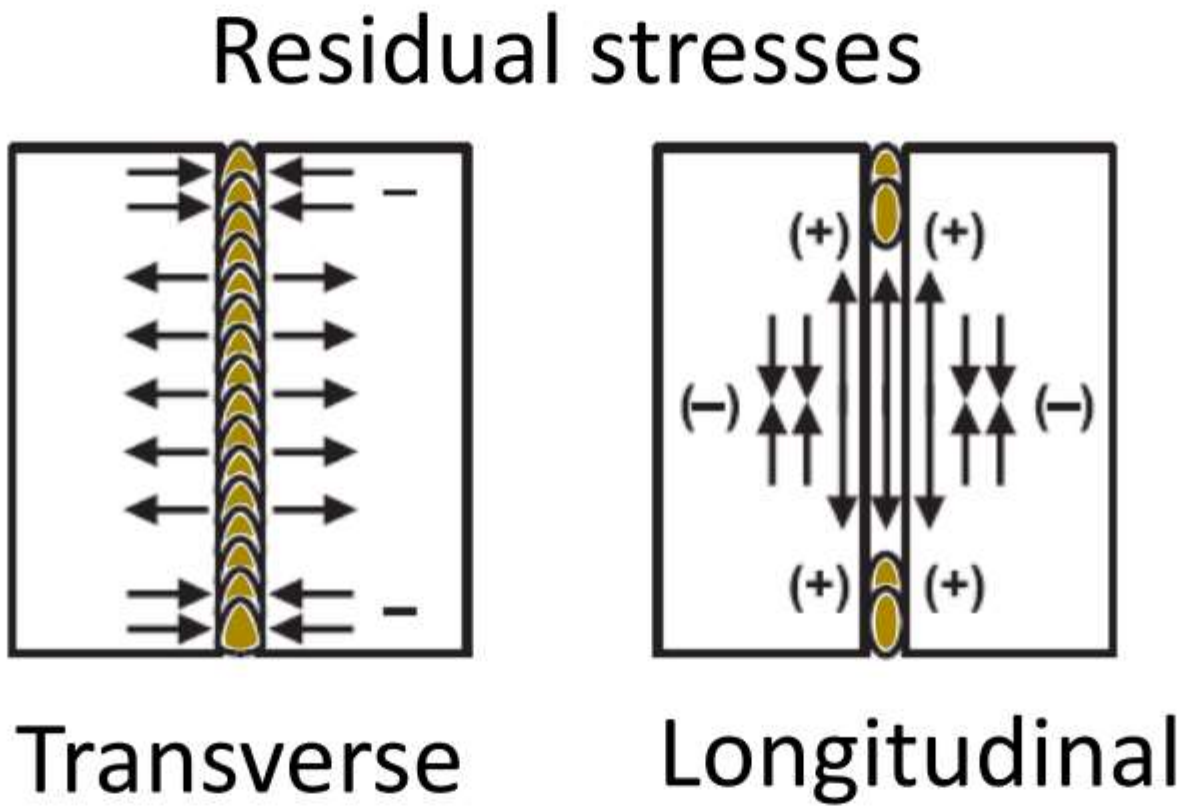
Residual stress in arc welding



Residual stress in arc welding



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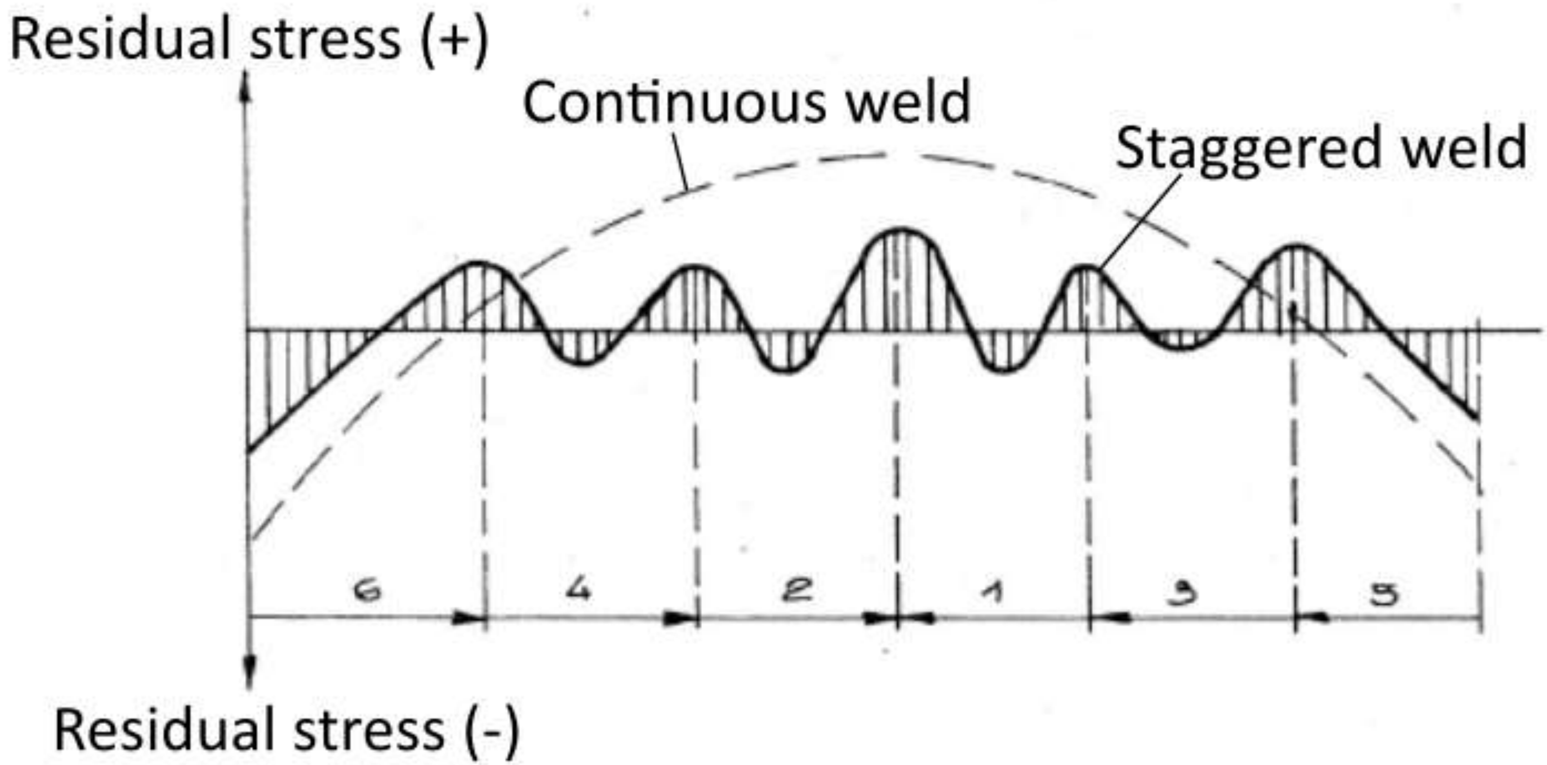
Residual stress in arc welding



Useful Topic Related Links

[Residual stress]

[Residual stress in welding - Lecture]

I.3. Materials weldability and heat treatment

I.3.5. Preheating, post heating

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Aim & Objectives

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Lecture Outline

- Definition of preheating
- Purpose of preheating
  - Reduce residual stresses
  - Remove moisture
  - Promote fusion
- Preheating temperatures
- Post-weld heating, definition, purpose
- Stress relief
- Post-weld heating temperatures
- Techniques

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Preheating and post-weld heating

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Preheating - Definition

- Preheating is a procedure, applied to the base metal immediately before welding.
- Preheating can be applied locally to areas to be welded, or to the whole component.
- It is essential, that the minimum preheat temperature should be maintained during the whole welding operation.

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Preheating - Purpose

- Slow down the cooling rate after welding (reduce hardening)
- Reduce shrinkage and distortion
- Remove moisture (diffusible hydrogen)
- Promote fusion

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Preheating – Reduce shrinkage and distortion

- In case of highly restrained joints and low ductility materials.
- The surrounding material around the weld cannot withstand the shrinkage after welding.
- This effect can be reduced by preheating.

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Preheating – Remove moisture

- The remnant moisture can act as a source of diffusible hydrogen, which highly increases the risk of HIC.
- In case of metal, which forms a porous oxide layer on air (aluminum, stainless steel) the risk of moisture absorption from atmosphere is more likely.

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Preheating – Promote fusion

- In case of alloys, which have a very high thermal conductivity the weld metal can cool down quickly after welding.
- Preheat is used to raise the initial temperature before welding to ensure sufficient fusion from the start.
- Generally used in case of copper and aluminum alloys.

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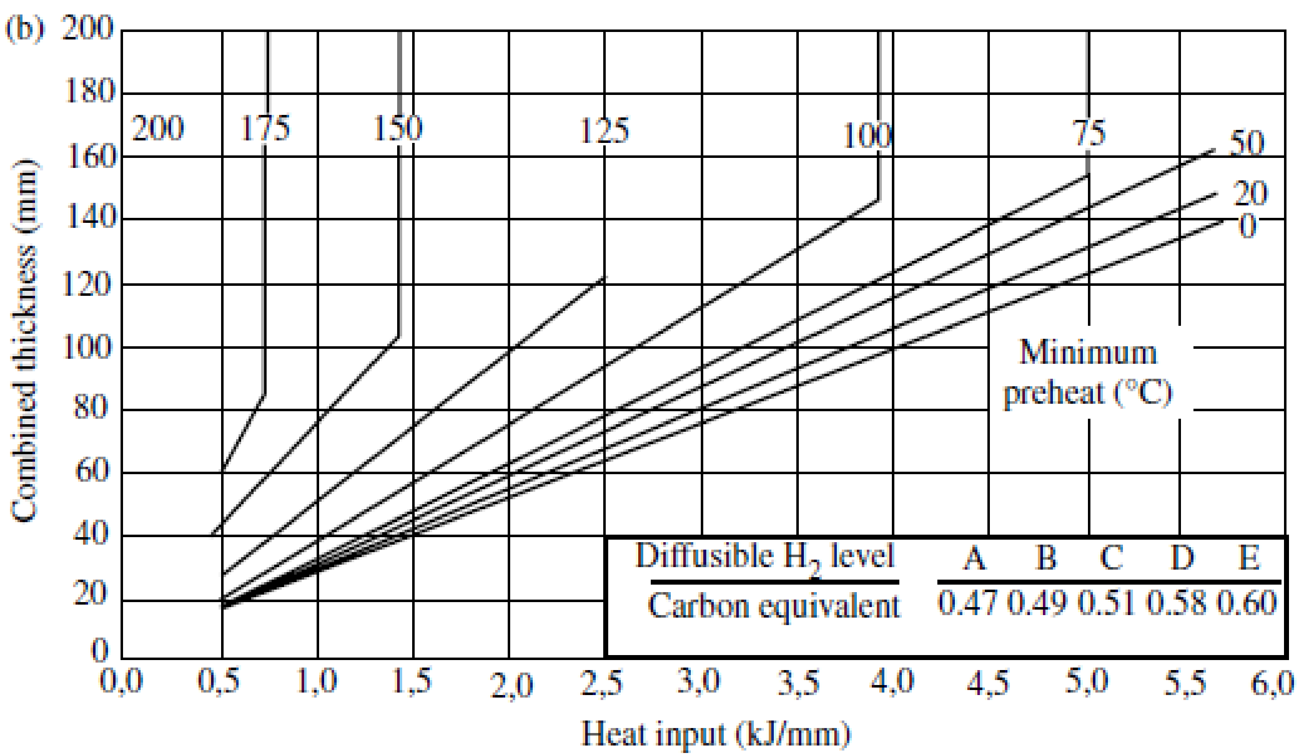
Preheating temperature in terms of HIC

- According to EN 1011 standard



Diffusible hydrogen (mL/100g)	CE axis
>15	A
10-15	B
5-10	C
3-5	D
<3	E

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Post-weld heating

- Post-weld heat treatment (PWHT) is the application of heat after welding.
- The purpose of PWHT is similar to preheating: reduce cooling rate after welding:
  - Minimize risk of HIC.
  - Reduce hardness, brittleness and increase toughness and ductility in HAZ and WM.
  - Reduce residual stresses after welding.

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Post-weld heating – Stress relieving

- PWHT can be used in order to reduce stresses in WN and HAZ after welding.
- During PWHT the maximum temperature is under any phase transformation temperature.
- The closer the temperature to the critical re-crystallization temperature, the more effective the stress relief.

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Post-weld heating

Steel Grade	BS EN 13445	ASME VIII	BS PD 5500
	Temp range °C	Normal holding temp ˚C	Temp range °C
C Steel	550-600	593	580-620
C 1/2 Mo	550-620	593	630-670
1Cr 1/2 Mo	630-680	593	630-700
2 1/4 Cr/Mo	670-720	677	630-750
5CrMo	700-750	677	710-750
3 1/2 Ni	530-580	593	580-620

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Techniques

- Material thickness, size of weld, available space, equipment, heating time, cost all should be considered.
- The actual temperature should be checked all time.
- Minimum and maximum temperatures should be considered.
- Furnace, torches, induction, radiant heaters etc.

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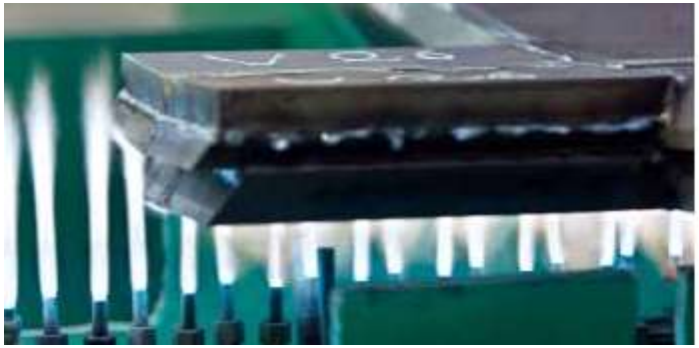
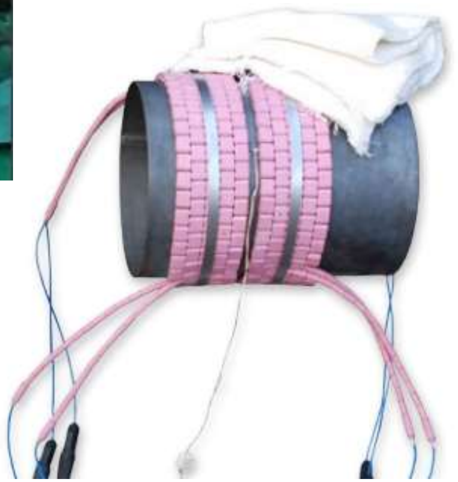
Techniques – Flame heating



Techniques – Induction heating



Useful Topic Related Links

Weldability

Preheating

Post weld heat treatment - ASME

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I.3. Materials weldability and heat treatment

I.3.6. Relationship between heat input and shrinkage, residual stress and distortion

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Aim & Objectives

Module Aim:	Knowing different aspects concerning weldability, heat treatment, residual stress and distortion.
Number of hours:	e-learning – 4 h, self-study – 4 h
Learning Outcomes:	• Knowing different theoretical and practical aspects concerning the materials weldability. • Knowing the main heat treatments applied for the materials used for welded structures • Explain fully the origin, influencing factors and magnitude of residual stress and distortion in welded fabrication. • Detailed procedures on how to minimize distortion and stress.
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Lecture Outline

- Distortion caused by welding
- Estimation of shrinkage
- Transverse shrinkage in butt welds
- Longitudinal shrinkage in butt welds
- Angular distortion of fillet welds
- Effects of heat input on distortions
- Neutral axis

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Relationship between heat input and shrinkage, residual stress and distortion

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Distortions caused by welding

- The welding heat causes residual stress and distortion.
- Usually, the distortion occurs in compounding forms, not in a simple form.
- Types of distortion:
  - Shrinkage: longitudinal and transverse
  - Angular distortion: transverse shrinkage
  - Bending distortion: longitudinal shrinkage
  - Buckling: longitudinal shrinkage, thin sheets
  - Twisting: high longitudinal shrinkage, thin sheets

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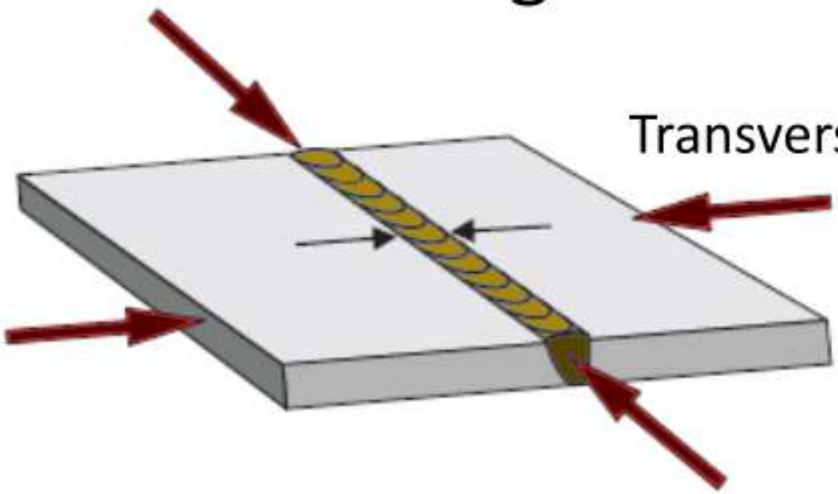
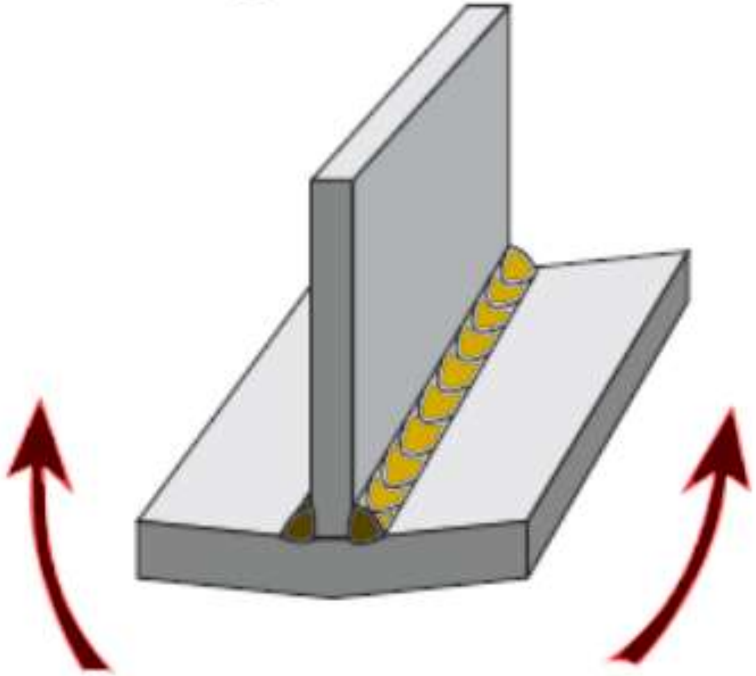
Distortions caused by welding



Distortions caused by welding

Angular distortion



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Distortions caused by welding

Bending distortion

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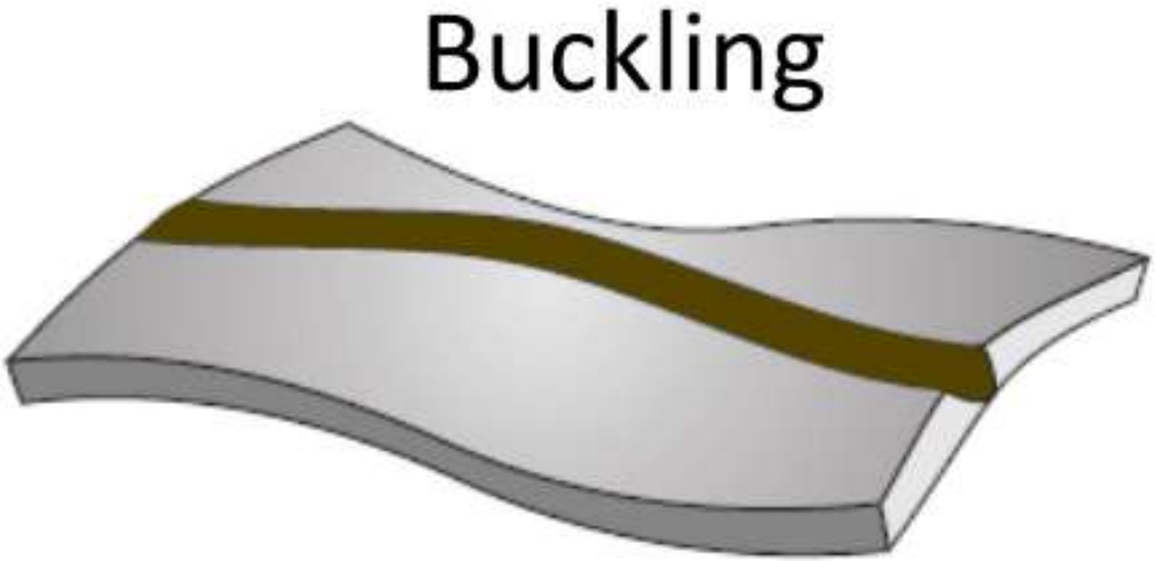
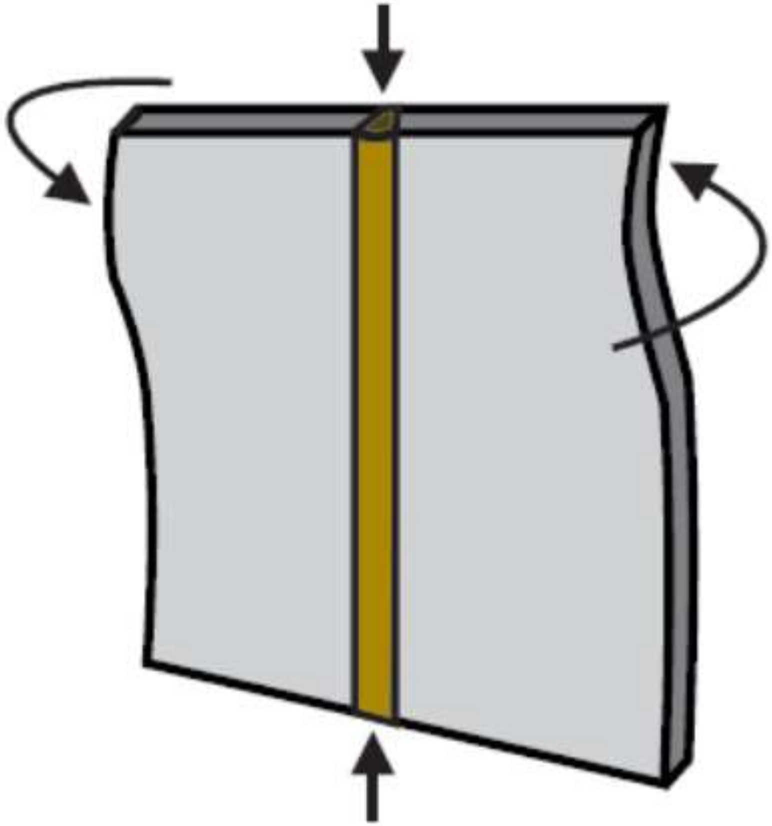
Distortions caused by welding



Distortions caused by welding

Twisting



Estimation of shrinkage

- Formulas are available to estimate the amount of shrinkage after welding.
- These formulas do not give the exact results, but provide some indicators to estimate the amount of shrinkage.

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Transverse shrinkage in butt welds

- S – transverse shrinkage
- Aw – cross sectional area of weld metal
- t – thickness of plate
- d – root opening
- k = 0.18 for 6 mm ≤ t ≤ 25 mm
- k = 0.20 for t ≥ 20 mm

$$S = k\frac{A_w}{t} + 0.05\,d$$

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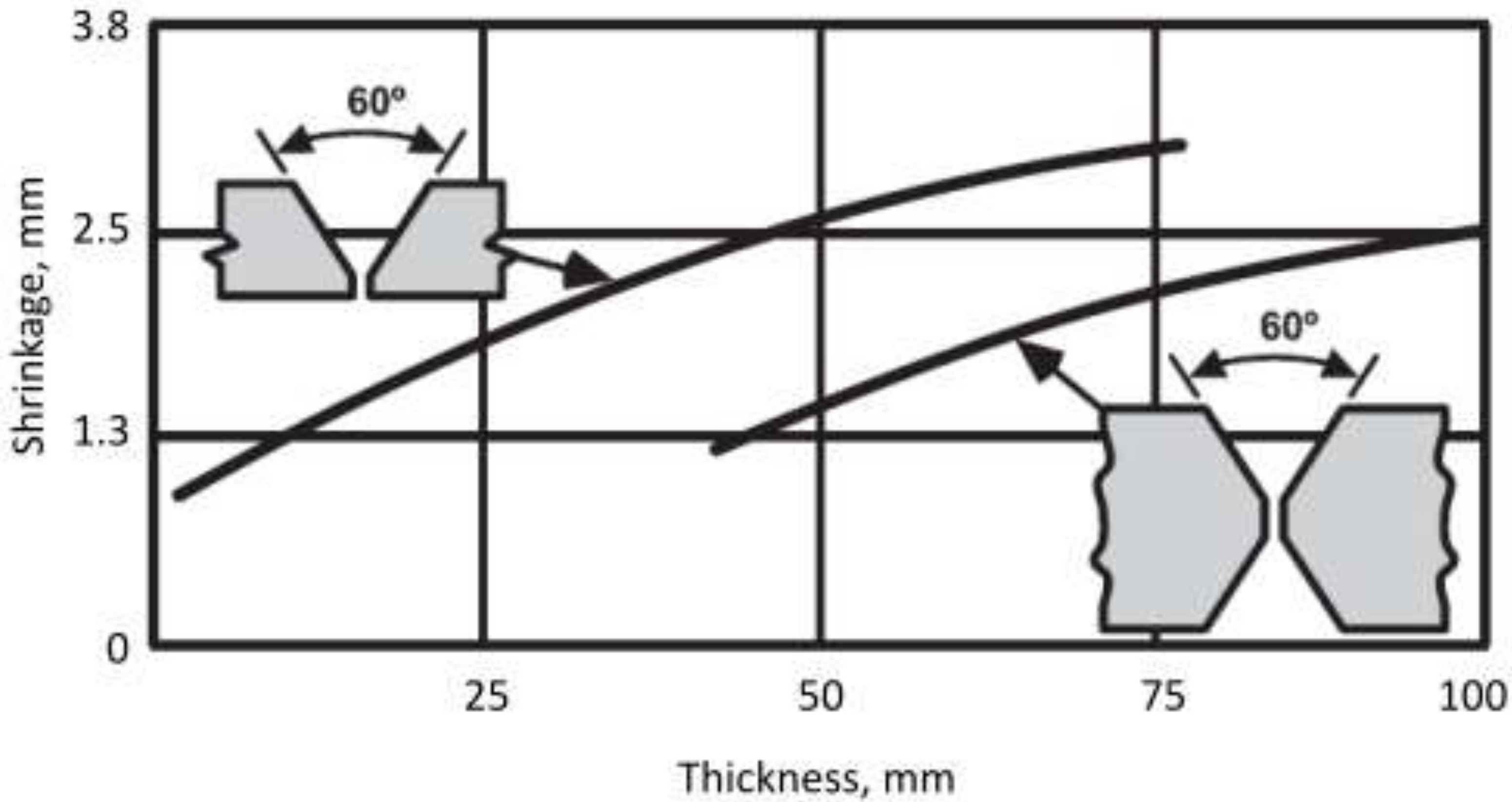
Transverse shrinkage in butt welds



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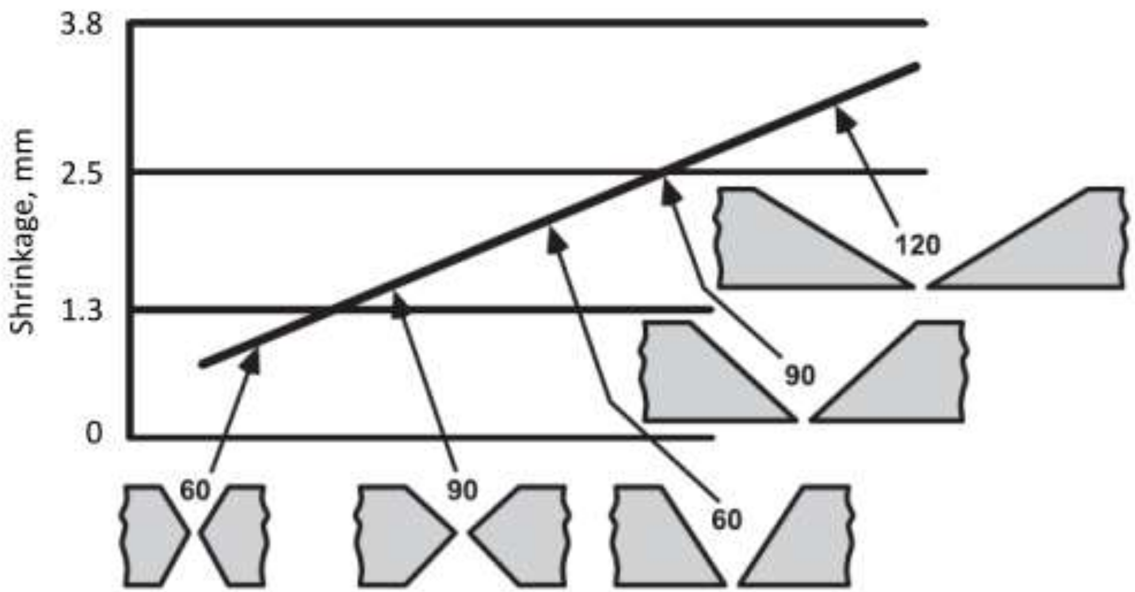
Transverse shrinkage in butt welds

- For the same thickness of plate the shrinkage reduces if the weld metal area decreases. The minimum shrinkage can be reached with double groove of minimum groove angle.



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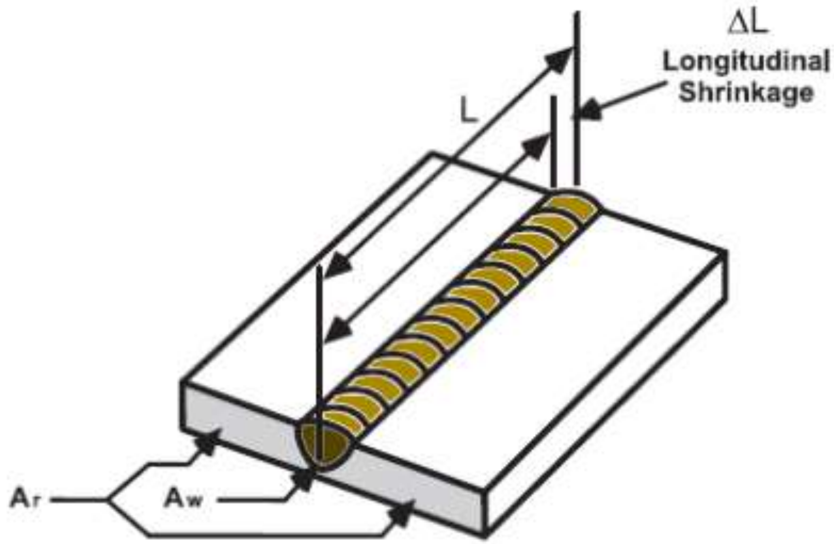
Longitudinal shrinkage in butt welds

- ΔL – longitudinal shrinkage
- Aw – cross sectional area of weld metal
- Ar – cross sectional area restraining plates
- L – length of welded joint

$$\Delta L = \frac{A_w}{A_r} \cdot 0.025\, L$$



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Angular distortion

- The angular distortion results form the non-uniform contraction of the weld metal due to greater width of the top of the weld compared to the root.
- If the weld metal could be deposited in a more uniform section between the edges, only uniform contraction will occur perpendicular to the weld.

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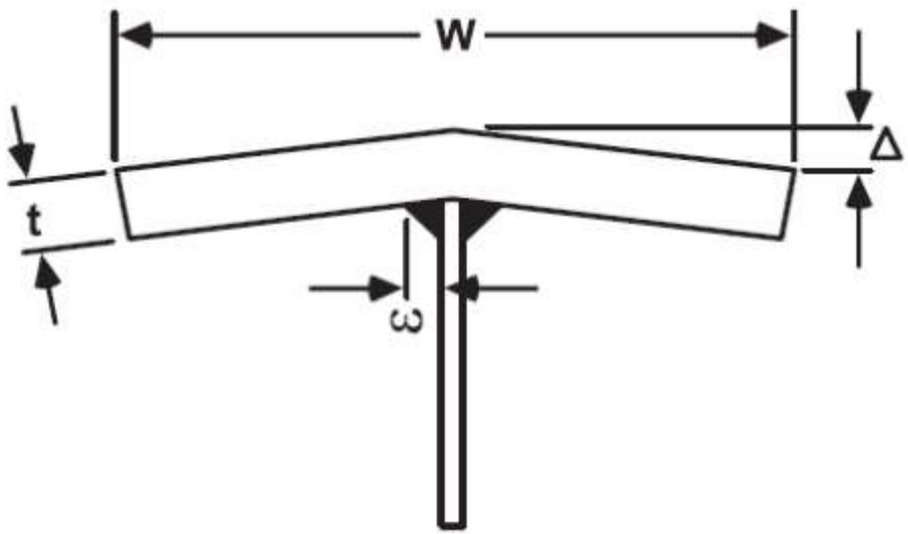
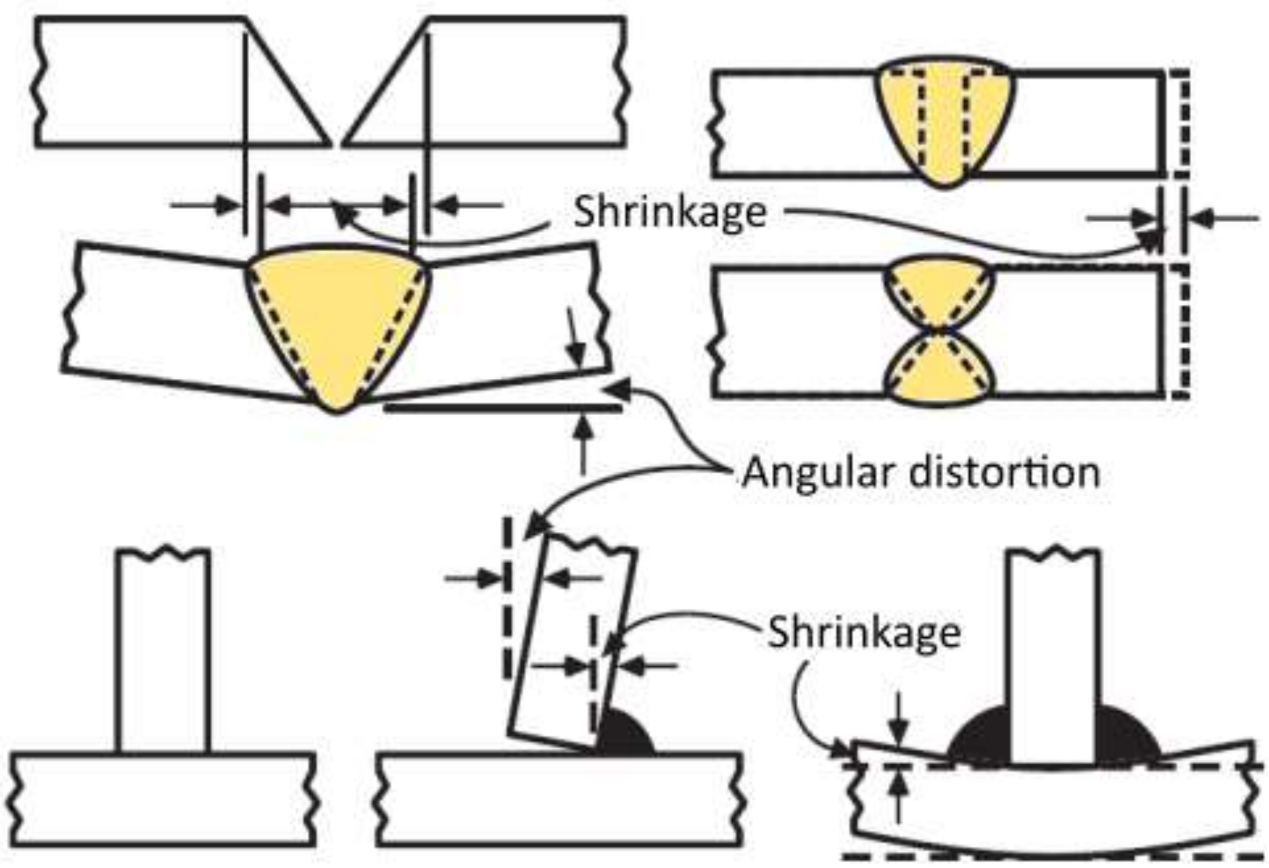
Angular distortion of fillet welds

- Δ – displacement
- W – width of the flange
- ω – fillet leg size
- t – plate thickness

$$\Delta = 0.193\, W\, \omega^{1.3} / t^2$$



Angular distortion



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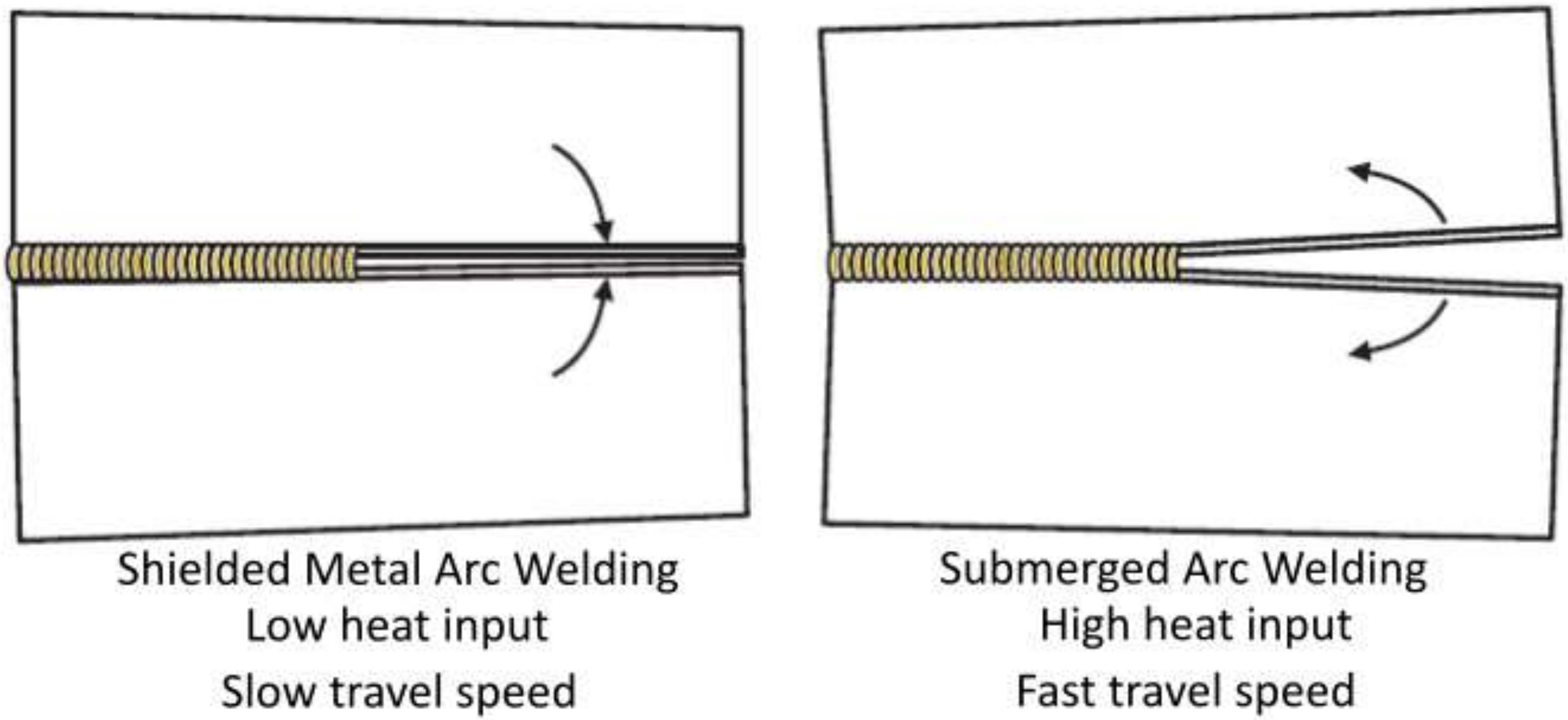
Effects of heat input on distortion

- The lower heat input and lower travel speed allows the plate edges to contract, which will result in the far end of the joint moving closer during welding. To prevent this wedge blocks can be inserted to keep constant root gaps.
- Contrary in case of high heat input and fast travel speed keep the plate edges expanding state ahead of welding arc. In this case heavy tack welds should be used.

Effects of heat input on distortion



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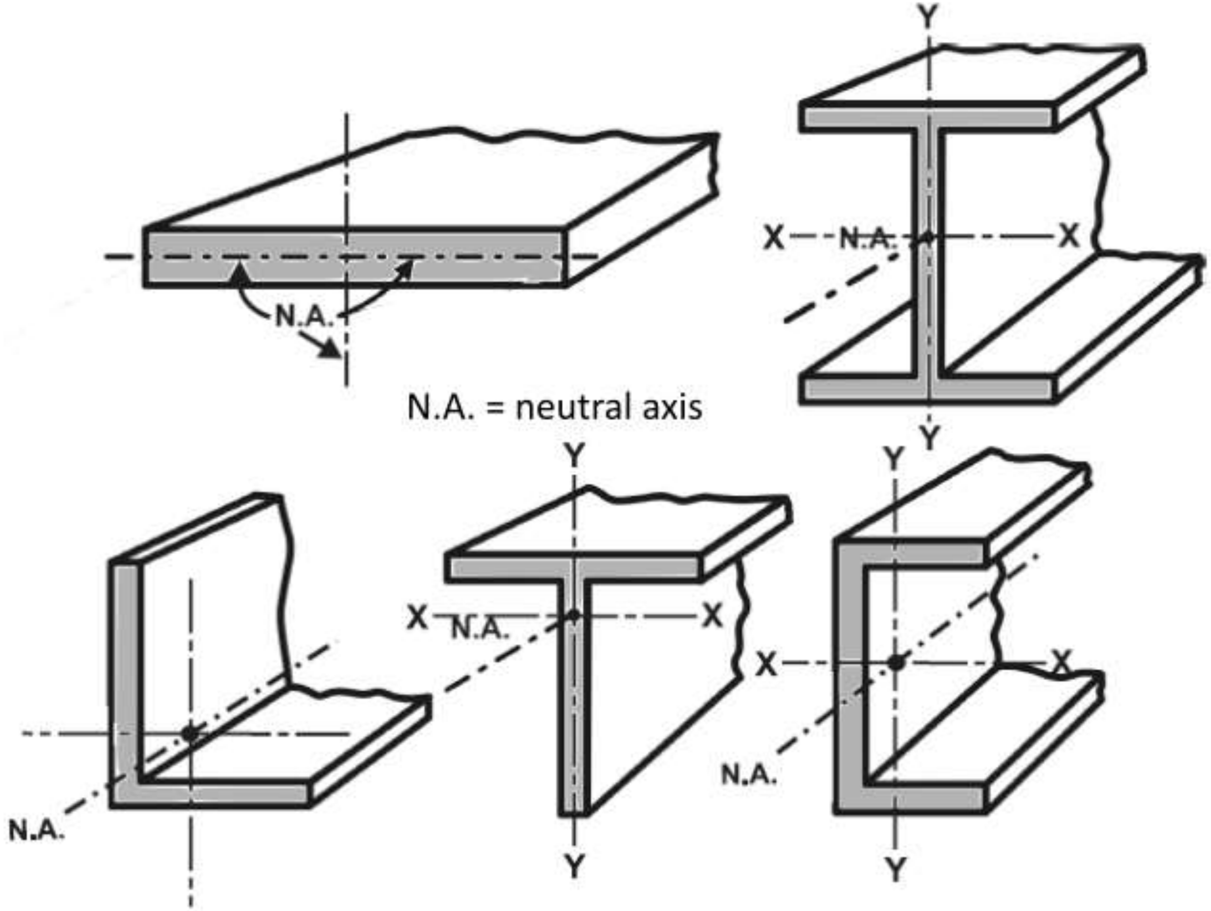
Neutral axis

- When the distribution of residual stresses is symmetrical around the neutral axis, bending or buckling will not occur only longitudinal shrinkage.
- The neutral axis is located through the center of gravity of the cross-section of a shape.
- When the residual stress is not symmetrical, a moment is created, which can lead to visible distortion.

Neutral axis



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Distortions - Summary

1. Longitudinal distortion – shortening in length
2. Bending distortion – unbalanced residual stresses
3. Angular distortion – transverse contraction
4. Buckling distortion – longitudinal plus transverse contraction
5. Twisting distortion – longitudinal contraction likely in thin sheets

Useful Topic Related Links

[Distortion](#)

[Welding distortions - Lecture](#)

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I.3. Materials weldability and heat treatment

I.3.7. Corrective measures, procedure, welding technique, sequence, joint preparation, pre-setting

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Aim & Objectives

Module Aim:	Knowing different aspects concerning weldability, heat treatment, residual stress and distortion.
Number of hours:	e-learning – 4 h, self-study – 4 h
Learning Outcomes:	• Knowing different theoretical and practical aspects concerning the materials weldability. • Knowing the main heat treatments applied for the materials used for welded structures • Explain fully the origin, influencing factors and magnitude of residual stress and distortion in welded fabrication. • Detailed procedures on how to minimize distortion and stress.
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Lecture Outline

- Measurement of distortion
- Prevention of distortion
- Welding sequence
- Joint preparation
- Pre-setting

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Corrective measures, procedure, welding technique, sequence, joint preparation, pre-setting

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Measurement of distortions

- The distortion after welding can be determined by angular and length measurement techniques.
- The longitudinal and transverse shrinkage can be determined by measurement tapes or strain gauge rosettes.
- The angular distortion is measured on a measuring plate.

Prevention of distortion

- Design
  - Replace the position of weld seam
  - Reduce the amount of weld metal
  - Reduce the number of welds
  - Balanced weld arrangement

- Use tack welds instead of continuous weld lines, if possible to reduce amount of weld. For example in case of welding stiffeners, the amount of weld metal can be reduced by using tack welds, while the length of the weld seams remain sufficient.

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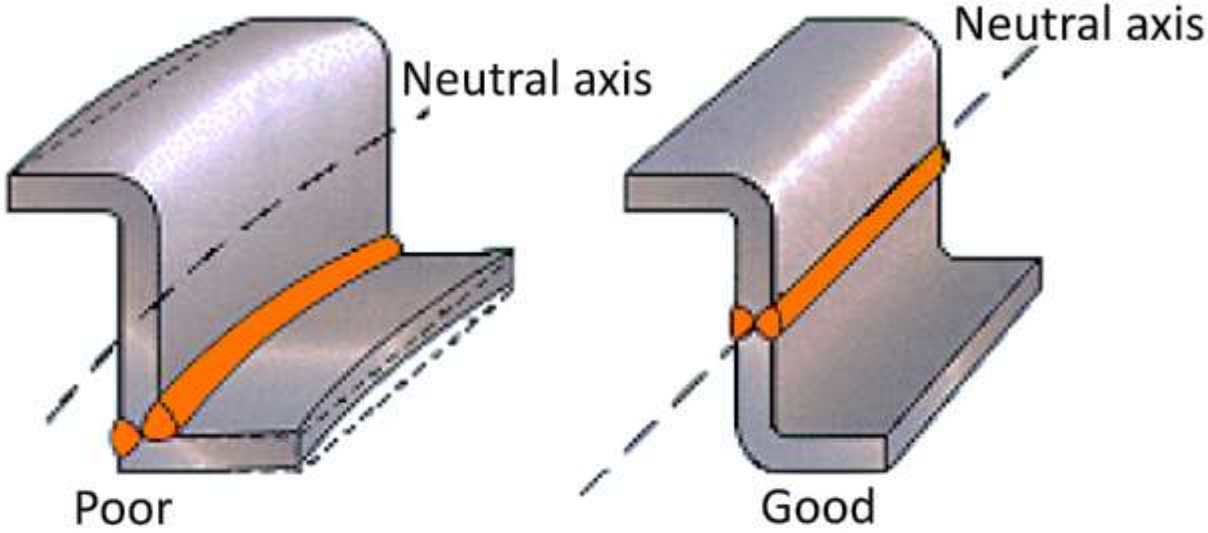
Prevention of distortion

- The distortion can be reduced welding in the neutral axis.



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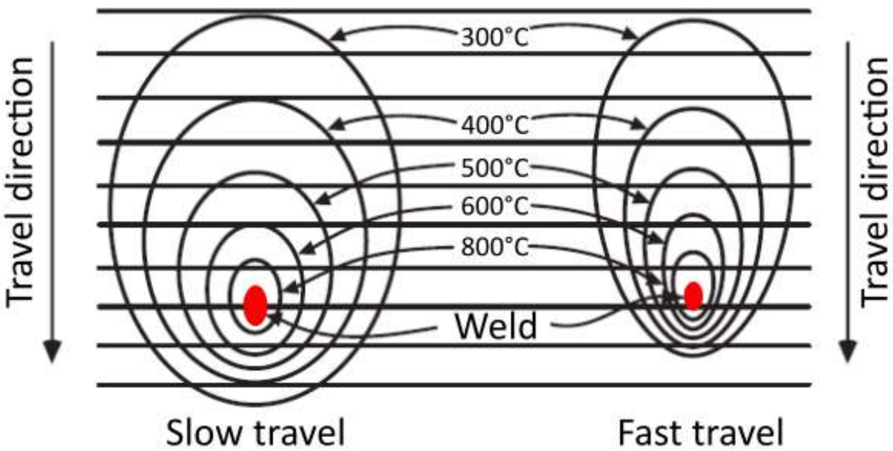
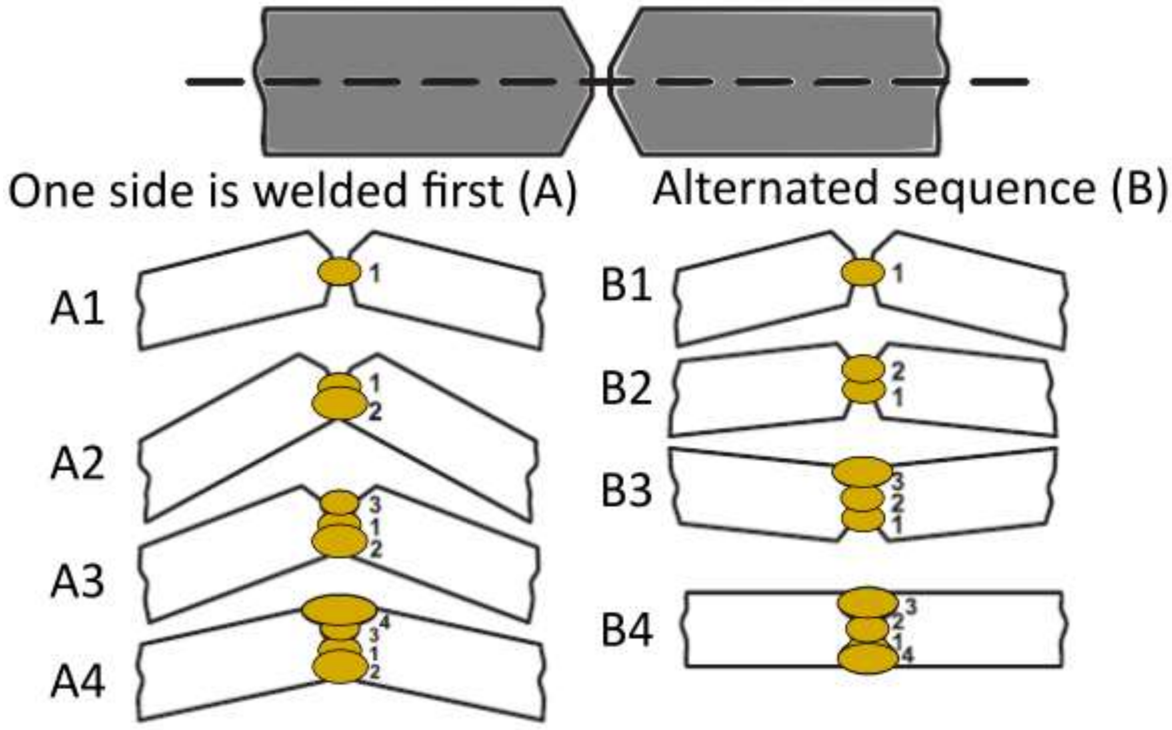
Welding procedure

- Number of welding passes
  - Usually, multi-pass welding increases the angular distortion and transverse shrinkage.
- Travel speed of welding arc
  - Slower → more time for heat spreading, faster → less heat spread.



Welding sequence

- Welding sequence is an essential part of any welding procedure and highly affects the amount of distortion.



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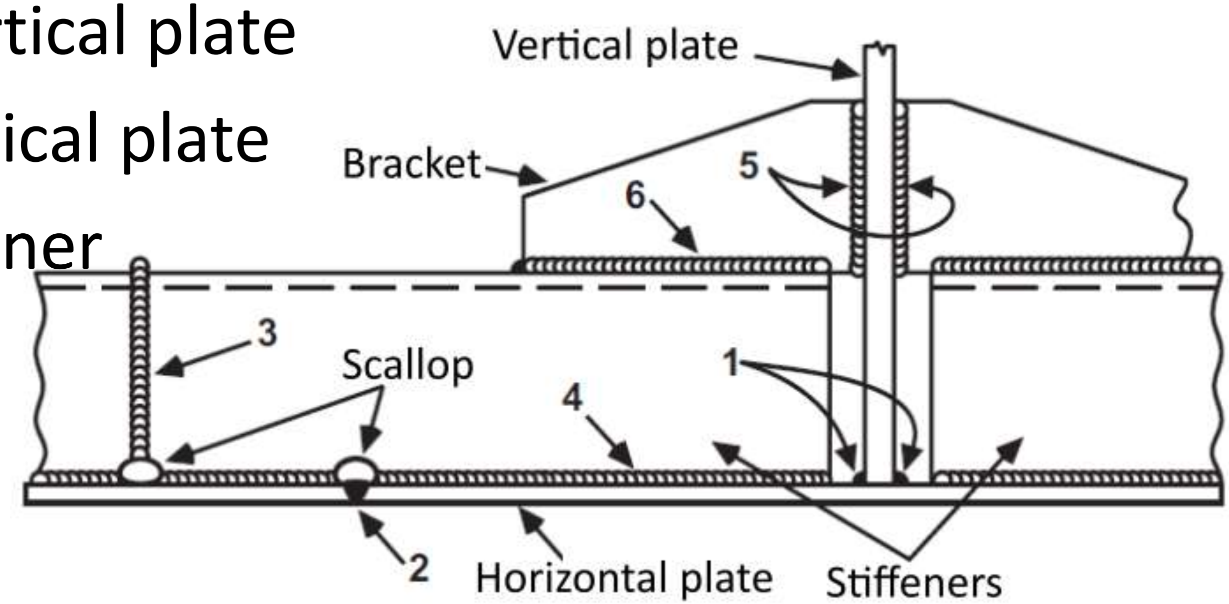
Welding sequence - Construction

- 1 – allows horizontal plate to shrink
- 2 – plate is free to move
- 3 – butts in stiffeners
- 4 – stiffeners to vertical plate
- 5 – brackets to vertical plate
- 6 – bracket to stiffener



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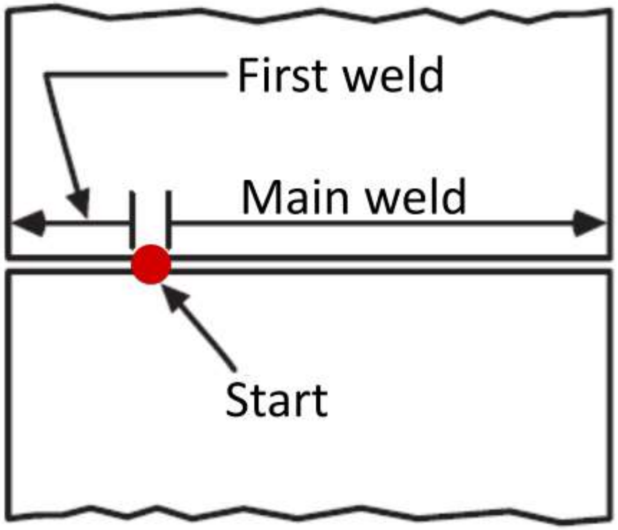
Welding sequence – Seam welding

- The simplest way is to start the weld some distance from the plate edge.
- In case of long weld seams, the best practice is to weld at spaced intervals along the joint.



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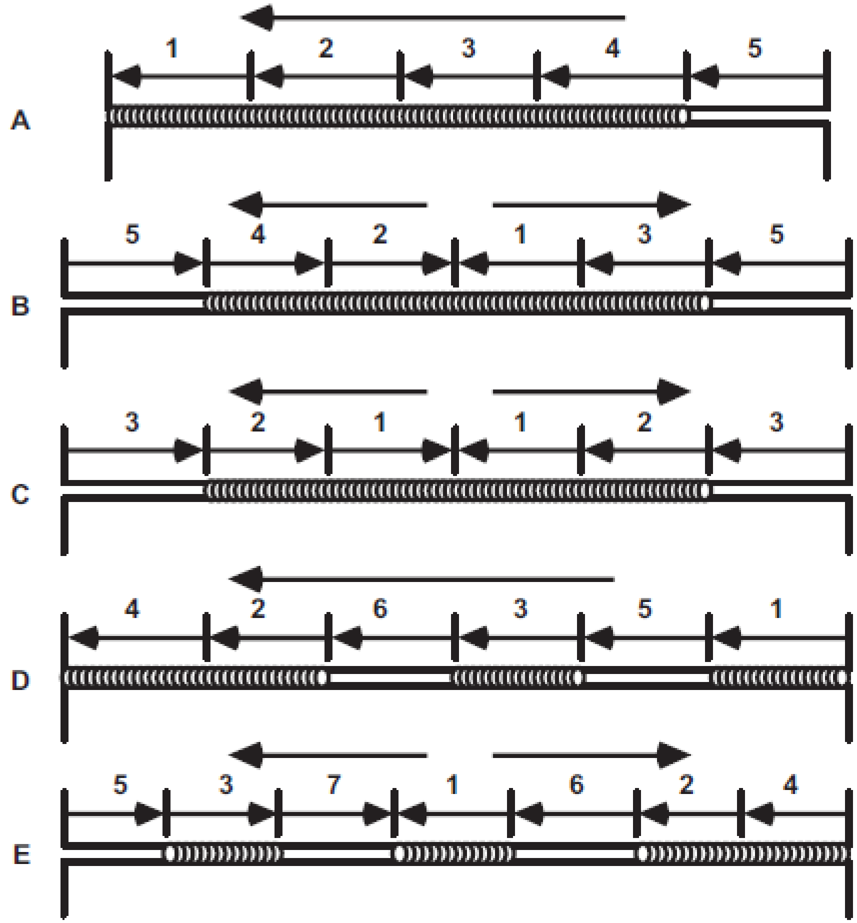
Welding sequence – Seam welding

- Examples of this principle
  - A: back-stepping
  - B: back-step and skip
  - C, E: outward from center point
  - D, E: staggered



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Joint preparation

- The more symmetrical edge preparation will lead to less angular distortion.
- U groove is better than V groove.
- The smaller the weld means less distortion.
- V grooves should be designed for a minimum bevel.

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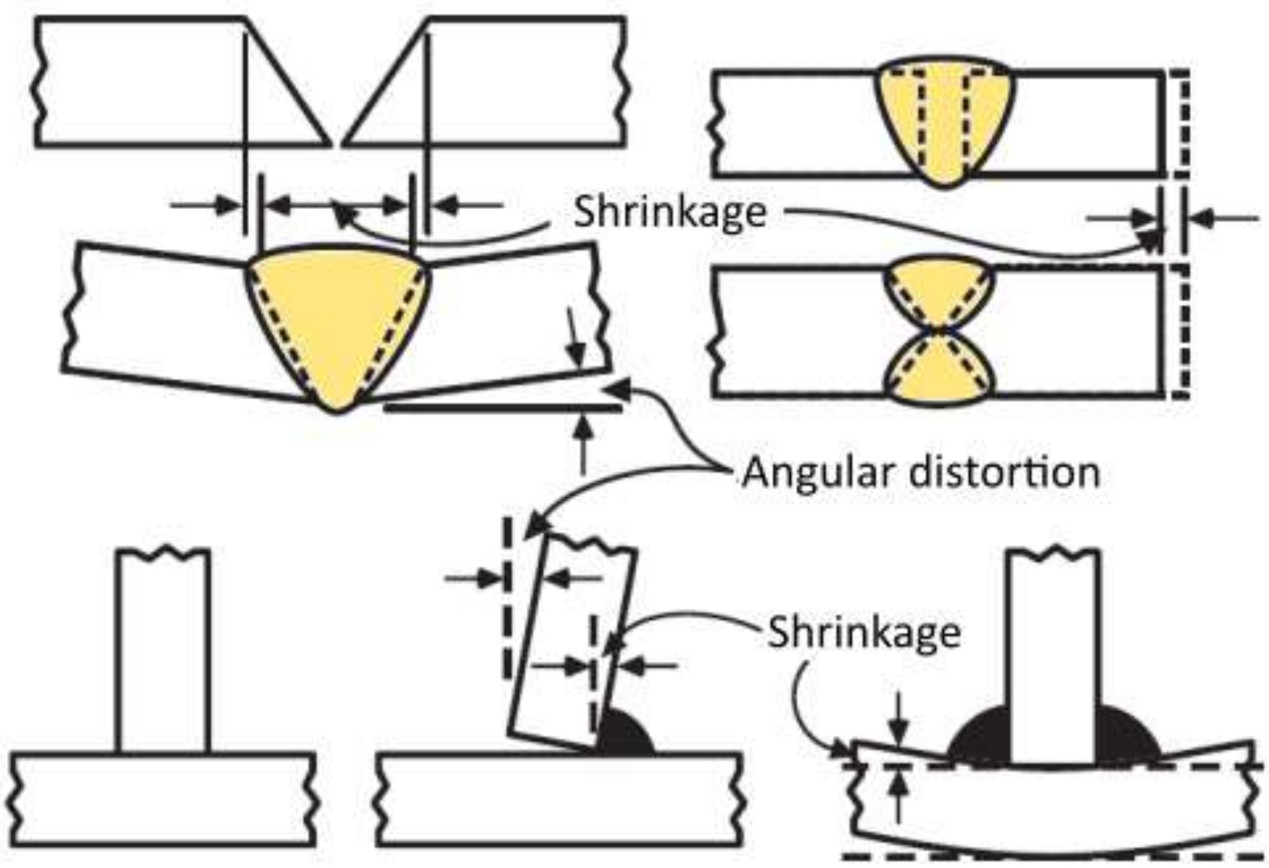
Joint preparation



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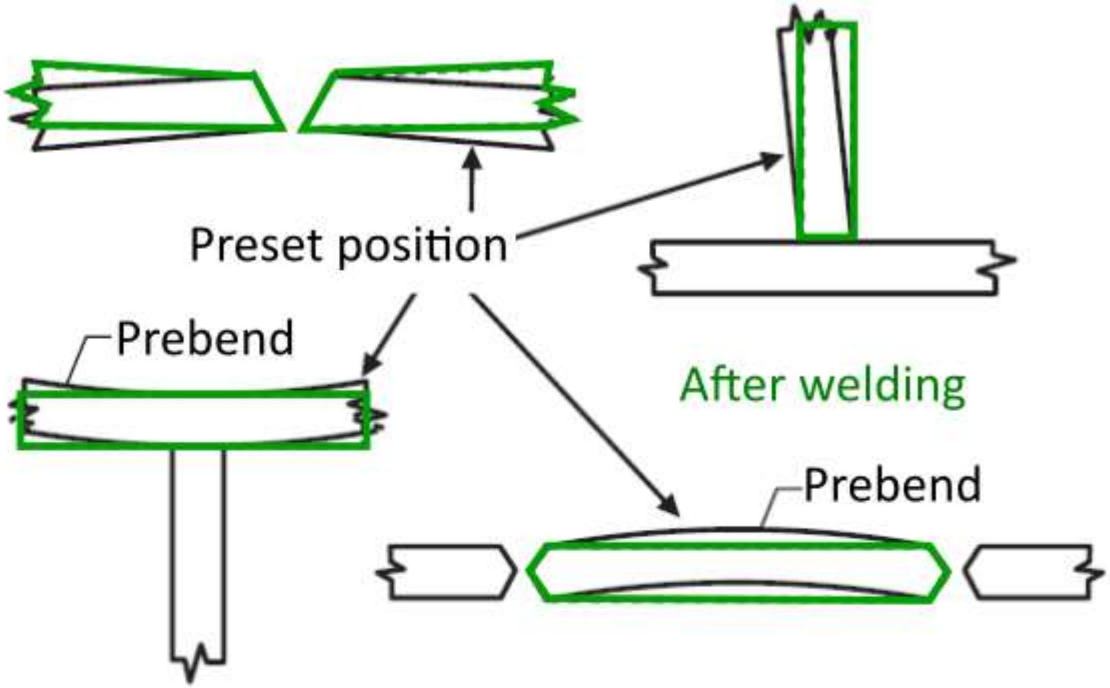
Pre-setting

- Pre-setting is a type of mechanical control, which allows recovery of angle or longitudinal distortion.



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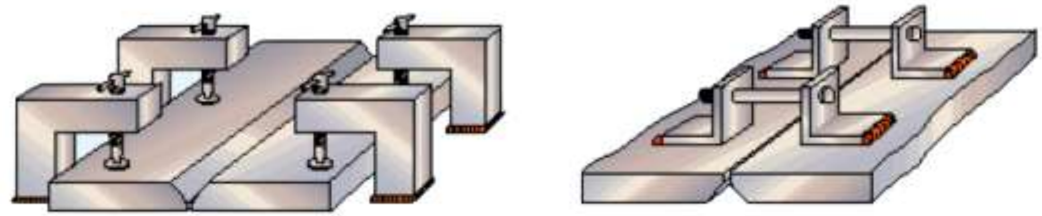
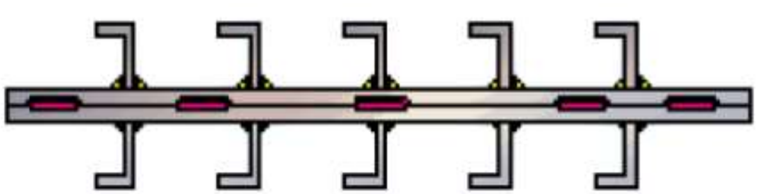
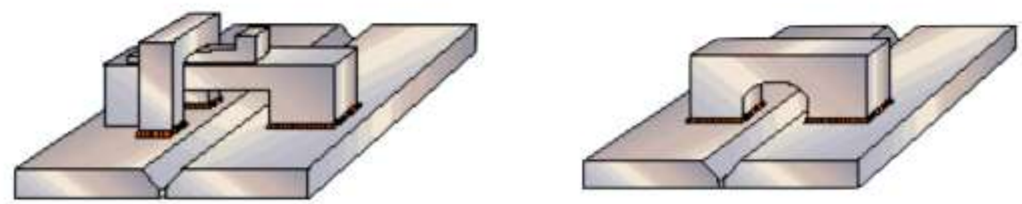
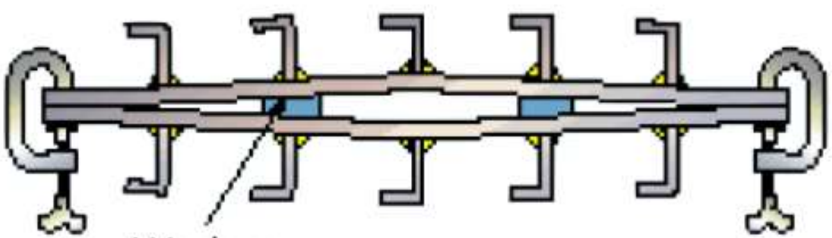
Pre-setting

- Pre-setting can be done using wedges and clamping devices









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Useful Topic Related Links

[Distortion]

[Prevention and control of distortions in arc welding]

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I.3. Materials weldability and heat treatment

I.3.8. Correction of distortion after welding

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Lecture Outline

- Mechanical straightening
  - Hammering
  - Pressing
- Hot straightening
  - Line heating
  - Wedge shape heating

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Correction of distortion after welding

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Cold (mechanical) straightening

The principal mechanical techniques are hammering and pressing. Hammering may cause surface damage and work hardening.

It is important to impose sufficient deformation to give over-correction so that the normal elastic spring-back will allow the component to assume its correct shape.

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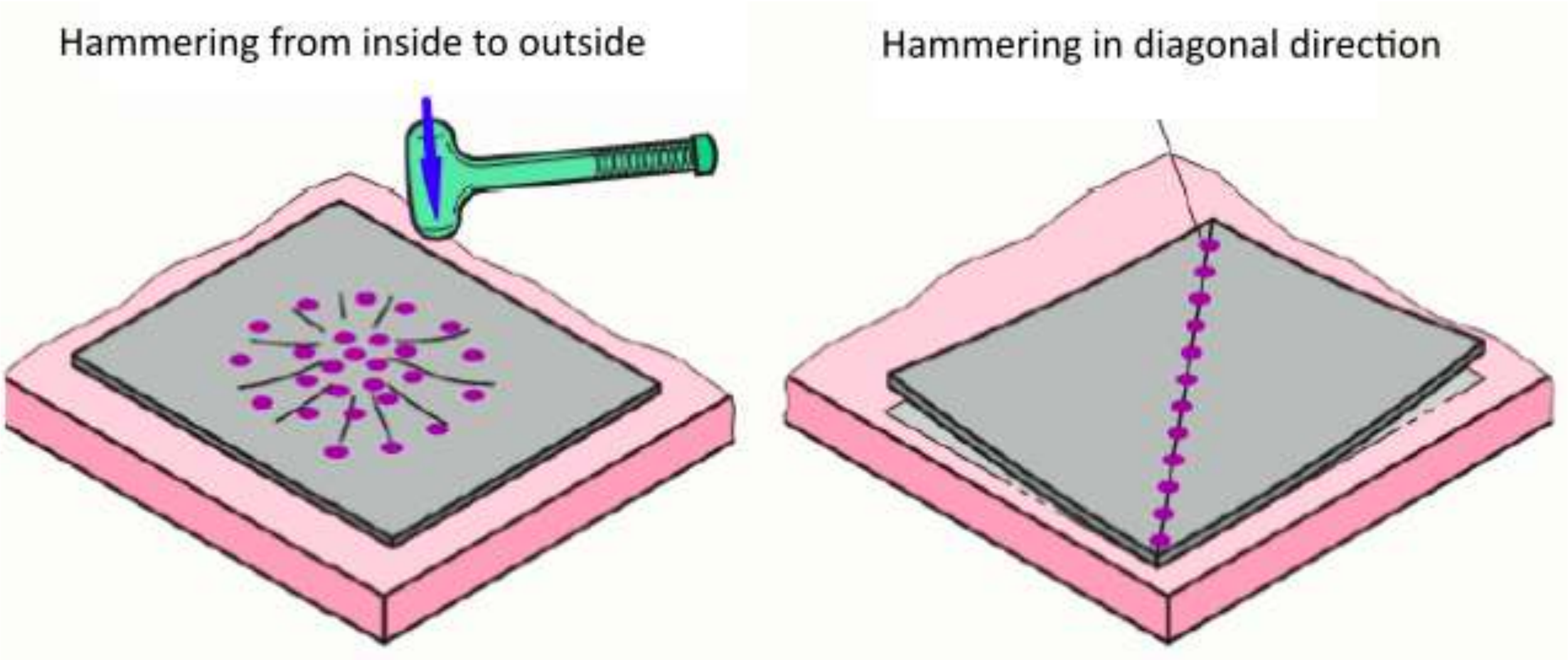
Hammering



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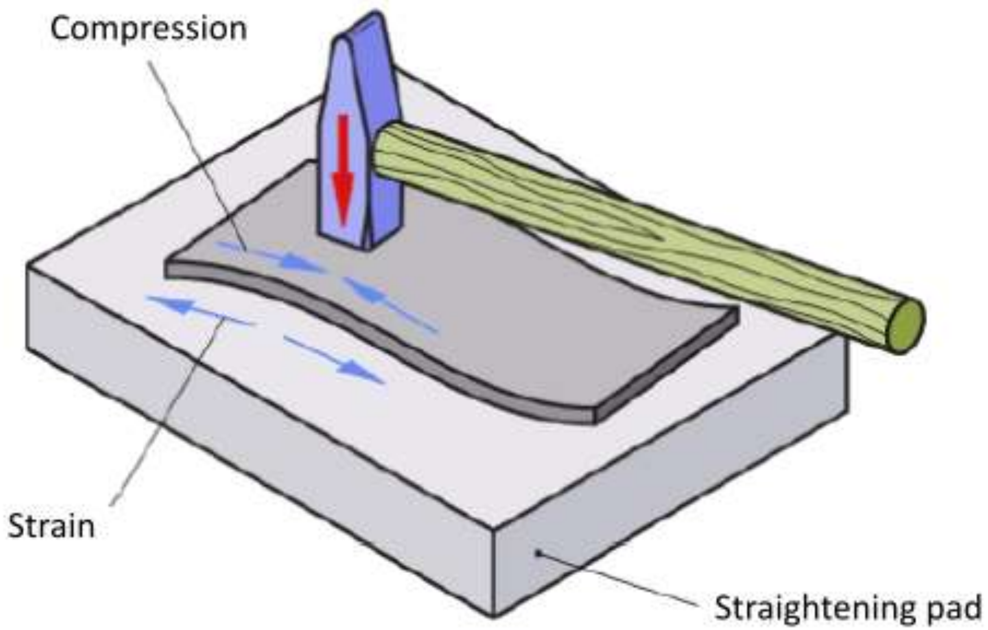
Hammering



Pressing

- Use packing pieces which will over correct the distortion so that spring-back will return the component to the correct shape
- Check that the component is adequately supported during pressing to prevent buckling
- Use a former (or rolling) to achieve a straight component or produce a curvature
- As unsecured packing pieces may fly out from the press, the following safe practice must be adopted:
  - bolt the packing pieces to the platen
  - place a metal plate of adequate thickness to intercept the missile'
  - clear personnel from the hazard area

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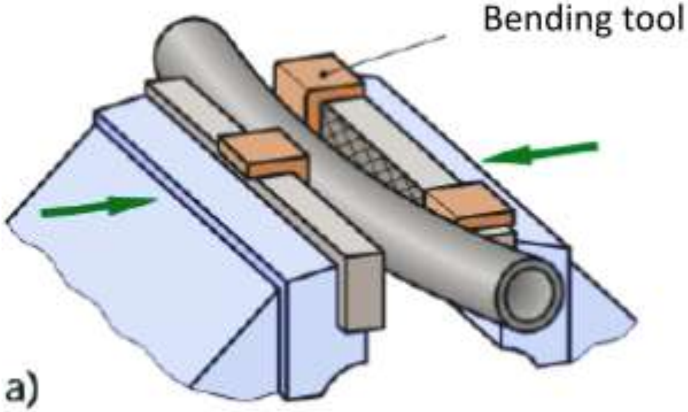
Pressing



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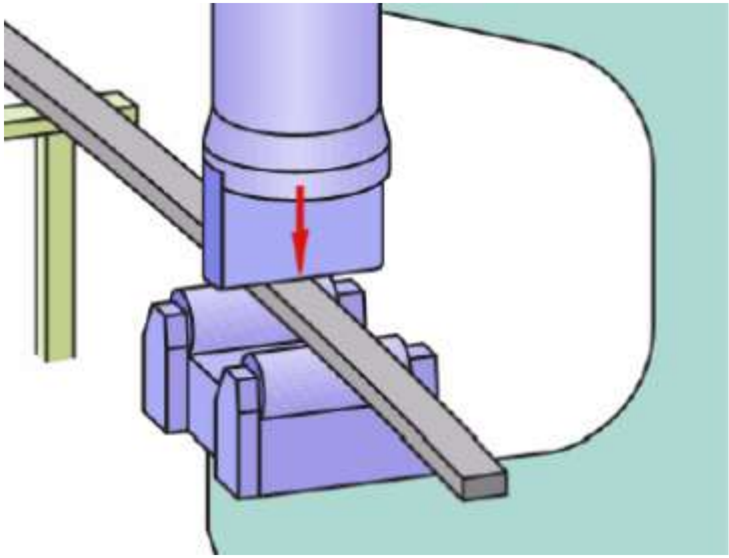

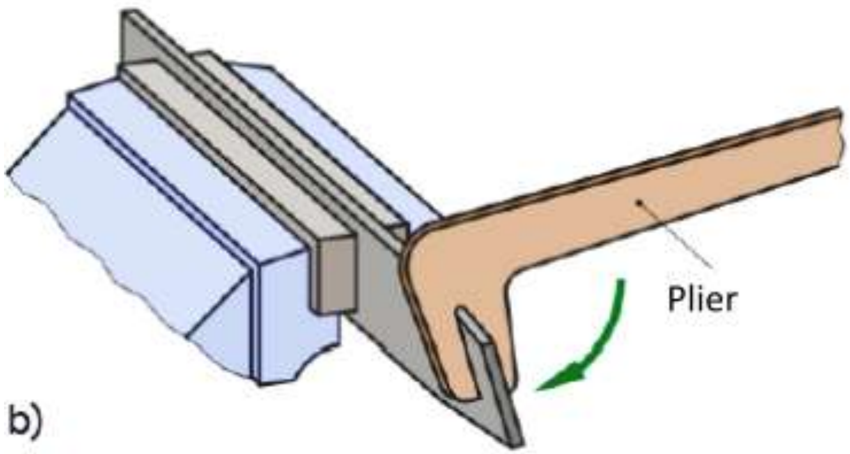

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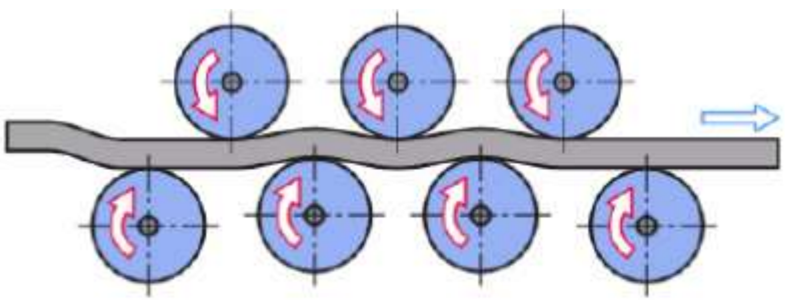

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Flame straightening (thermal heating)

- Heating temperature < A1 or tempering temperature
- The thermal expansion is restricted
- The reduction of the distortion is caused by the tensile stress, occurring during the cooling of the heated area

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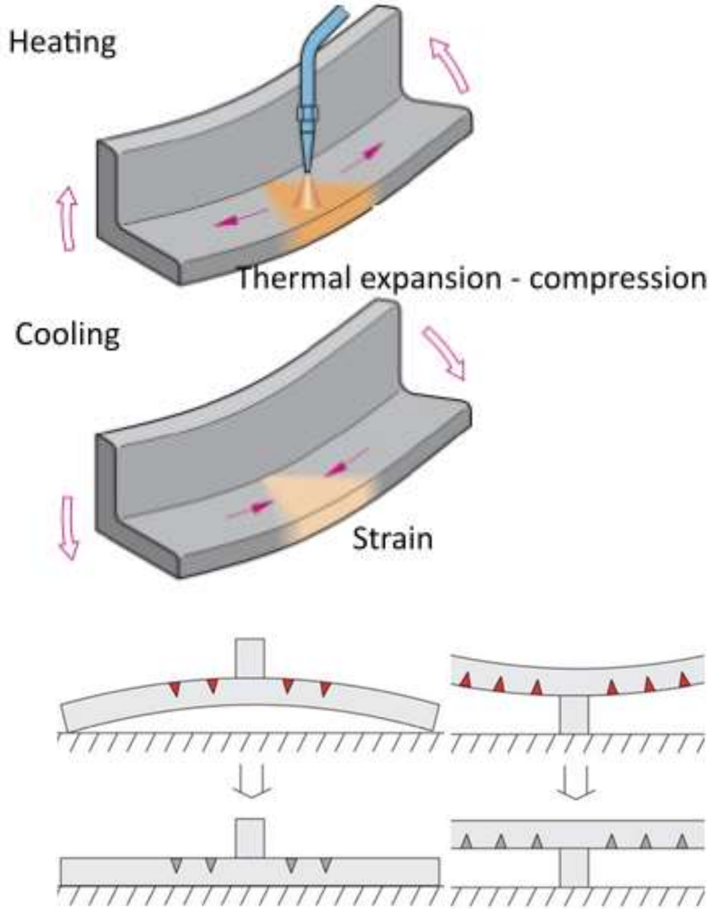
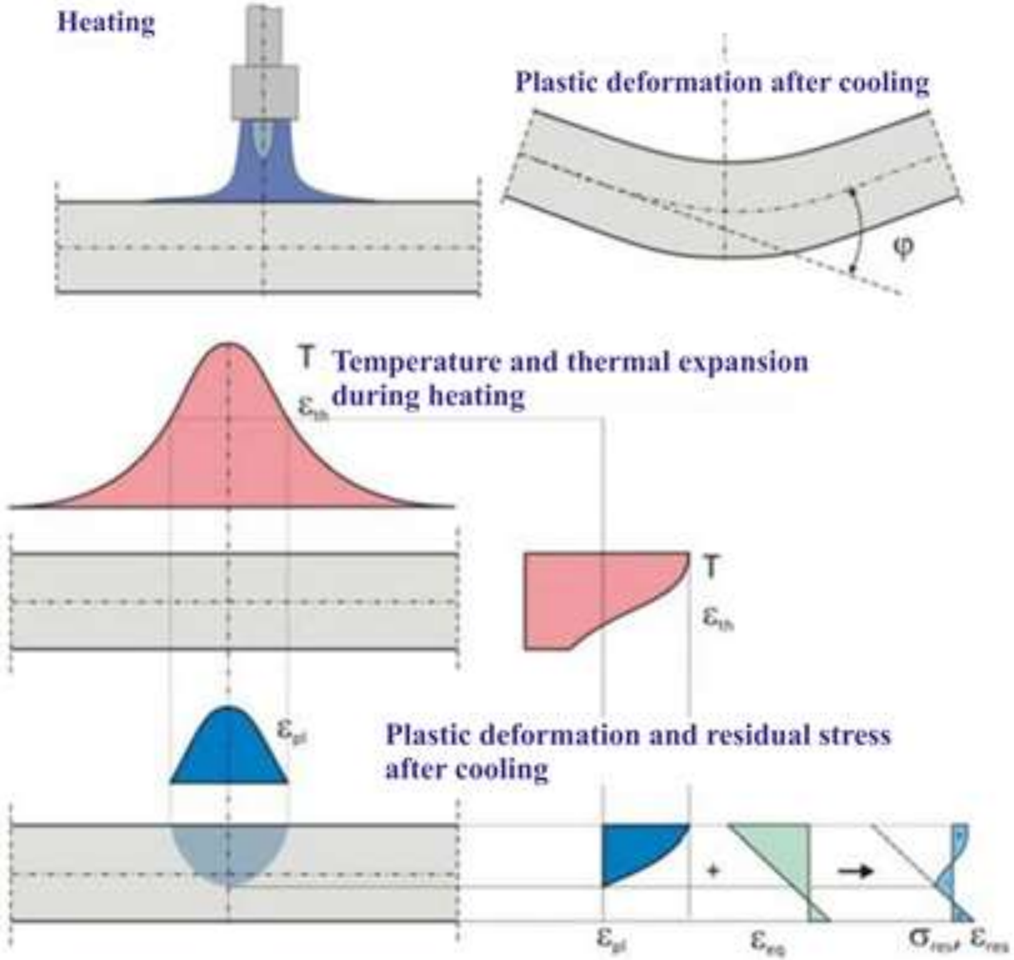
Hot straightening (thermal heating)





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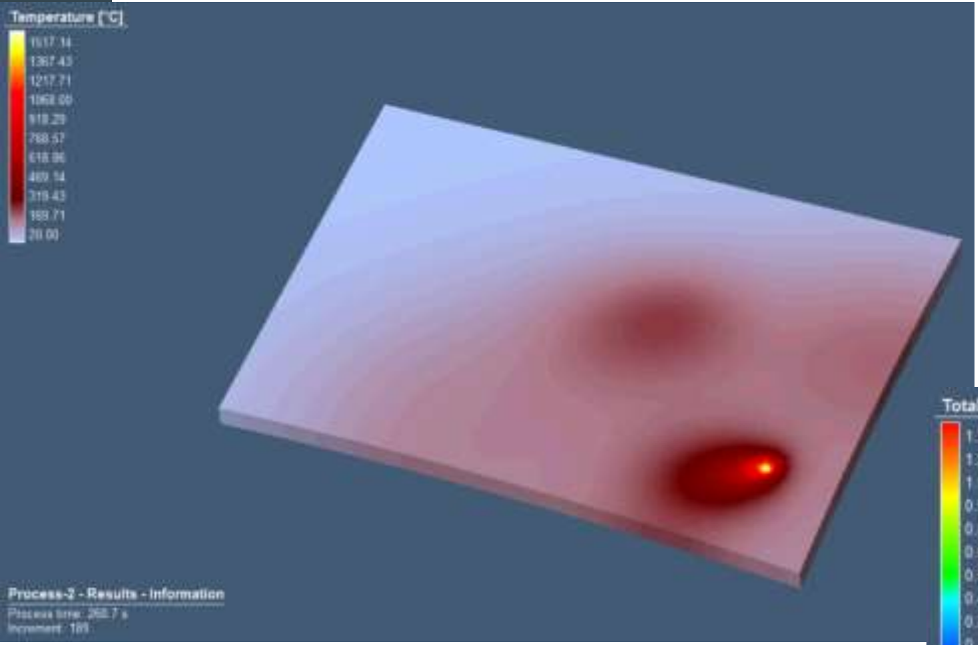
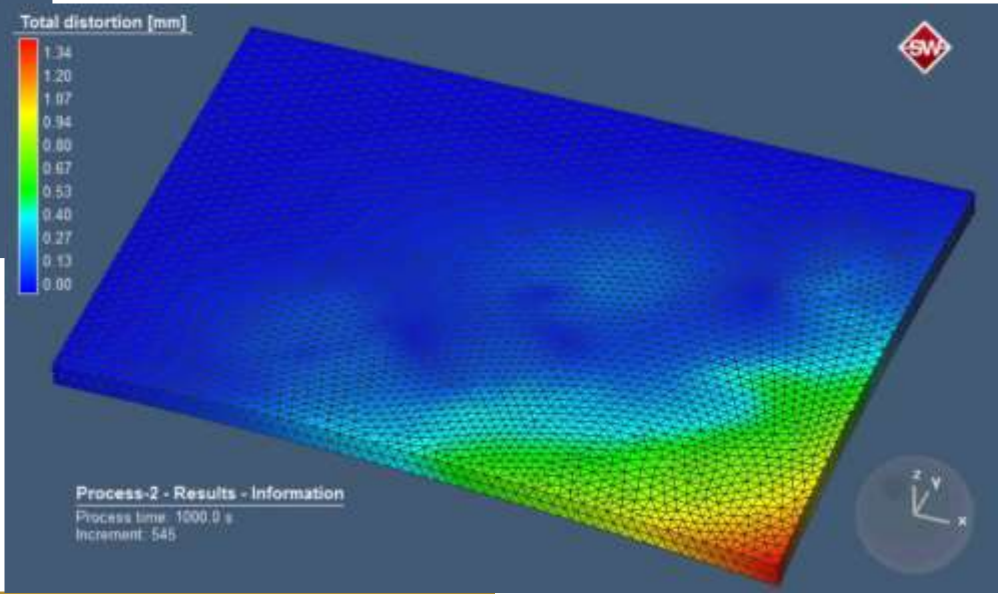
Flame / arc straightening (thermal heating)





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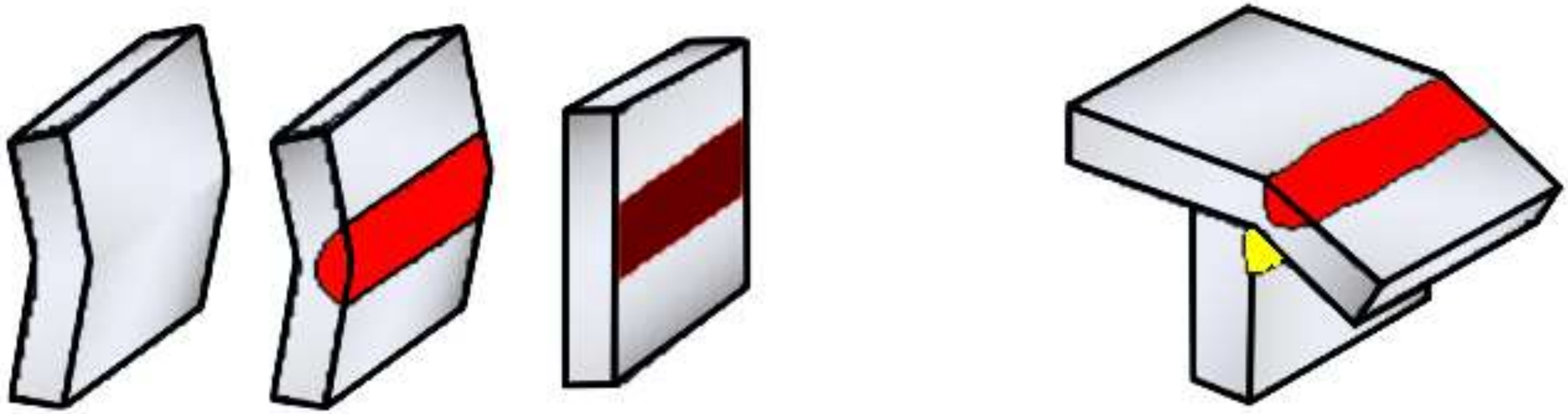
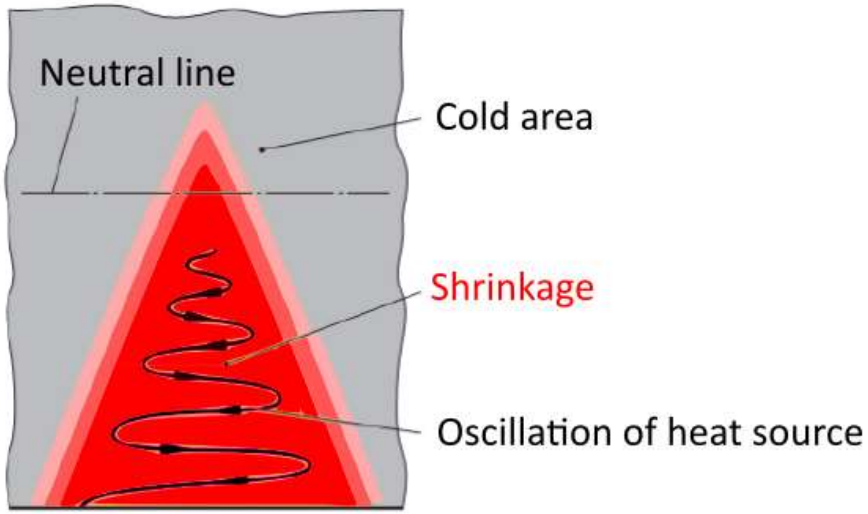
Thermal heating – line heating

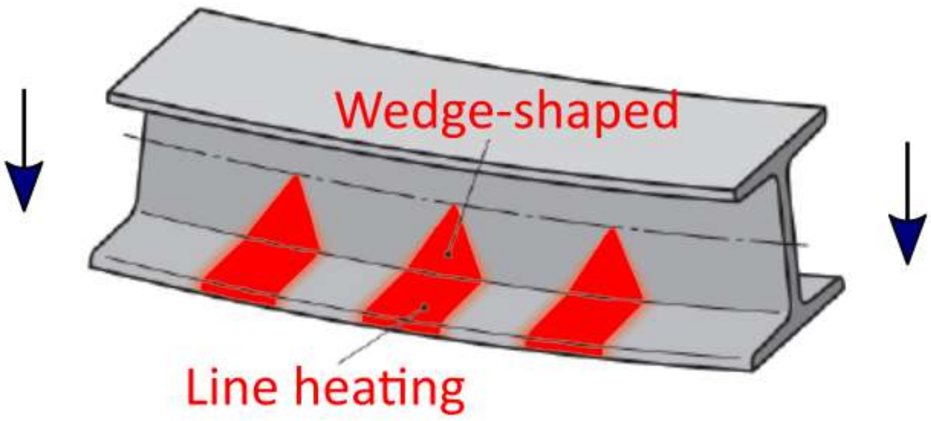
- Frequently used for straightening of angular distortion in corner and butt welds
- The heat is concentrated to the opposite side of the weld



Thermal heating – wedge-shaped heating

- For thicker parts it is necessary to heat up wider areas
- Usually double heat sources are used





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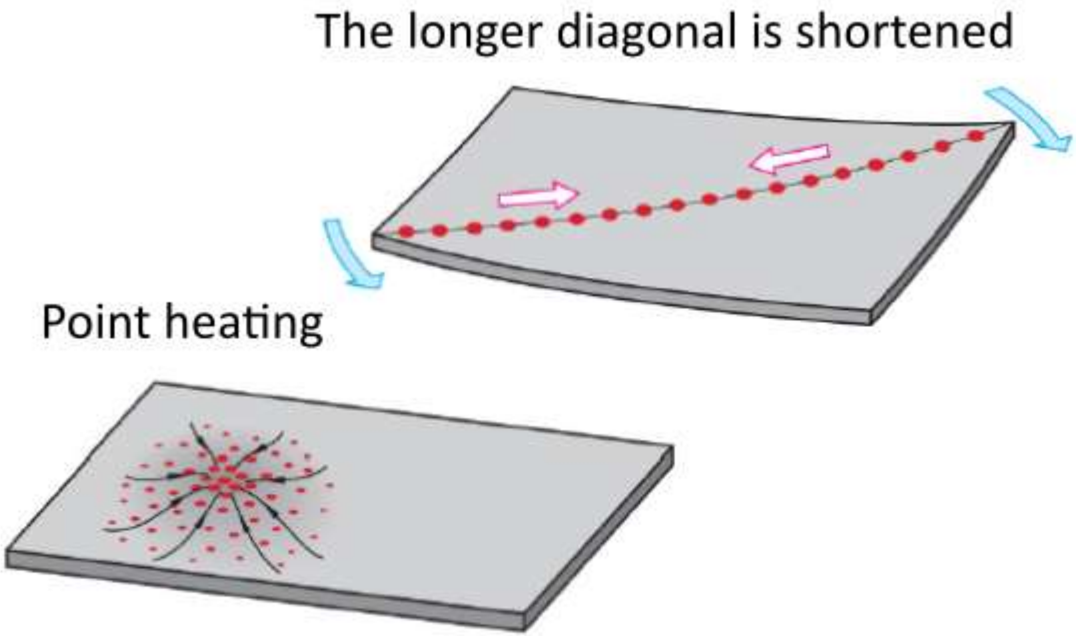
Thermal heating – point heating

- Usually used for reduction of bent distortion



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Useful Topic Related Links

[Distortion](#)

[How to fix welding distortion](#)

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I.4. Quality assurance and qualification in welding

I.4.1. Imperfections and acceptance criteria

2016-1-RO01-KA202-024508

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Aim & Objectives

Module Aim:	The module offers information regarding the classification and description of weld imperfections and quality levels of imperfections in fusion-welded joints
Number of hours:	2 e-learning and 2 self-study
Learning Outcomes:	• Weld imperfection • Quality levels for imperfections
ECVET:	4 (for Training Units Nº 4)

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Lecture Outline

- Classification of Weld imperfections
- Origin of imperfections
- Quality levels of imperfections in fusion-welded joints in all types of steel, nickel, titanium and their alloys

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Imperfections and acceptance criteria

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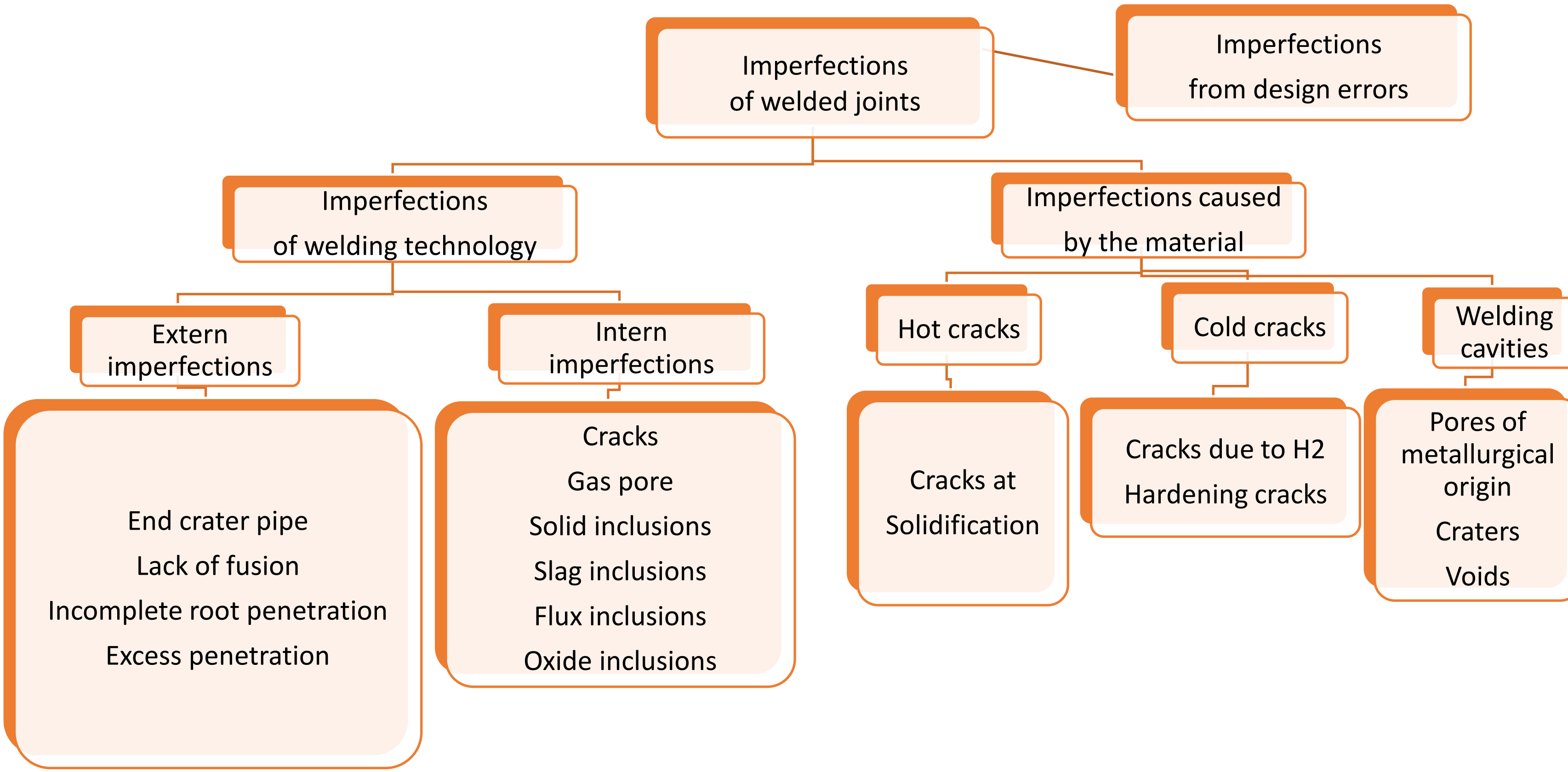
Origin of imperfections

Imperfection: any deviation from the ideal weld.

Defect: unacceptable imperfection.

Quality level: description of the quality of a weld on the basis of type, size and amount of selected imperfections.

Origin of imperfections



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Origin of imperfections

The principal type of imperfections according to the ISO 6520-1 standard *“Welding and allied processes - Classification of geometric imperfections in metallic materials - Part 1: Fusion welding”* are:

- cracks;
- cavities;
- solid inclusions;
- lack of fusion and penetration;
- imperfect shape and dimension;
- miscellaneous imperfections.

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Survey of specific weld imperfections and their cause

First group – Cracks

Cracks are considered dangerous and are not allowed. They can be defined as discontinuities in the material, having an elongated shape, a very small radius of the curvature in the tip and a gap between its flanks.

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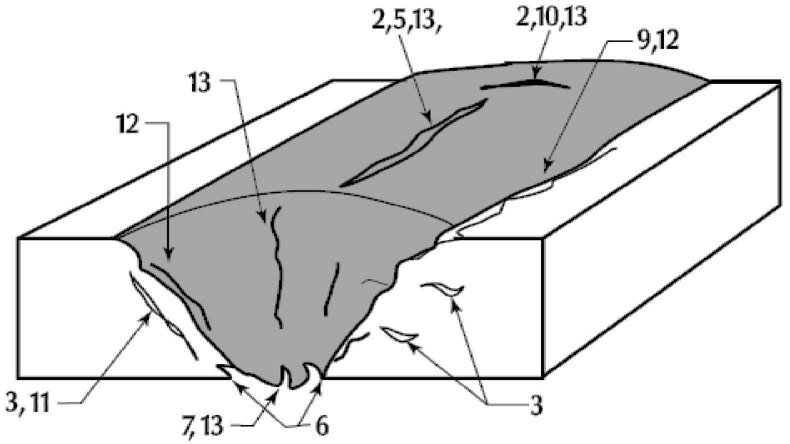
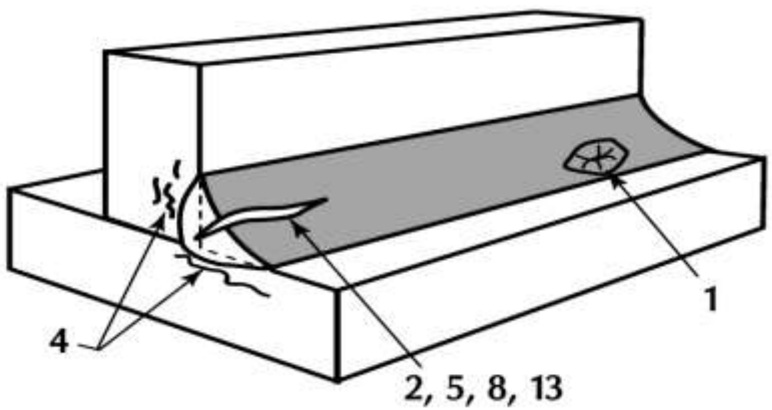
Survey of specific weld imperfections and their cause

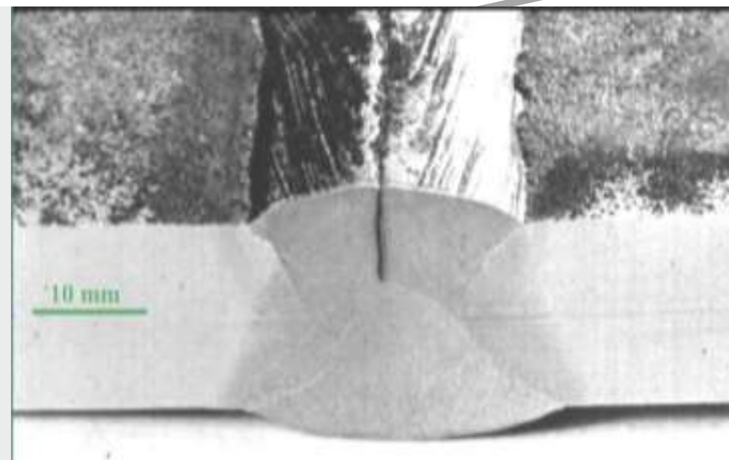
Type of cracks:
1 – radiating cracks,
2,8 – frontal crack,
3– crack in the heat affected zone
4 – group of separate cracks
5,9 – longitudinal crack
6 – crack at the root
7 – crack on the root surface
10 – transversal crack
11 – cold crack
12 – crack at the base material – filler material interface
13 – crack in the weld material



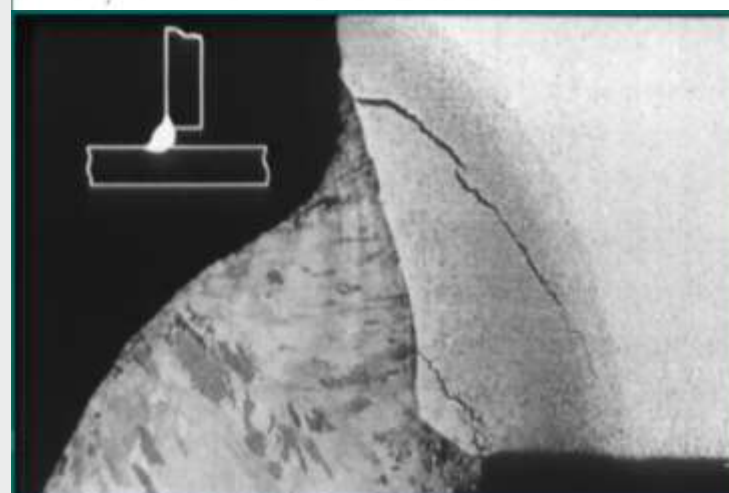


Survey of specific weld imperfections and their cause

Hot crack



Cold crack



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Survey of specific weld imperfections and their cause

The main causes that lead to cracks in welded joints are :

- ***Technological causes:*** wrong choice of filler material; choosing an inappropriate welding process, failing to observe the welding process parameters.
- ***Metallurgical causes:*** Inappropriate cooling conditions; structural changes in the molten zone; reduced hot plasticity properties of the deposited metal; the appearance of tough structures; the presence of hydrogen in the joint; internal tensions that exceed certain limits.

Survey of specific weld imperfections and their cause

Second group **– Cavities**

The pores are cavities filled with gas, with glossy surface that most of the times have spherical shape.

If the gas bubble discharge velocity is less than the forward velocity of the crystallization front, the gas bubbles remain trapped and the metal solidifies around them.

The gases from the pore and cracks are: carbon dioxide, carbon dioxide, methane, hydrogen sulfide, etc.

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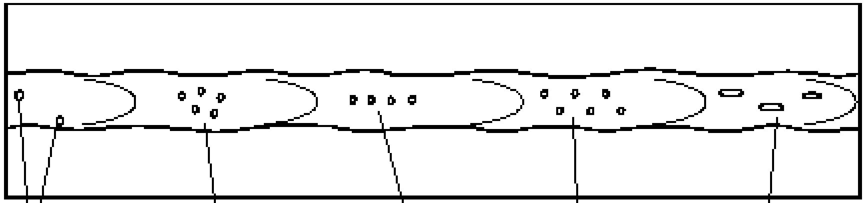
Influence of weld imperfections on product performance

- 200 – cavity
- 201 – gas cavity
- 202 - shrinkage cavity
- 2011 – gas pore
- 2012 – uniformly distributed porosity
- 2013 – clustered (localized) porosity
- 2014 – linear porosity
- 2015 – elongated cavity



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Survey of specific weld imperfections and their cause

The main causes that lead to gas cavities in the welded joints are :

- the excess of sulfur in the base material or in the filler material;
- high hydrogen content in the molten metal bath or impurities of protective gases
- Insufficient welding parameters;

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Survey of specific weld imperfections and their cause

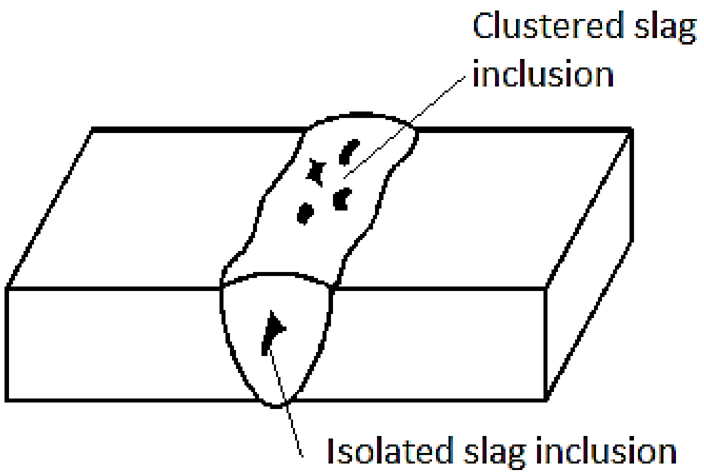
Third group – Solid inclusions;

Inclusions are defects with different chemical composition from the metal in the welded seam. They may be metallic or non-metallic, and from a chemical point of view they can be oxides, silicates, sulphides, nitrides, etc. In welded joints, non-metallic inclusions such as slag, oxides, nitrides and gas cavities are more common.

Survey of specific weld imperfections and their cause

Solid Inclusions :

- *non-metallic: slag, flux, oxide film, impurities;*
- *metallic: tungsten, copper* ***etc.***



Survey of specific weld imperfections and their cause

The main causes that lead to solid inclusions in the welded joints are :

- inappropriate technological parameters;
- the surface of the base material in the groove area covered with rust, slag, paint, oil, etc. ;
- insufficient removal of the slag from each layer and root;
- high solidification speed, reduced possibility of eliminating the inclusions in slag;
- decreasing the solubility of certain elements in the base metal, with the decrease of the temperature, which leads to the formation of metal inclusions;
- insufficient protection for MIG, MAG, TIG welding when tungsten or titanium metal inclusions occur;

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Survey of specific weld imperfections and their cause

Forth group – Lack of fusion and penetration

401 - Lack of fusion is the result of inappropriate mixing between the base metal and the addition metal or between the deposited metal layers. Places where there may be no melting: lateral, between the layers and the root.

402 - The lack of penetration characterizes the defect in which the molten material does not cover the entire section required for welding, so that there remains an interstitial gap between the deposited metal and the base metal. Lack of penetration reduces static mechanical resistance due to the modification of the active section of the joint.

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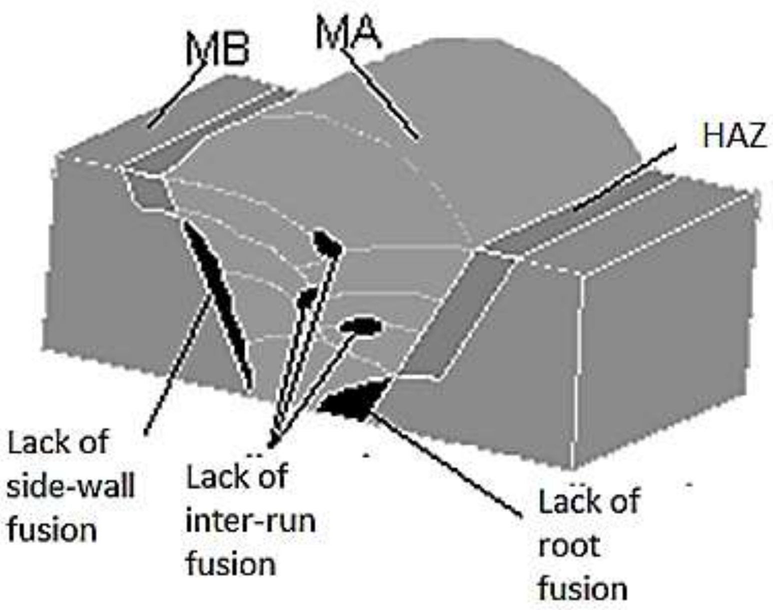
Survey of specific weld imperfections and their cause



Lack of fusion

The main causes that lead to it are:

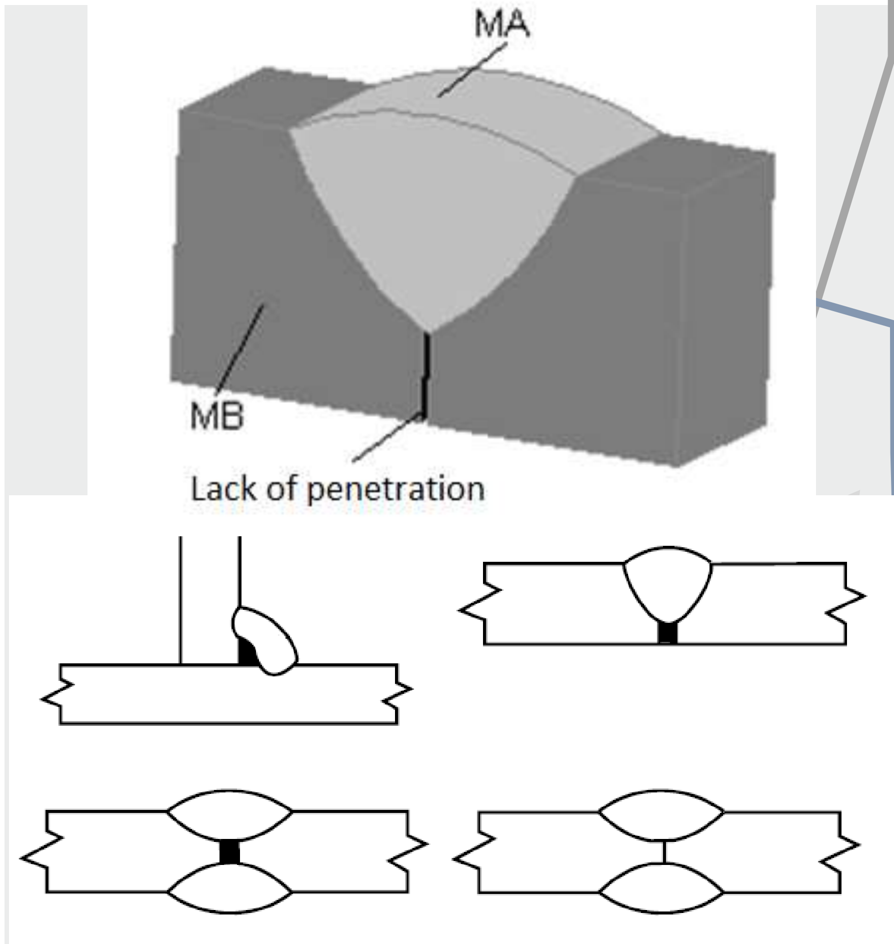
- using too little welding current;
- excessive welding speed;
- unpolluted cleaning of the materials: oxides, rust, paints and other adhesions impede a perfect fusion of the molten material with the base material. Careful cleaning before welding is required;
- inappropriate geometry of the joint;
- using an electrode with a too large diameter;
- inappropriate position and incorrect electrode handling.

Survey of specific weld imperfections and their cause

Lack of penetration

The main causes that lead to this type of defect are:

- too high threshold;
- too low welding current;
- incorrect geometry of the groove ;
- too large or too small diameter of the electrode or wire used to weld the root layer;
- Incorrect heating of the electrode or base material;
- unbalanced welding;
- tilting of the electrode
- too little current intensity;
- arc too long;
- too high welding speed .



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Survey of specific weld imperfections and their cause

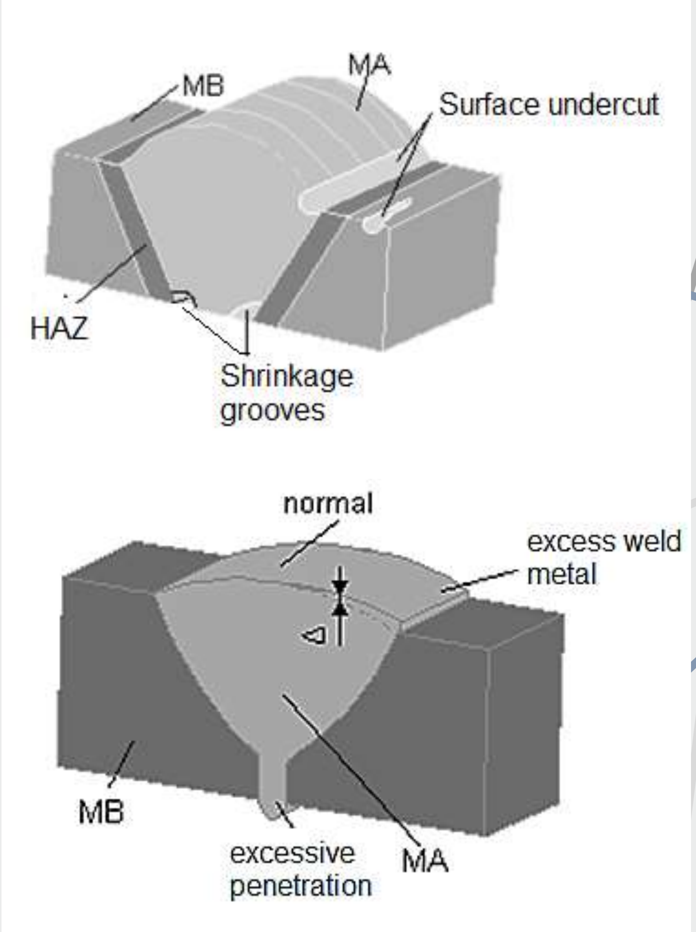
***Fifth group* – Imperfect shape and dimensions**

Shape and surface defects can influence either joint strength or mounting conditions . They produce local stress concentrations and increase fragility tendency.

Influence of weld imperfections on product performance

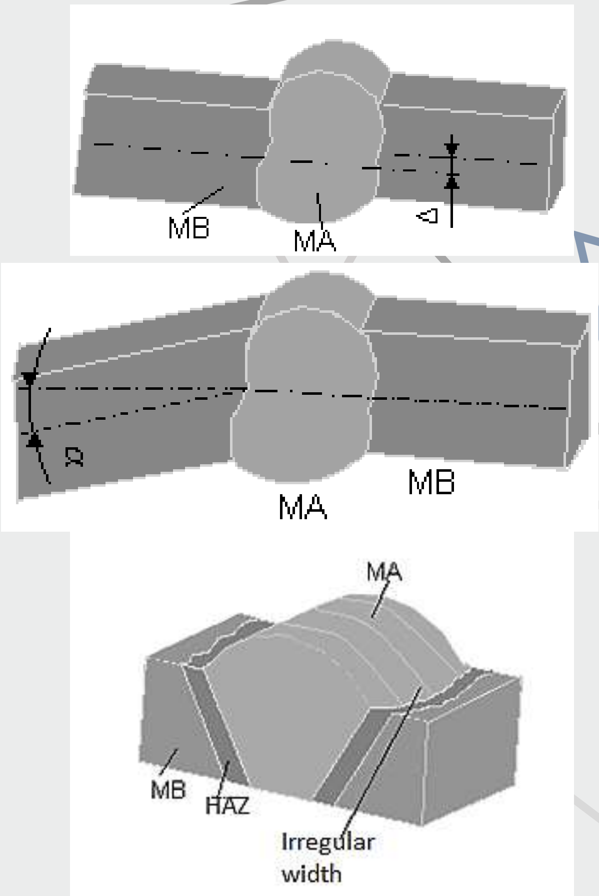
The main causes that lead to this type of defects are:

- ***undercut*** (marginal groove) - excessive welding current, use of a too long arc, high welding speed, insufficient number of layers, vertical welding;
- ***excess weld metal*** – forward speed and low welding current, flux quality;



Influence of weld imperfections on product performance

- **linear misalignment**– inappropriate assembly, non-uniform contraction to solidification;
- **angular misalignment** – poor positioning and grip, unfavorable welding steps, thickness differences between bilateral seams, too large and uneven number of layers;
- **irregular width** – uneven joint processing, wrong electrode handling, defective welding position;
- **irregular surface** – variation in the length of the arc;



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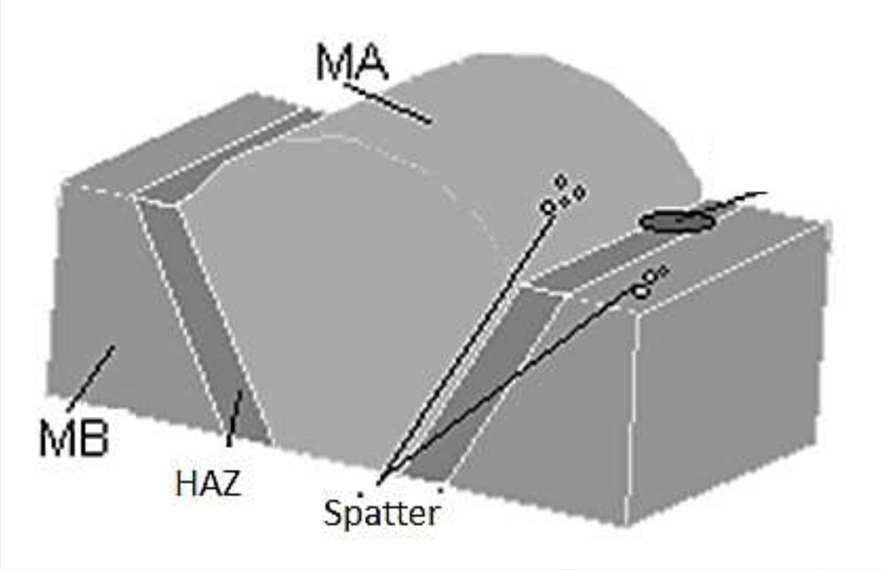
Sixth group – Miscellaneous imperfections

- **spatter** – welding current too high, welding arc too long;



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Influence of weld imperfections on product performance

- act as concentrators of efforts;
- reduce the area of the section where it is located;
- produce drainage paths for fluids;
- have the potential to initiate the cracking;
- predisposing the affected area to corrosion and erosion.

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The presence of imperfections involves:

- increasing work-repair time;
- cost increases (repairs);
- reducing productivity.

The importance of the presence of imperfections depends on:

- the microstructure of the material in the area where the imperfections lie;
- the mechanical properties of the material;
- the load of the welding structure : static, cyclic, shock, etc.
- working environment: corrosive or non-corrosive;
- the type and dimensions of imperfection;
- local tensions generated by imperfection.

Imperfections and acceptance criteria

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Acceptance criteria

The acceptance criteria - a principle, a rule to which reference is made to define, assessment and classification of situations or objects

Defects fall into acceptable or unacceptable categories depending on the product's destination, its functional role, its importance as a whole, its costs, the requirements imposed by standards, codes, norms or conventions between the beneficiary and the supplier.

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Acceptance criteria

ISO 5817:2008

Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) Quality levels for imperfections

Quality level of welding

- D Moderate Quality Level
- C Intermediate Quality Level
- B Severe Quality Level

ISO 10042:2006

Welding - Arc-welded joints In aluminium and its alloys - Quality levels for imperfections

ISO 9013:2002

Thermal cutting -- Classification of thermal cuts - Geometrical product specification and quality tolerances

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Acceptance criteria

ISO 5817: 2015

No	Reference to ISO 6520-1	Imperfection designation	Remarks	t mm	Limits of imperfections for quality levels		
					moderate D	Intermediate C	severe B
1.1.	100	Crack		≥0,5	Not permitted	Not permitted	Not permitted
1.3.	2017	Surface pore	Maximum dimension of a single pore for — butt welds — fillet welds	0,5 to 3	d ≤ 0,3 s d ≤ 0,3 a	Not permitted	Not permitted
			Maximum dimension of a single pore for — butt welds — fillet welds	> 3	d ≤ 0,3 s, but max. 3 mm d ≤ 0,3 a, but max. 3 mm	d ≤ 0,2 s, but max. 2 mm d ≤ 0,2 a, but max. 2 mm	Not permitted

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Useful Topic Related Links

Weld imperfections 1

Weld imperfections 2

Weld imperfections 3

Weld defects - 1

Weld defects - 2

Weld defects - 3

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I.4.Quality assurance and qualification in welding

I.4.2. Destructive testing of materials and welded joints (fracture test, bend test, macro section test, hardness test, etc.)

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Aim & Objectives

Module Aim:	Offers information regarding destructive testing of materials and welded joints
Number of hours:	2 hours e-learning and 2 hours self-study
Learning Outcomes:	• Recognize weld imperfections and destructive methods of detection • Outline how the main destructive methods work, their advantages and disadvantages when applied to welded structures.
ECVET:	4 (for Training Units Nº 4)

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Lecture Outline

- Fracture test
- Bend test
- Macro section test
- Hardness test, etc.

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Destructive testing of materials and welded joints

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Destructive testing of materials and welded joints

Destructive testing - is a test that puts the sample object under certain circumstances until it actually fails.

- The failed pieces are then studied and compared with known standards to determine the quality of the object.
- This type of testing is generally much easier to carry out, more likely to yield more information and much easier to interpret compared to non-destructive testing.
- Its drawback is that after performing, the test material cannot be reused.

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Destructive testing of materials and welded joints

The Destructive testing methods used for the analysis of welded structures are :

- Tensile test;
- Bend test;
- Hardness test;
- Impact test;
- Macroscopic and microscopic examination.

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Tensile test

- Tensile testing a way of evaluating a weld's strength and ability to withstand loading.
- It is most commonly used to evaluate the strength of butt-joint welds joining the ends of two pieces of material.
- A cross section is cut so that the tensile specimen is oriented across the weld.
- Tests performed on these specimens will encompass the weld material, the heat-affected zones (HAZs), and the base material at each end.

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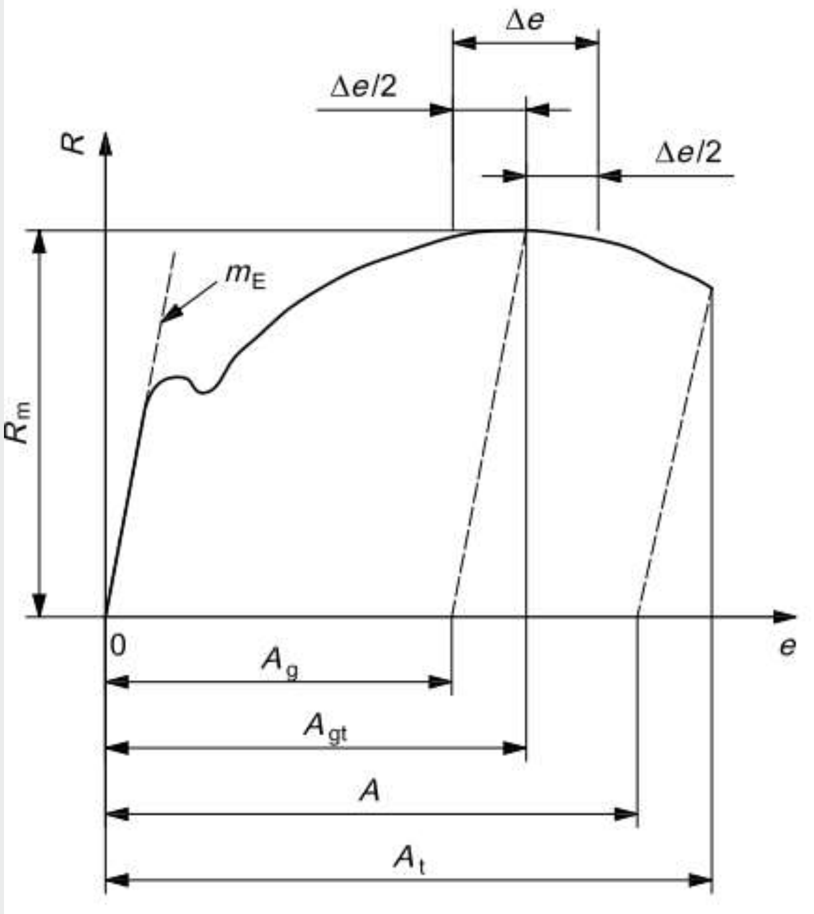
Tensile test results

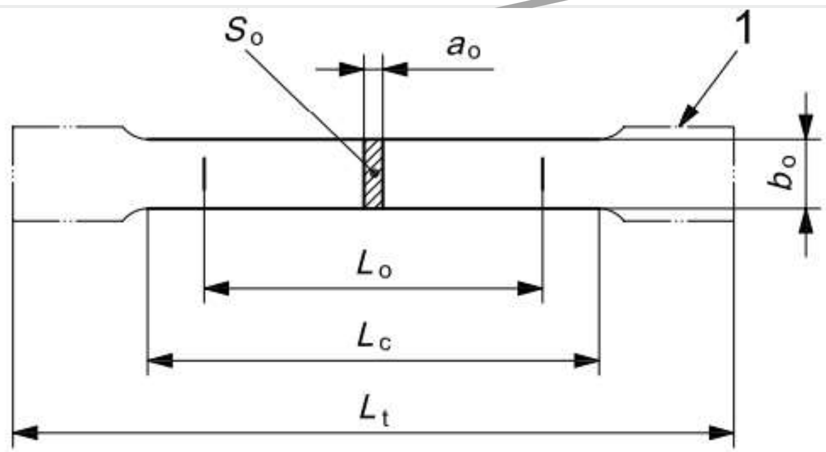
EN ISO 6892 Metallic materials — Tensile testing

A - elongation after fracture
A_g - plastic extension at maximum force
A_{gt} - total extension at maximum force
A_t - total extension at maximum fracture e percentage extension
m_E - slope of the elastic part of the stress-percentage extension curve
R - stress
R_m tensile strength
Δe tray extent

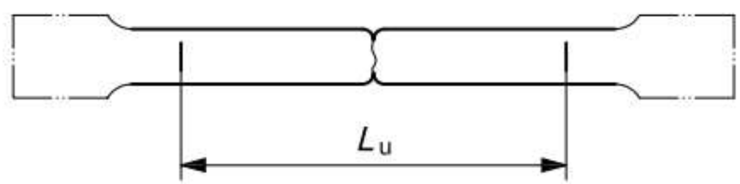


Tensile test specimens

$\mathbf{a_o}$ - original thickness of a flat test piece or wall thickness of a tube
$\mathbf{b_o}$ - original width of the parallel length of a flat test piece
$\mathbf{L_c}$ - parallel length Lo original gauge length
$\mathbf{L_t}$ - total length of test piece
$\mathbf{L_u}$ - final gauge length after fracture
$\mathbf{S_o}$ - original cross-sectional area of the parallel length
1 - gripped ends



a) Before testing



b) After testing

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Tensile test specimens

a_o - original thickness of a flat test piece or wall thickness of a tube
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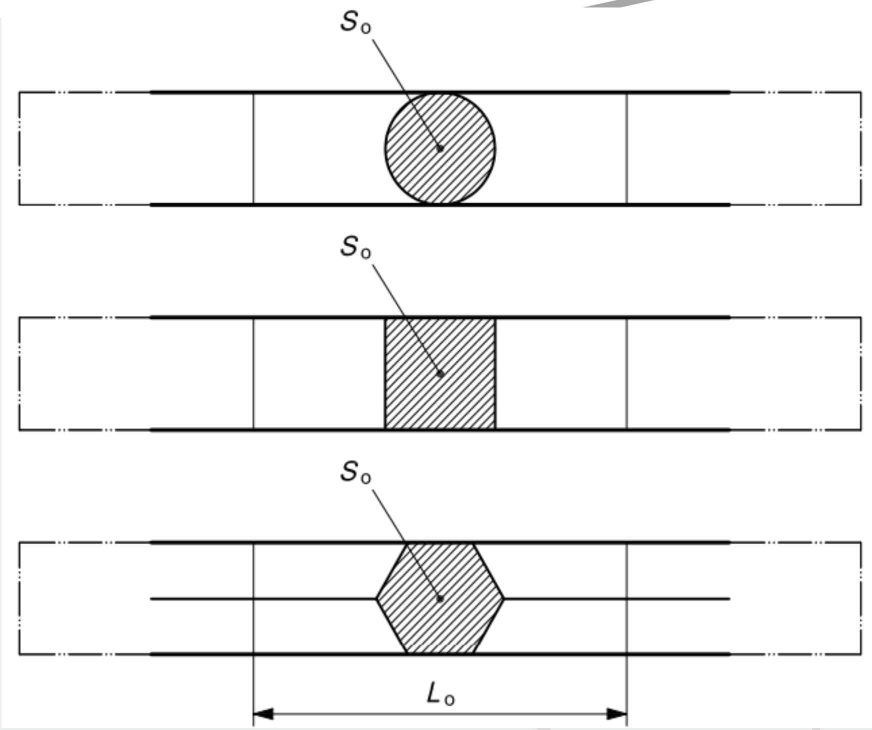
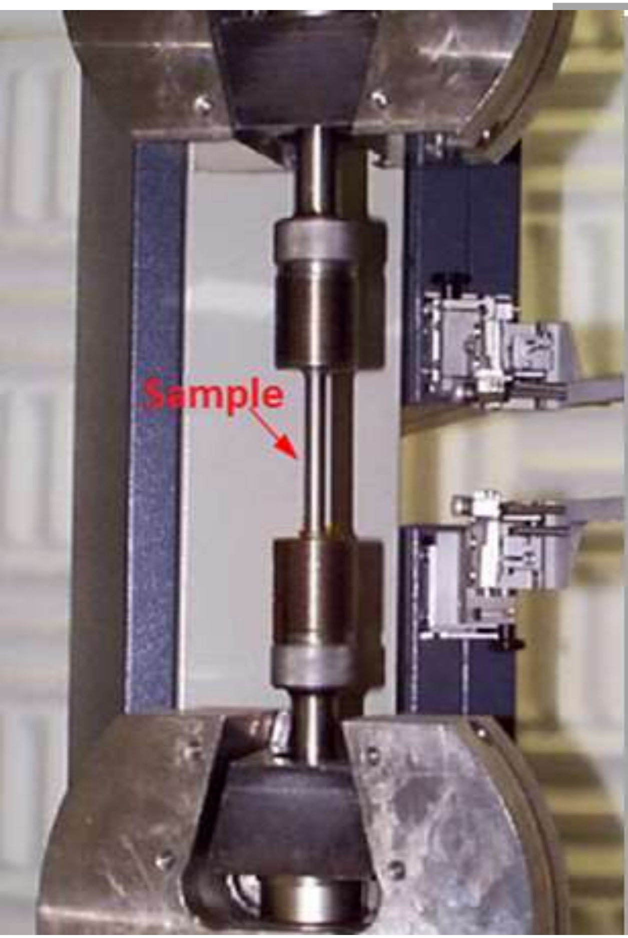
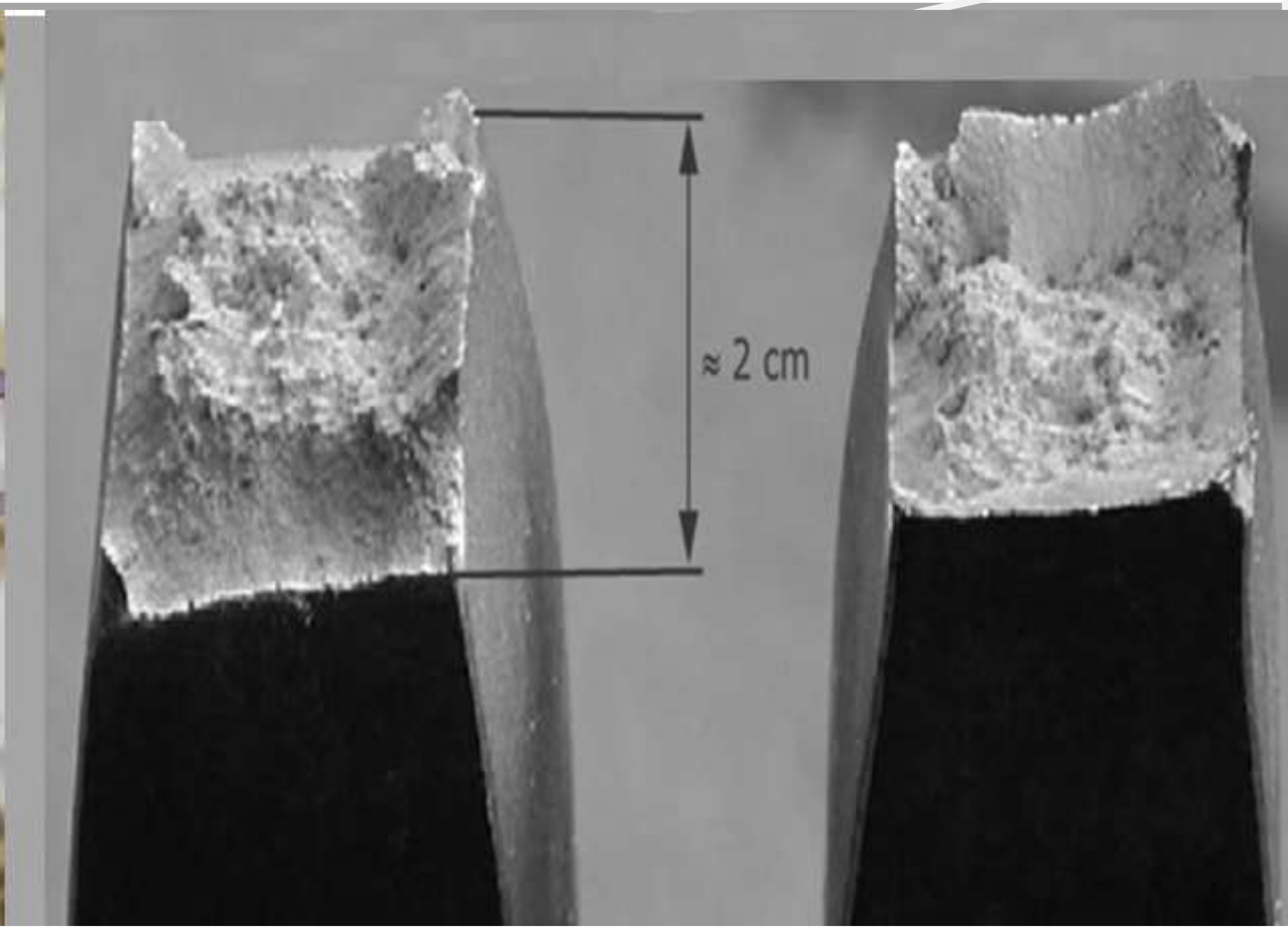


Tensile test specimen





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Bend test

- Bend testing a material allows for the determination of that materials ductility, bend strength, fracture strength and resistance to fracture.

- These characteristics can be used to determine whether a material will fail under pressure and are especially important in any construction process involving ductile materials loaded with bending forces.

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Bend test

EN ISO 5173 - Destructive tests on welds in metallic materials — Bend tests

- transverse face (side) bend test specimen for a butt weld TFBB
- transverse root bend test specimen for a butt weld TRBB
- transverse side bend test specimen for a butt weld SBB
- face (side) bend test specimen for cladding with (without) a butt weld

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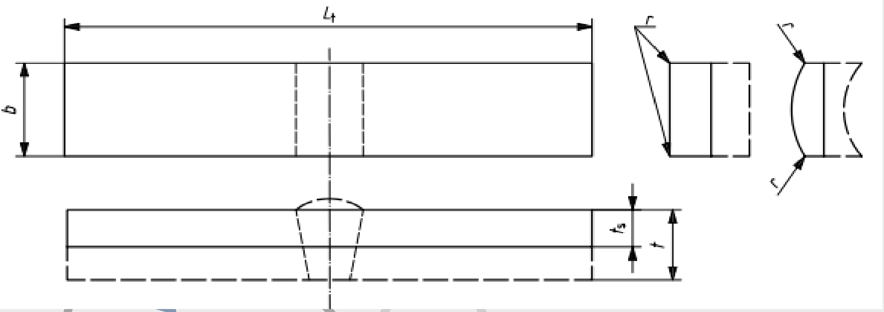
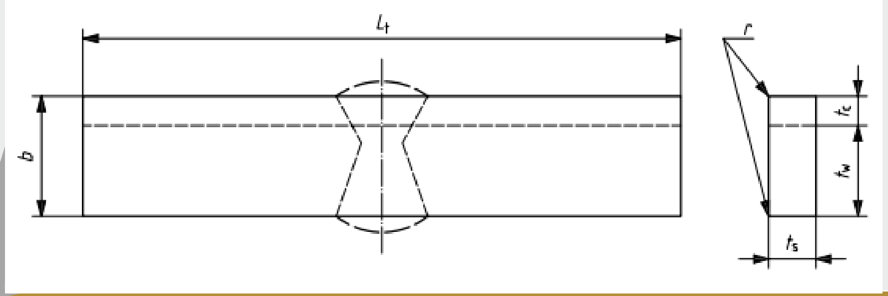
Bend test specimens



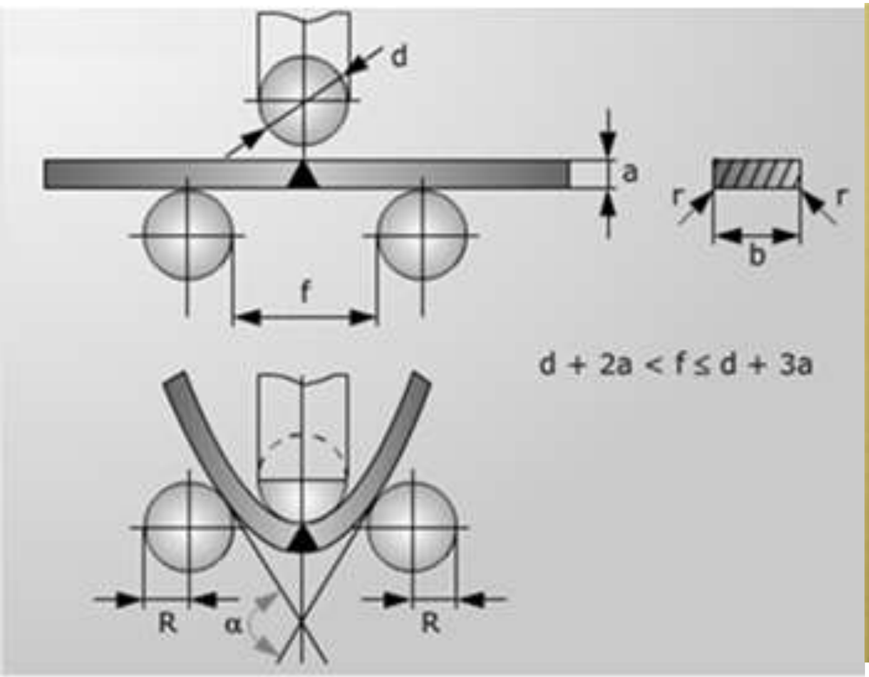


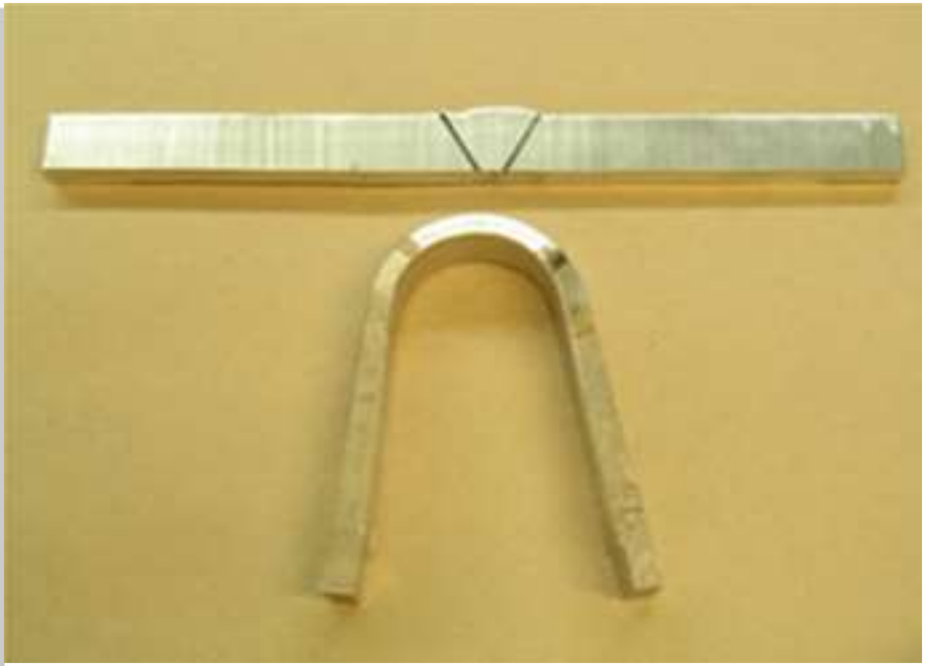
Specimens shall be prepared in such a manner that the preparation does not affect either the base material or the weld metal.

Bend test specimens for butt welds and cladding

Side bend test specimen for cladding with a butt weld (SBCB)

Bend test





Hardness test

- Hardness testing of welded materials is an excellent example of the traditional challenges associated with micro hardness testing.

- A series of hardness measurements traversed across the weld, and most importantly in the heat-affected zone (HAZ), can determine if the weld is applied correctly and within specifications.

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Hardness test

Brinell Hardness Test

ISO 6506 - Metallic materials -- Brinell hardness test

- The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg.

- For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation

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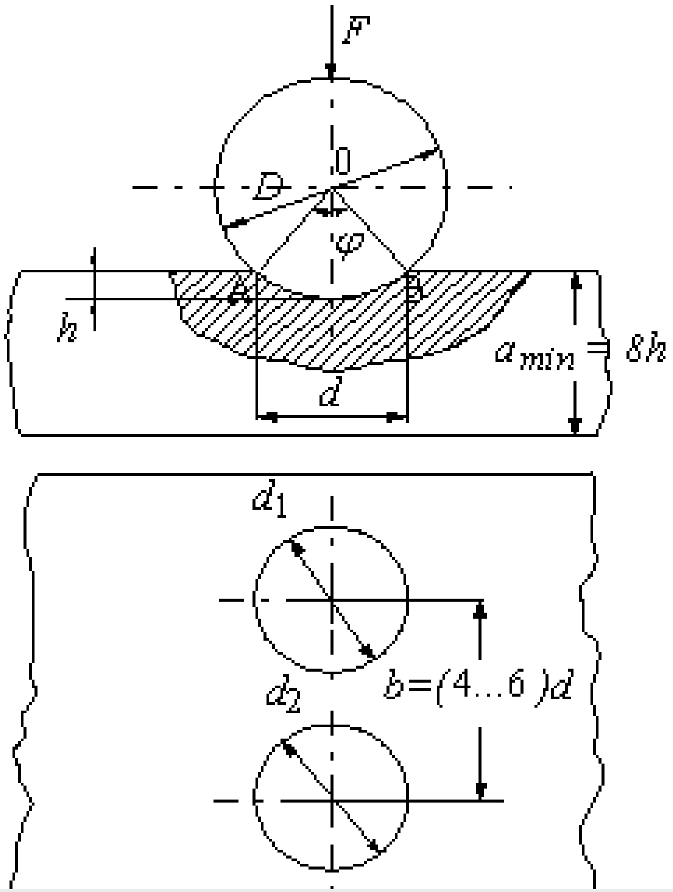
Hardness test



$$HB = \frac{F}{S} = \frac{2F}{\pi D(D - \sqrt{D^2 - d^2})},$$

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Hardness test

Vickers Hardness Test

EN ISO 6507: Metallic materials — Vickers hardness test

- Consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf.
- The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated.

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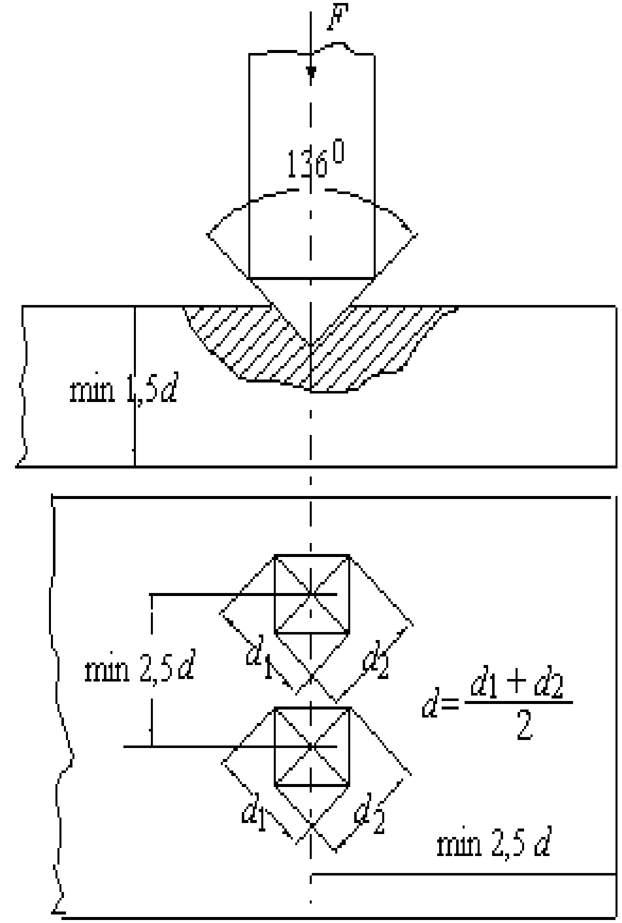
Hardness test

$$HV = \frac{F}{A} = \frac{2F\sin 68^\circ}{d^2} = \frac{1{,}8544\,F}{d^2}$$



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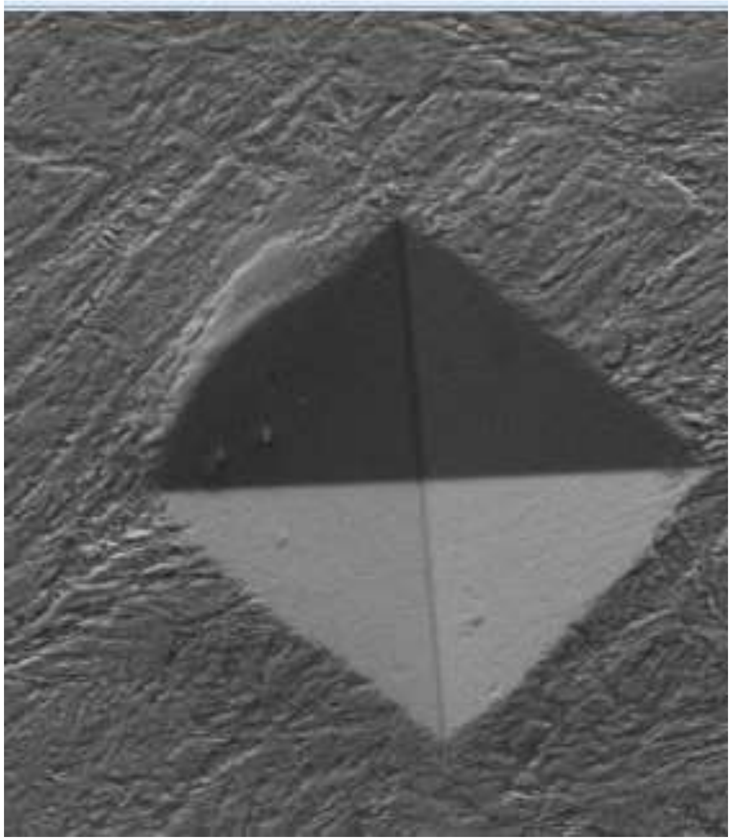
Hardness test



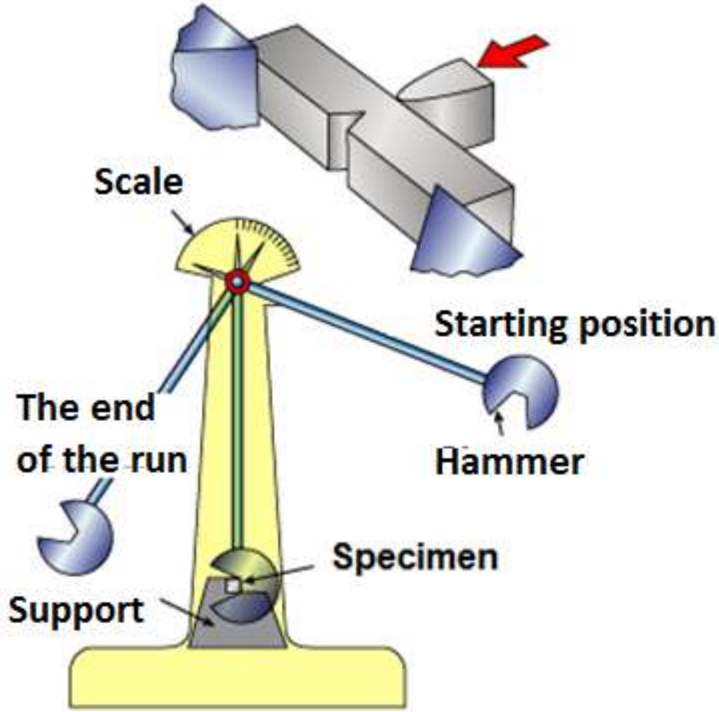
Impact test

ISO 14556:2015 - Metallic materials -- Charpy V-notch pendulum impact test -- Instrumented test method-

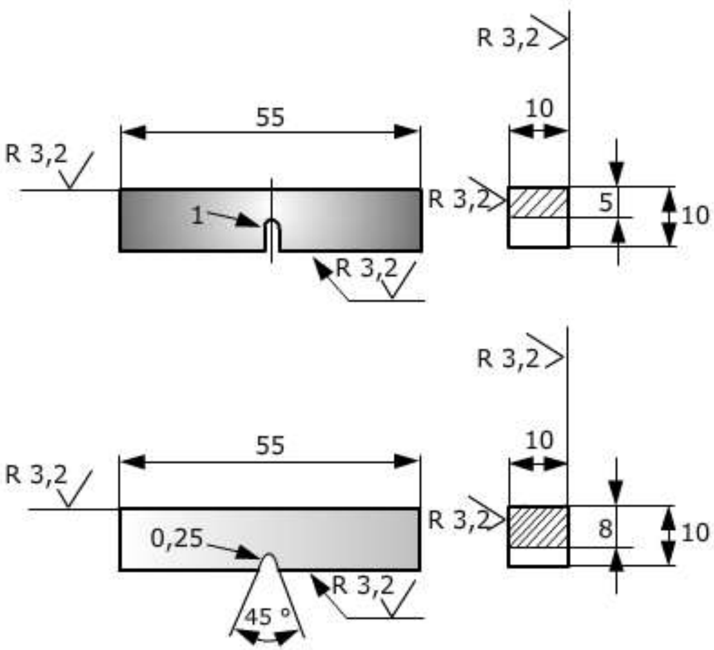
Impact testing of welded materials, using instrumented pendulum and drop weight testers, provides information about the impact strengths and behavior properties of the weld.

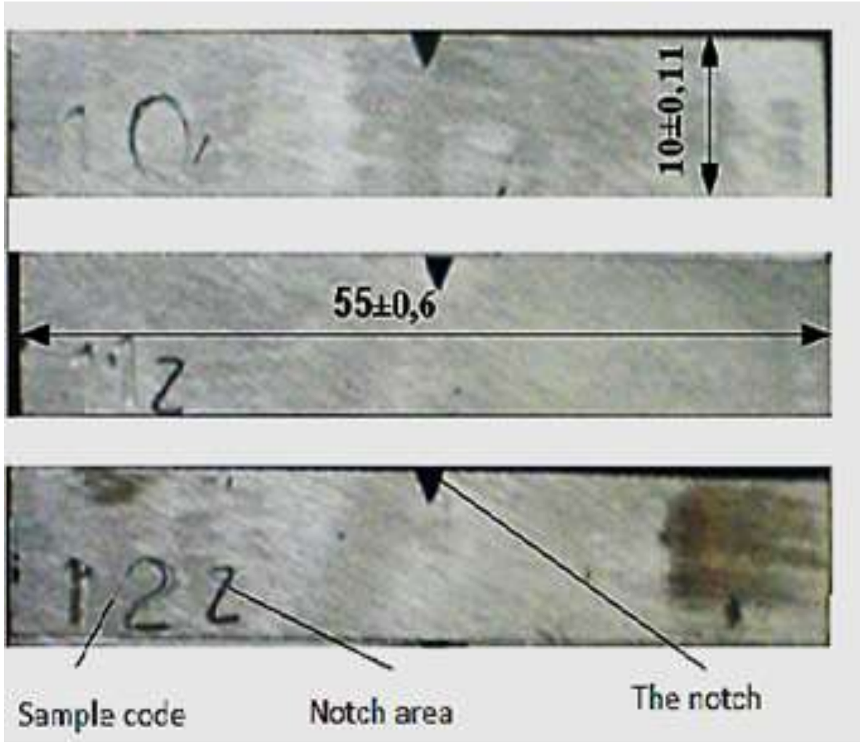
Weld properties behave differently if a preexisting fracture in the weld is exposed to a sudden impact, even more so at low or high temperatures.

Impact test


Scale
Starting position
The end
of the run
Hammer
Specimen
Support

Impact test specimens





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Macroscopic and microscopic examination

Macroscopic examination

Macro examination is mainly used for checking the quality of welds.

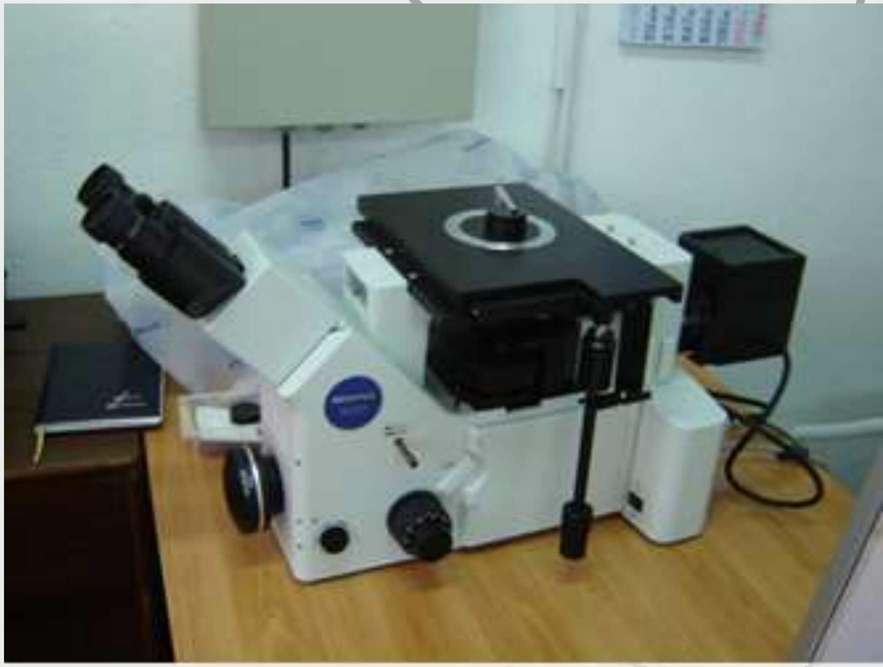
Porosity, lack of weld penetration, lack of side wall fusion, poor weld profile and other important defects are checked in accordance with the relevant welding standard.

Macroscopic and microscopic examination

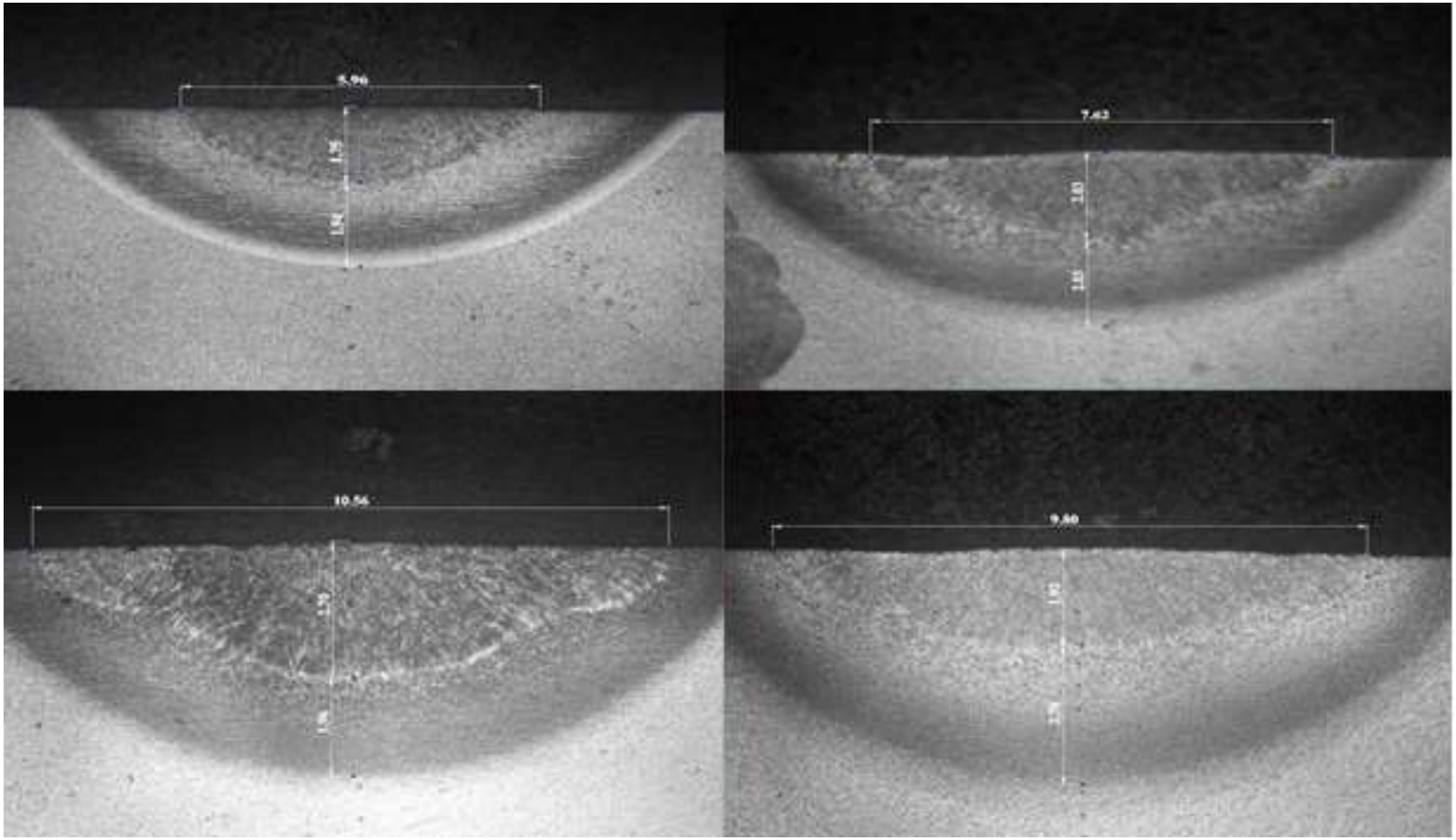
Light microscope, type *Euromex,*

Macroscopic and microscopic examination

Inverted optical microscope *type Olympus,*



Macroscopic and microscopic examination



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Macroscopic and microscopic examination

Microscopic examination

Microscopic examination is performed for a number of purposes, most commonly it is carried out to assess the structure of material for quality purposes:

- Ensures correct heat treatment is employed
- Ensures castings are free from cracks or voids and segregations
- Identifies where excessive grain growth has occurred

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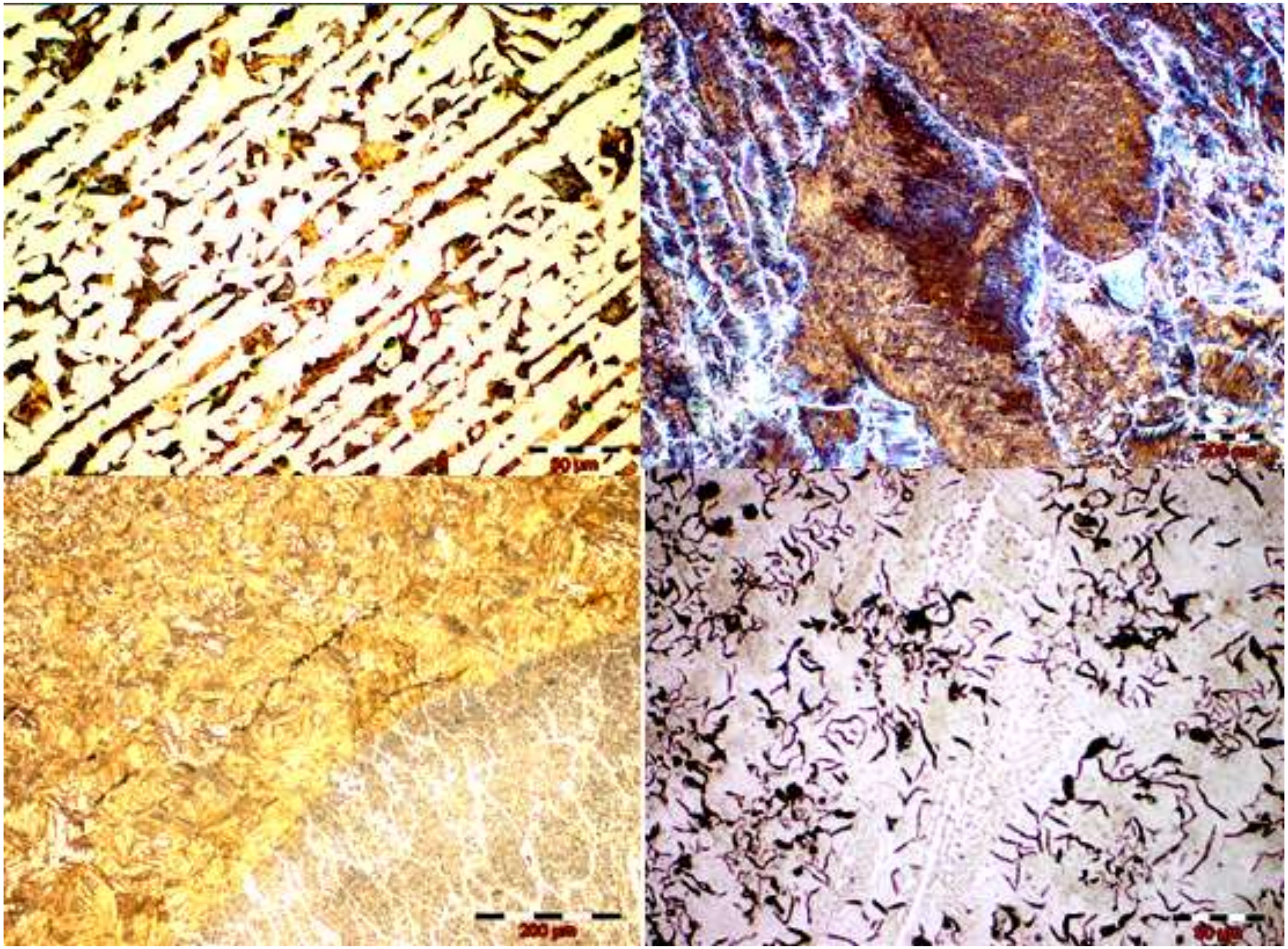

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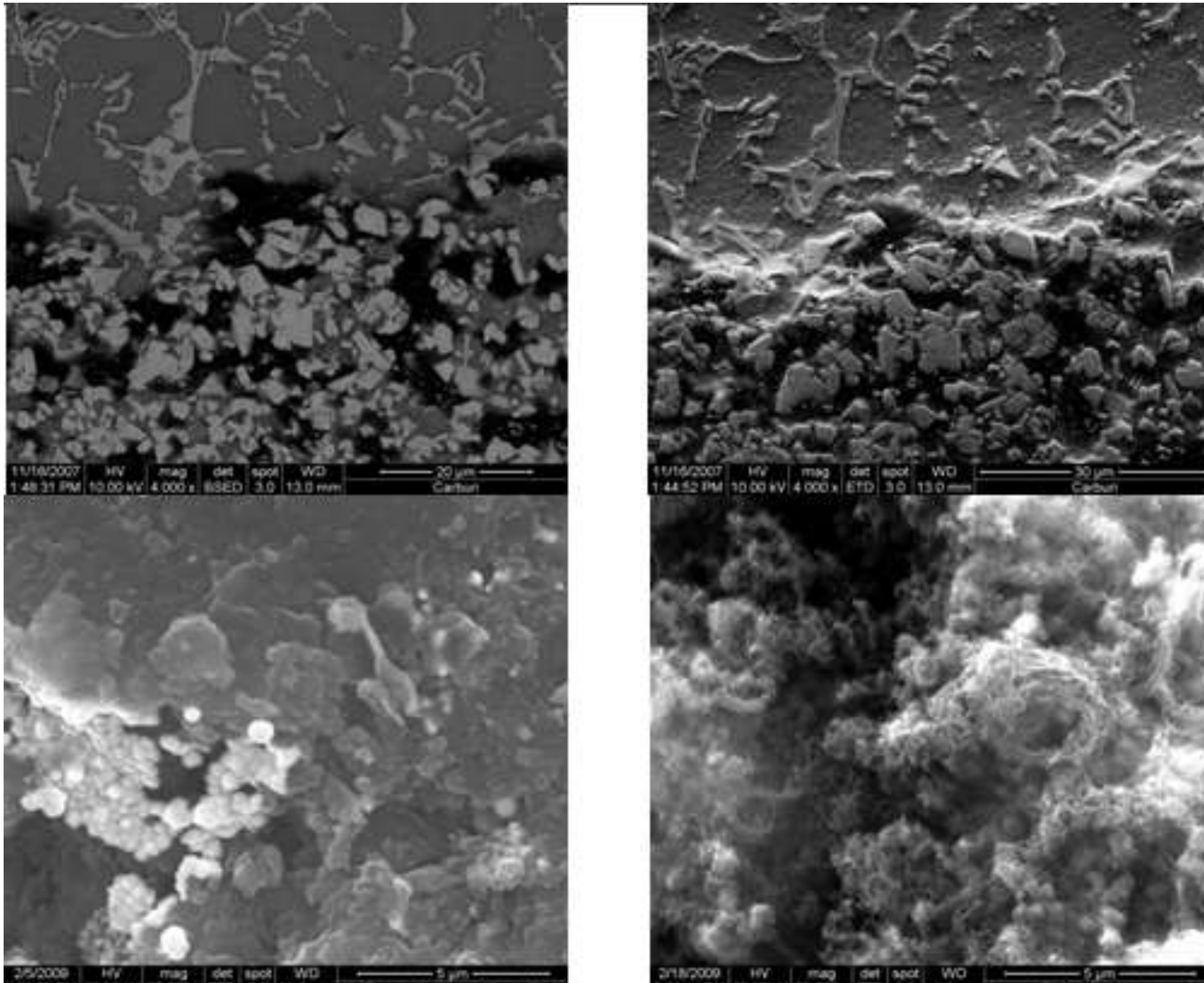
Macroscopic and microscopic examination

Scanning electron microscope (SEM)

Macroscopic and microscopic examination

Image of the sample attached to the specimenholder taken with the CCD sensor, Laboratory LAMET



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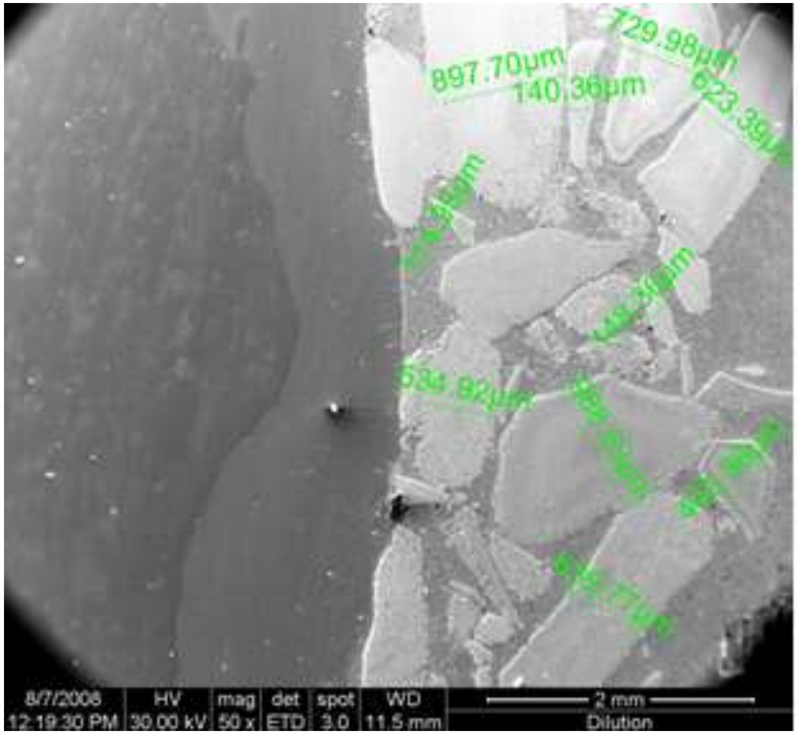
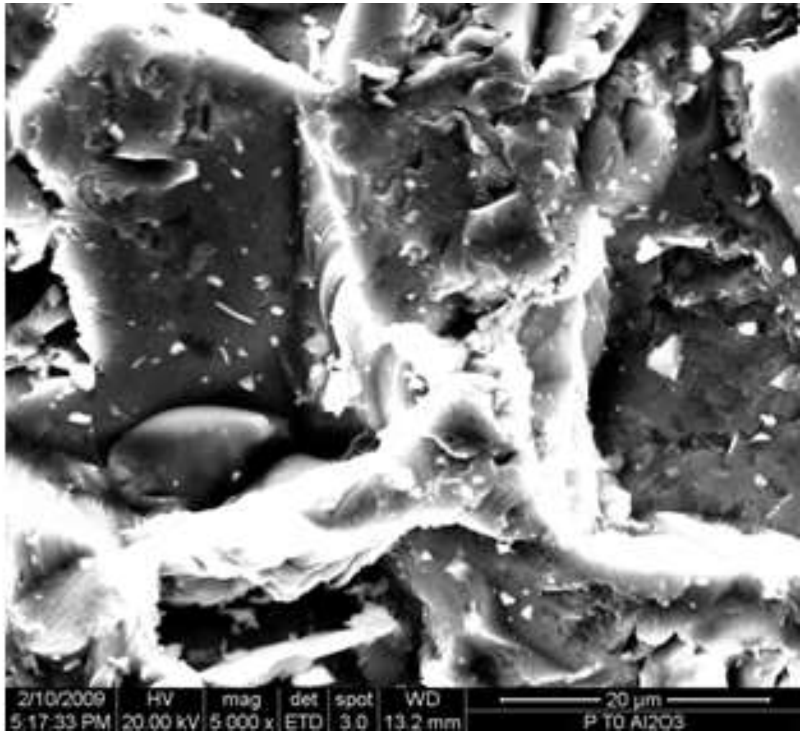
Macroscopic and microscopic examination





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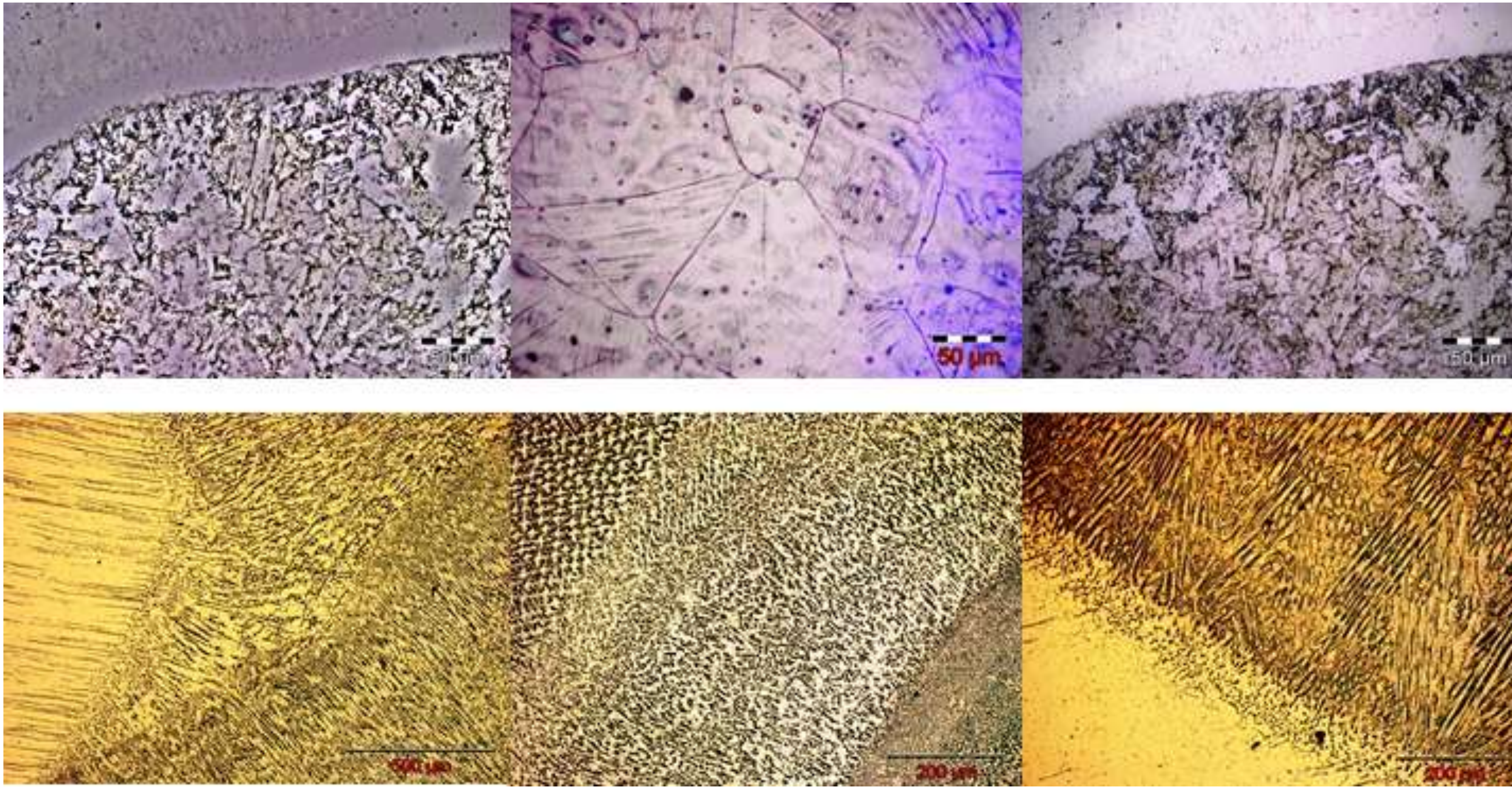

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Useful Topic Related Links

Destructive weld testing methods

Destructive Testing of Welds

Tensile testing

Bend testing

Micro and Macro Examinations

Tensile Test

Bending test

Hardness test

Macroscopis examination

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I.4. Quality assurance and qualification in welding

I.4.3. Non-destructive testing of materials and welded joints

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Aim & Objectives

Module Aim:	Offers information regarding non-destructive testing of materials and welded joints
Number of hours:	2 hours e-learning and 2 hours self-study
Learning Outcomes:	• Recognise weld imperfections and non-destructive methods of detection • Outline how the main NDT methods work, their advantages and disadvantages when applied to welded structures.
ECVET:	4 (for Training Units Nº 4)

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Lecture Outline

- Visual Testing
- Penetrant Testing
- Magnetic particles Testing
- Eddy Current Testing
- Infrared Thermographic Testing
- Radiographic Testing
- Ultrasonic Testing
- Acoustic emission testing

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I.4.3.1. Surface inspection of cracks and other surface imperfections

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Non-destructive testing of materials and welded joints

The field of Non-Destructive Examination is a very broad, interdisciplinary field that plays a critical role in inspecting that structural component and systems perform their function in a reliable fashion.

Certain standards have been implemented to ensure the reliability of the Non-Destructive tests and prevent certain errors due to fault in the used equipment, misapplication of the methods or skill and knowledge lack of the inspectors.

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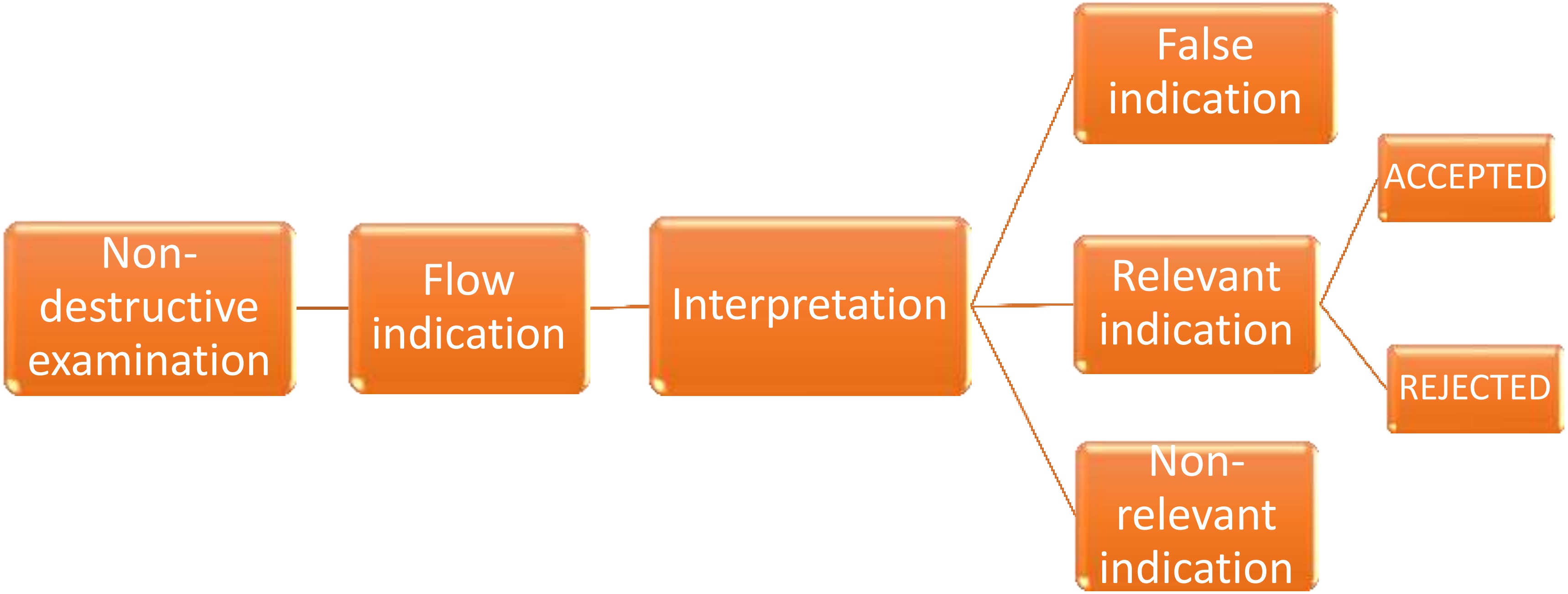
Non-destructive testing of materials and welded joints



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Non-destructive testing of materials and welded joints

No.	Technique	Capabilities	Limitations
1	Visual Testing	Macroscopic surface flaws Small surface flaws	Small flaws are difficult to detect, no subsurface flaws.
2	Penetrant Testing	Surface flaws	No subsurface flaws not for porous materials
3	Magnetic particles Testing	Surface / near surface and layer flaws	Limited subsurface capability, only for ferromagnetic materials.
4	Eddy Current Testing	Surface and near surface flaws	Difficult to interpret in some applications; only for metals.
5	Infrared Thermographic Testing	material imperfections such as cracks, defects, voids, cavities and other inhomogeneities.	is influenced by a number of factors such as the thermo-optical properties of the object (emissivity, transmissivity, reflectivity),[3] ambient temperature, environment properties, etc
6	Radiographic Testing	Subsurface flaws	Smallest defect detectable is 2% of the thickness; radiation protection. No subsurface flaws not for porous materials
7	Ultrasonic Testing	Subsurface flaws	Material must be good conductor of sound.
8	Acoustic emission	Can analyze entire structure	Difficult to interpret, expensive equipment.

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Surface inspection of cracks and other surface imperfections

Surface examination and status monitoring techniques include:

- Visual testing
- Liquid penetrant testing
- Magnetic particle testing

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Visual testing (VT)

Visual testing—method of nondestructive testing using electromagnetic radiation at visible frequencies.

Visual inspection can be applied to all types of materials for the detection of surface cracks, voids, pores, inclusions and for the assessment of surface roughness. It can be applied in metrology and dimensional measurements using mechanical gauges.

Process control applications of visual inspection include both on-line and off-line monitoring control.

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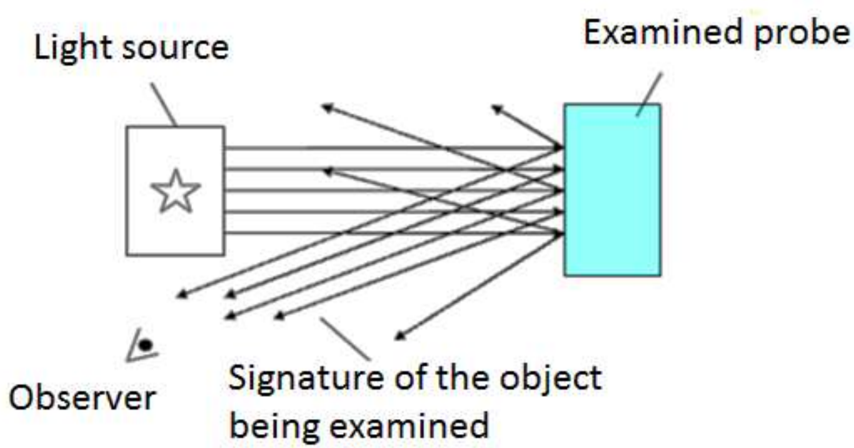
Visual testing (VT)



Direct Visual Testing

Direct visual testing may usually be applied for local visual testing when access is sufficient to place the eye within 600 mm of the surface to be tested and at an angle not less than 30° to the surface to be tested.

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Visual testing (VT)

The specific part, component, vessel, or section thereof, under immediate test, shall be illuminated, if necessary, with auxiliary lighting, to attain a minimum of 160 lux for general visual testing and a minimum of 500 lux for local visual testing.

Consideration shall be given to the application of luminance to maximize the effectiveness of the test by:

- Using the optimum direction of light with respect to the viewing point;
- Avoiding glare;
- Using an illumination level compatible with the surface reflectivity.

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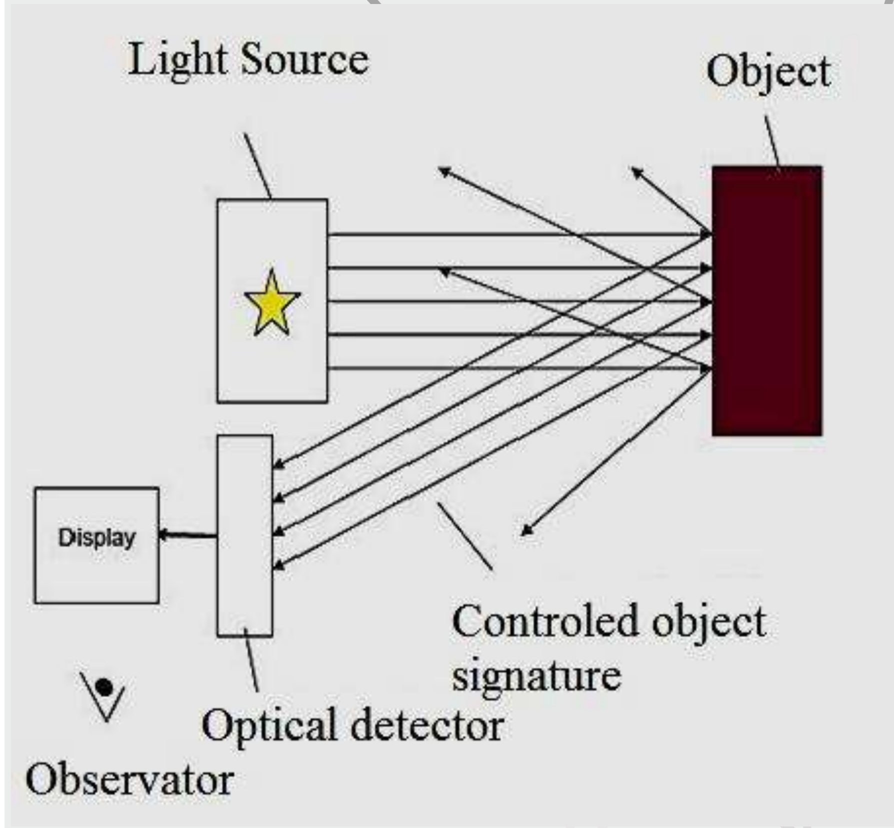
Visual testing (VT)

When direct visual testing cannot be utilized, remote visual testing may have to be substituted. Remote visual testing uses visual aids such as endoscopes and fibro optics, coupled to cameras or other suitable instruments.



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Visual testing (VT)

The following equipment may be needed:

- mirrors, endoscopes, boroscopes, optic fibers or video cameras
- Magnifying lens
- Radius gauge
- Various set of weld gauges for measuring fillet welds, reinforcement, undercuts, misalignment etc.
- Light source
- Lux meter.

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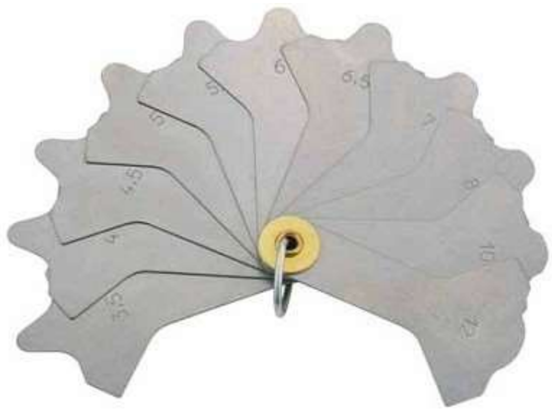
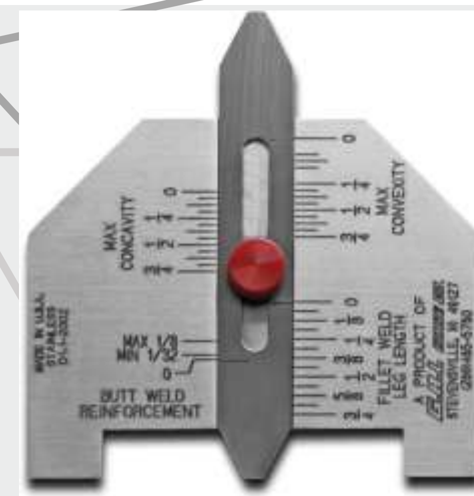
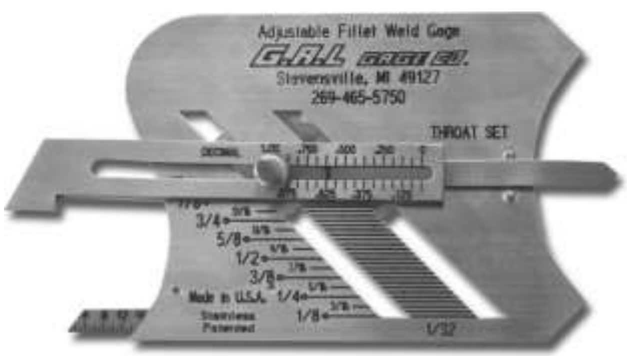
Visual testing (VT)







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Visual testing (VT)

Advantages

- It is simple and less technologically advanced compared to other methods;
- Inexpensive:
- Highly portable;
- Immediate results;
- Can be applied to any type of product;
- Minimum training for the operator;
- Minimum sample preparation;

Visual testing (VT)

Disadvantages

- The result of the examination depends on the physiological attributes of the operator;
- Interpretation errors;
- The sensitivity of the examination is limited to the human eye (only sometimes it can be improved by the use of optical tools)
- Visual contact with the surface of the examined product is required
- The accuracy of the examination depend on the lighting conditions .

Penetrant testing (PT)

Penetrant testing (PT) is one of the most widely used nondestructive testing methods for the detection of surface discontinuities in nonporous solid materials.

The technique is based on the ability of a liquid to be drawn into a "clean" surface discontinuity by capillary action.

After a period of time called the "dwell time", excess surface penetrant is removed and a developer applied. This acts as a blotter that draws the penetrant from the discontinuity to reveal its presence.

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Penetrant testing (PT) - Steps

Preparation and precleaning of the surface

Contaminants, e.g. scale, rust, oil, grease or paint shall be removed, if necessary using mechanical or chemical methods or a combination of these methods. Pre-cleaning shall ensure that the test surface is free from residues and that it allows the penetrant to enter any defects/discontinuities.

Penetrant testing (PT) - Steps

Drying the surface

As the final stage of precleaning, the object to be tested shall be thoroughly dried, so that neither water or solvent remains in the defects / discontinuities.

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Penetrant testing (PT) - Steps

Penetrant Application and Dwell Time

The penetrant can be applied to the object to be tested by spraying, brushing, flooding or immersion.

In order to minimize moisture entering effects/discontinuities, the temperature of the test surface shall generally be within the range from 10°C to 50°C.

Penetrant testing (PT) - Steps

Excess penetrant removal

The removal shall be done so that no penetrant is removed from the defects / discontinuities. It is not allowed to spray the cleaner directly upon the surface to be tested.

To remove the excess of penetrant we can use:

- Water
- Solvent
- Emulsifiertent

Penetrant testing (PT) - Steps

Drying the surface

For quick drying, any droplets and puddles of water shall be removed from the object.

Except when using water-based developer the test surface shall be dried as quickly as possible after excess penetrant removal.

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Penetrant testing (PT) - Steps

Developer Application

The developer shall be maintained in an uniform condition during use and shall be evenly applied to the test surface. The application of the developer shall be carried out as soon as possible after the removal of excess penetrant.

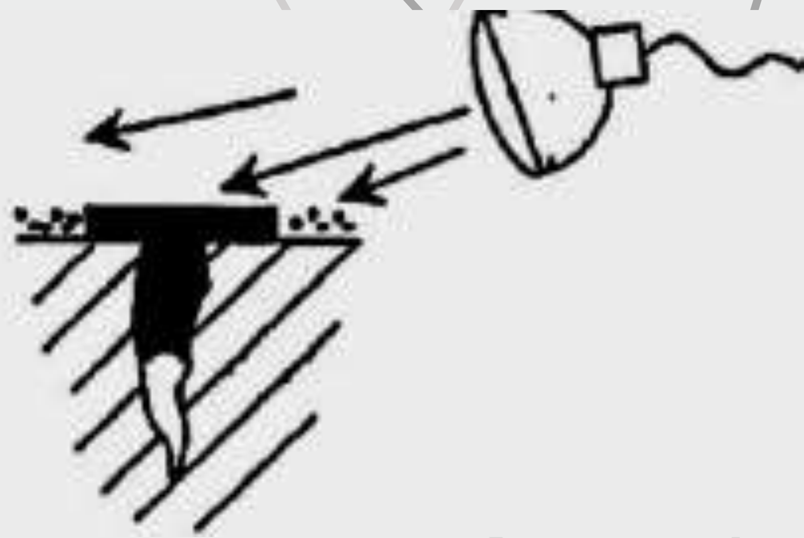
The developing time shall as a minimum be the same as the penetration time, however, longer times may be agreed.

Penetrant testing (PT) - Steps

Inspection

Inspection is then performed under appropriate lighting to detect indications from any flaws which may be present.

Generally, it is advisable to carry out the first examination just after the application of the developer or soon as the developer is dry. This facilitates a better interpretation of indications. The final inspection shall be carried out when the development time has elapsed.

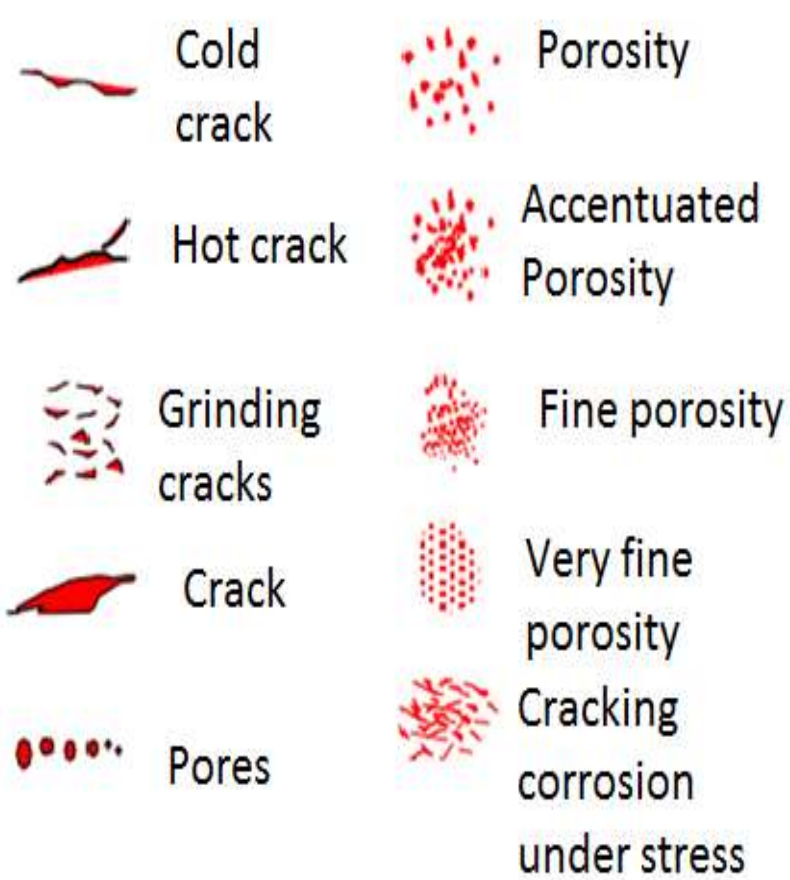


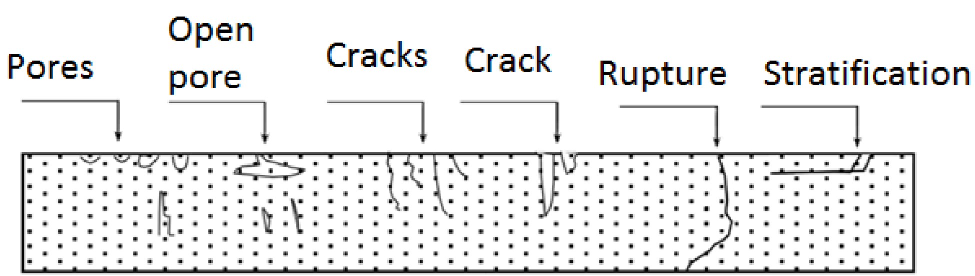
Penetrant testing (PT) - Steps

Cleaning the surface

After final inspection, post cleaning of the object is necessary only in those cases where the penetrant testing products could interfere with subsequent processing or service requirements.

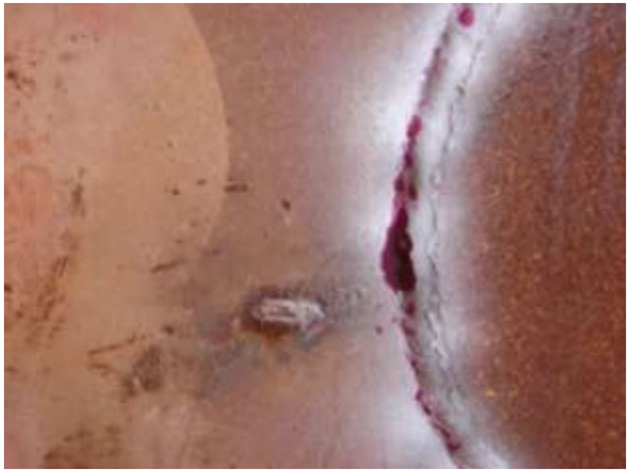
Penetrant testing (PT)





Detectable surface discontinuities with penetrating liquids in any material(with the exception of porous or fibrous materials)

Penetrant testing (PT)



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Penetrant testing (PT)

Advantages:

- High sensitivity (small discontinuities can be detected).
- Few material limitations (metallic and nonmetallic, magnetic and nonmagnetic, conductive and nonconductive materials may be inspected).
- Quick inspection of large areas and volumes.
- Suitable for parts with complex shapes.
- Indications are produced directly on the surface of the part and constitute a visual representation of the flaw.
- Portable (materials are available in aerosol spray cans)
- Low cost (materials and associated equipment are relatively inexpensive)

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Penetrant testing (PT)

Disadvantages

- Only surface breaking defects can be detected.
- Only materials with a relatively nonporous surface can be inspected.
- Precleaning is critical since contaminants can mask defects.
- Metal smearing from machining, grinding, and grit or vapor blasting must be removed.
- Surface finish and roughness can affect inspection sensitivity.
- Multiple process operations must be performed and controlled.
- Post cleaning of acceptable parts or materials is required.
- Chemical handling and proper disposal is required.

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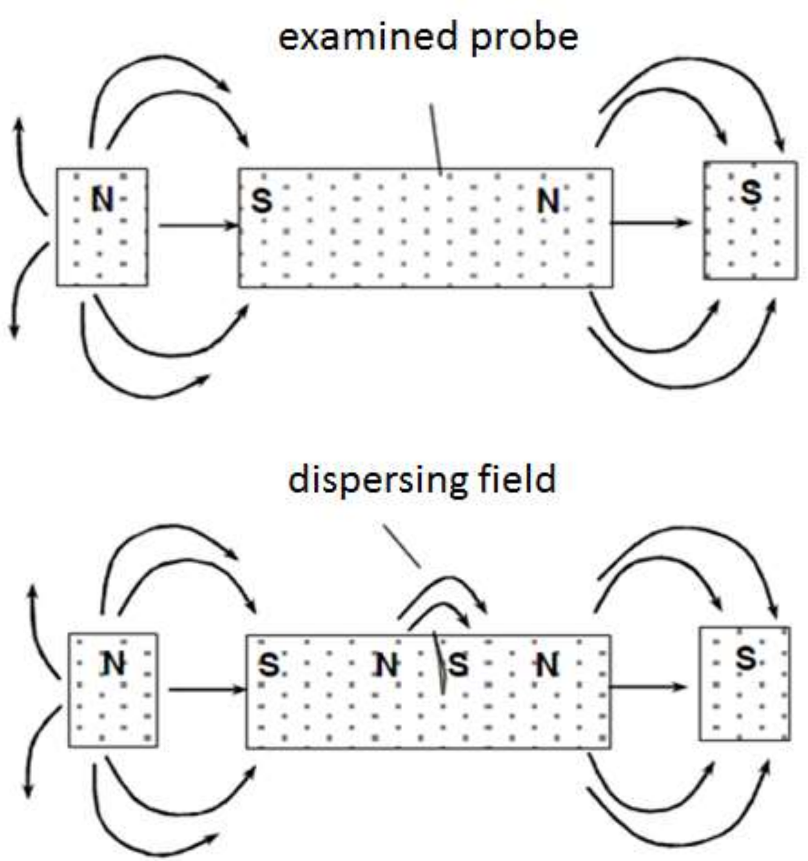
Magnetic particle testing(MT)

Magnetic particle testing — A nondestructive test method that provides the detection of linear, surface, and near-surface discontinuities in ferromagnetic test materials.

Magnetic particle testing (MT) is a nondestructive testing (NDT) method for detecting discontinuities that are primarily linear and located at or near the surface of ferromagnetic components and structures. MT is governed by the laws of magnetism and is therefore restricted to the inspection of materials that can support magnetic flux lines.

Magnetic particle testing(MT)



For the case of a bar magnet, the magnetic field is in and around the magnet. Any place that a magnetic line of force exits or enters the magnet is called a “pole” (magnetic lines of force exit the magnet through the north pole and enter it through the south pole).

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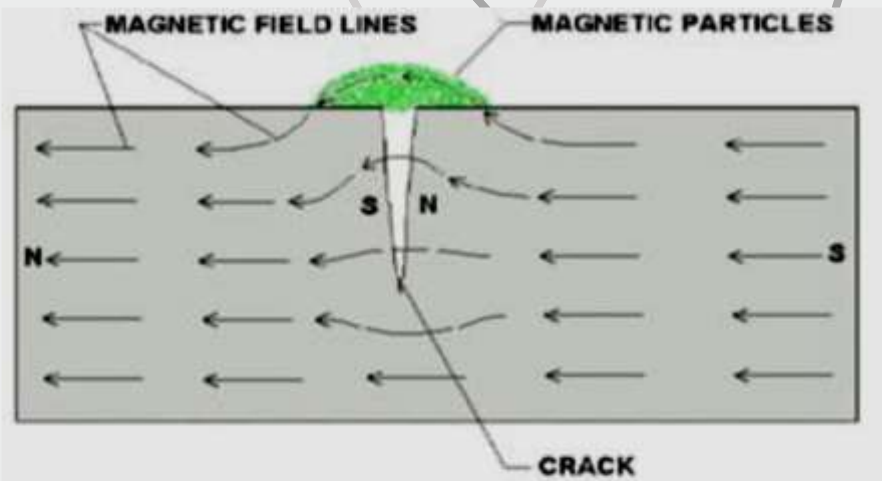
Magnetic particle testing(MT)

The first step in a magnetic particle testing is to magnetize the component that is to be inspected.

If any defects on or near the surface are present, they will create a leakage field.

After the component has been magnetized, iron particles, either in a dry or wet suspended form, are applied to the surface of the magnetized part.

The particles will be attracted and cluster at the flux leakage fields, thus forming a visible indication that the inspector can detect.



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Magnetic particle testing(MT) – Equipment

Permanent Magnets

Permanent magnets can be used for magnetic particle inspection as the source of magnetism (*bar magnets or horseshoe magnets*).

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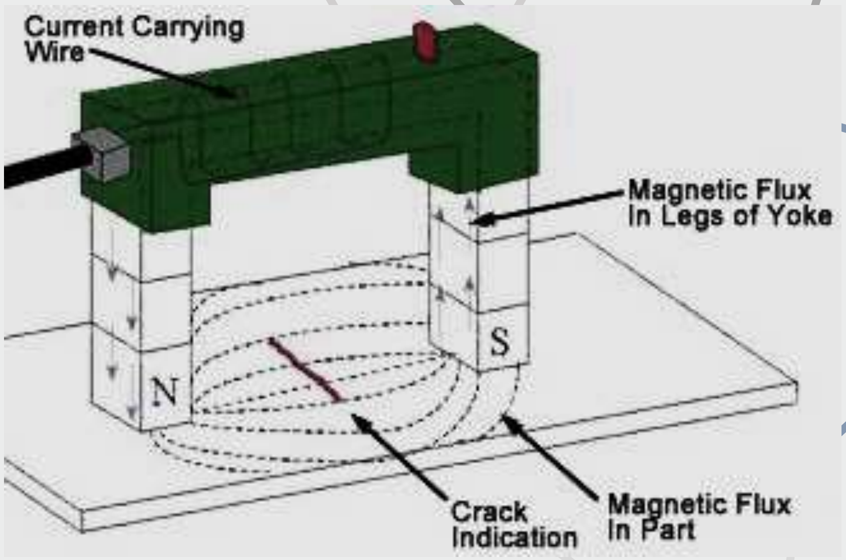
Magnetic particle testing(MT) - Equipment

Electromagnetic Yokes

A switch is included in the electrical circuit so that the current and, therefore, the magnetic field can be turned on and off. They can be powered with AC from a wall socket or by DC from a battery pack. This type of magnet generates a very strong magnetic field in a local area where the poles of the magnet touch the part being inspected.



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Magnetic particle testing(MT) - Equipment

Prods

Prods are handheld electrodes that are pressed against the surface of the component being inspected to make contact for passing electrical current (*AC or DC*) through the metal. Prods are typically made from copper and have an insulated handle to help protect the operator.

Portable Coils and Conductive Cables

Coils and conductive cables are used to establish a longitudinal magnetic field within a component. When a preformed coil is used, the component is placed against the inside surface on the coil. Coils typically have three or five turns of a copper cable within the molded frame. A foot switch is often used to energize the coil.

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Magnetic particle testing(MT) - Equipment

Portable Power Supplies

Portable power supplies are used to provide the necessary electricity to the prods, coils or cables. Power supplies are commercially available in a variety of sizes. Small power supplies generally provide up to 1,500A of half-wave DC or AC. They are small and light enough to be carried and operate on either 120V or 240V electrical service.

Stationery Equipment

Stationary magnetic particle inspection equipment is designed for use in laboratory or production environment. The most common stationary system is the wet horizontal (bench) unit. Wet horizontal units are designed to allow for batch inspections of a variety of components. The units have head and tail stocks (*similar to a lathe*) with electrical contact that the part can be clamped between. A circular magnetic field is produced with direct magnetization.

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Magnetic particle testing(MT) - Steps

Preparation of the test specimen

Loose rust and scale should be removed from the component. Machined parts should be degreased using appropriate solvents. In painted parts the paint should be removed locally to provide adequate contact areas for the current flow tests.

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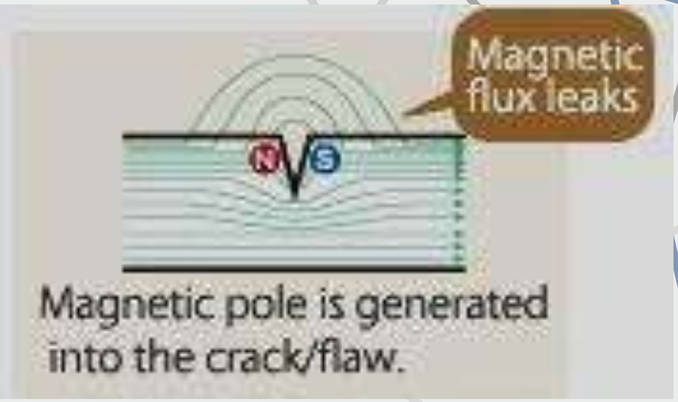
Magnetic particle testing(MT) - Steps

Magnetization of the test specimen

The test specimen may be magnetized depending on its shape and configuration by using any of the methods. It is advisable to devise and write down the technique to be used listing the operations required with all details of directions of tests and jigs needed.



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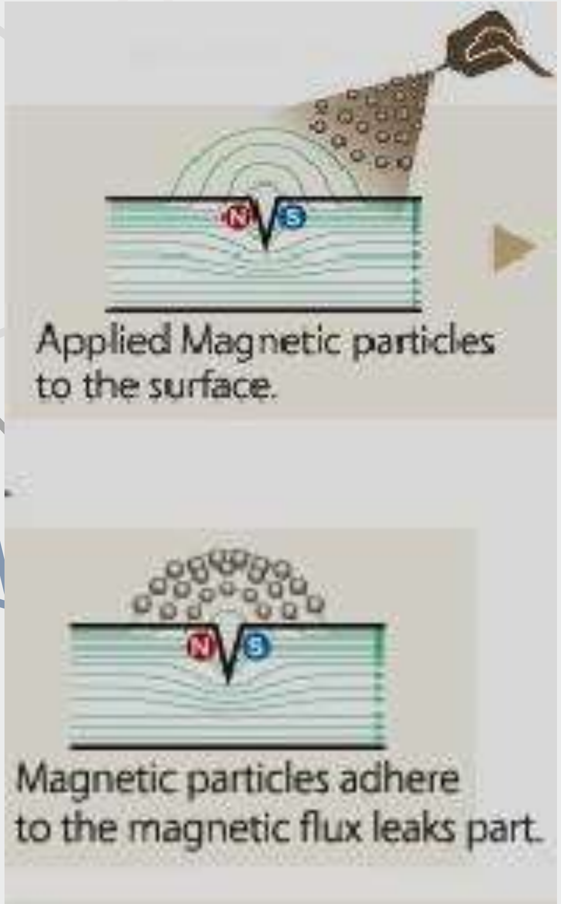
Magnetic particle testing(MT) - Steps



Application of the magnetic powder

Magnetic particles are available in red or black colors. The red material improves visibility on dark surfaces. There are also fluorescent materials available.

These magnetic particles may be applied to the test specimen either in dry or in wet form.

If a dry powder is used it should be applied to the magnetized component such as to achieve an even distribution. Tapping the test specimen with a rubber hammer is often helpful.

For the wet magnetic particles it is best that these are applied during magnetization.

Magnetic particle testing(MT) - Steps

Viewing and recording of indications

The whole surface gone under testing should be viewed. Viewing the underneath surfaces may need a mirror.

Bores may need special lighting and viewing the end faces may require removing the test specimen from between the contacts.

Doubtful indications are often more evident if the component is allowed to drain for a few minutes.

Any indications found can be marked with a grease pencil after allowing the ink to drain. It is frequently desirable to record not only the appearance of indications on a part but also their locations.

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Magnetic particle testing(MT) - Steps

Demagnetization

Demagnetization of the testing sample is sometimes necessary before, during, and at the end of an inspection, for a variety of reasons.

Cleaning the surface

After final inspection, post cleaning of the object is necessary only in those cases where the penetrant testing products could interfere with subsequent processing or service requirements.

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Magnetic particle testing(MT)

Advantages

- High sensitivity (small discontinuities can be detected).
- Indications are produced directly on the surface of the part and constitute a visual representation of the flaw.
- Minimal surface preparation (no need for paint removal)
- Portable (materials are available in aerosol spray cans)
- Low cost (materials and associated equipment are relatively inexpensive)

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Magnetic particle testing(MT)

Disadvantages

- Only surface and near surface defects can be detected.
- Only applicable to ferromagnetic materials.
- Relatively small area can be inspected at a time.
- Only materials with a relatively nonporous surface can be inspected.
- The inspector must have direct access to the surface being inspected.

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I.4.3.2. Detectability of internal imperfections of welds

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Radiographic testing (RT)

The method of radiographic testing involves the use of a source of radiation from which the radiations hit the test specimen, pass through it and are detected by a suitable radiation detector placed on the side opposite to that of the source.

While passing through the test specimen the radiations are absorbed in accordance with the thickness, physical density and the internal defects of the specimen and the detector system therefore receives the differential radiations from different parts of the defective specimen which are recorded on to the detector.

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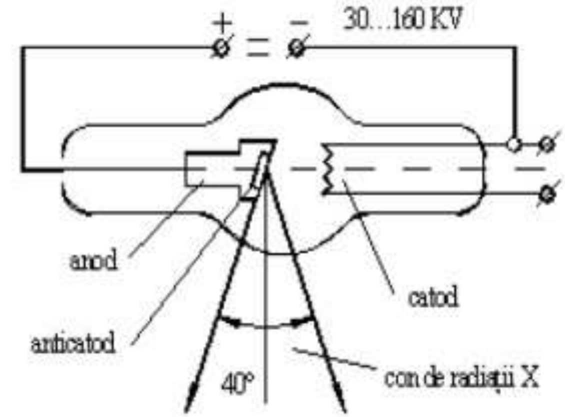
Radiographic testing (RT)

General principle

The sample is placed between the radiation source and a piece of film.

Thicker and more dense area will stop more of the radiation.

The film darkness (density) will vary with the amount of radiation reaching the film through the test object



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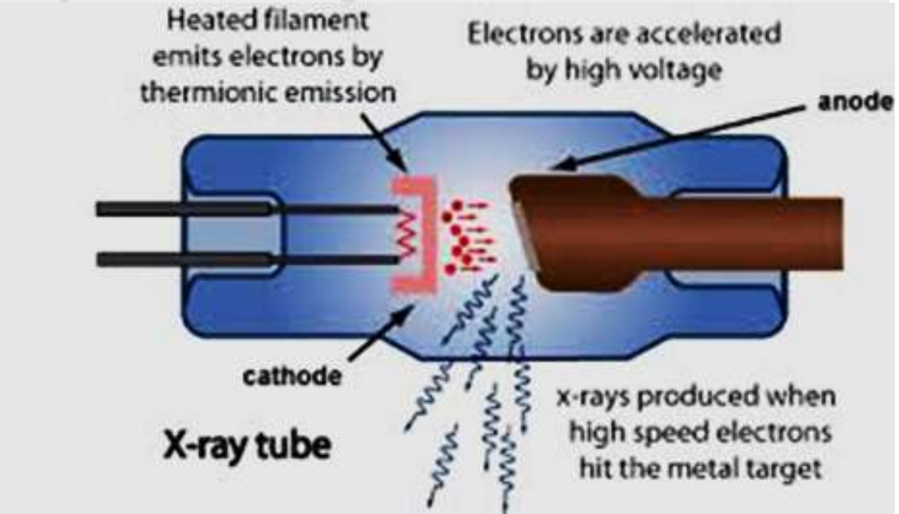
Radiographic testing (RT) - *Equipment*



X-Ray Equipment

In general, industrial x-ray equipment can be categorized by energy groups. Those x-ray

units that produce energies up to about 125 kV are considered low energy; from 125 up to

400 kV, medium energy; and those systems that produce radiation energies above 400 kV are considered high energy.

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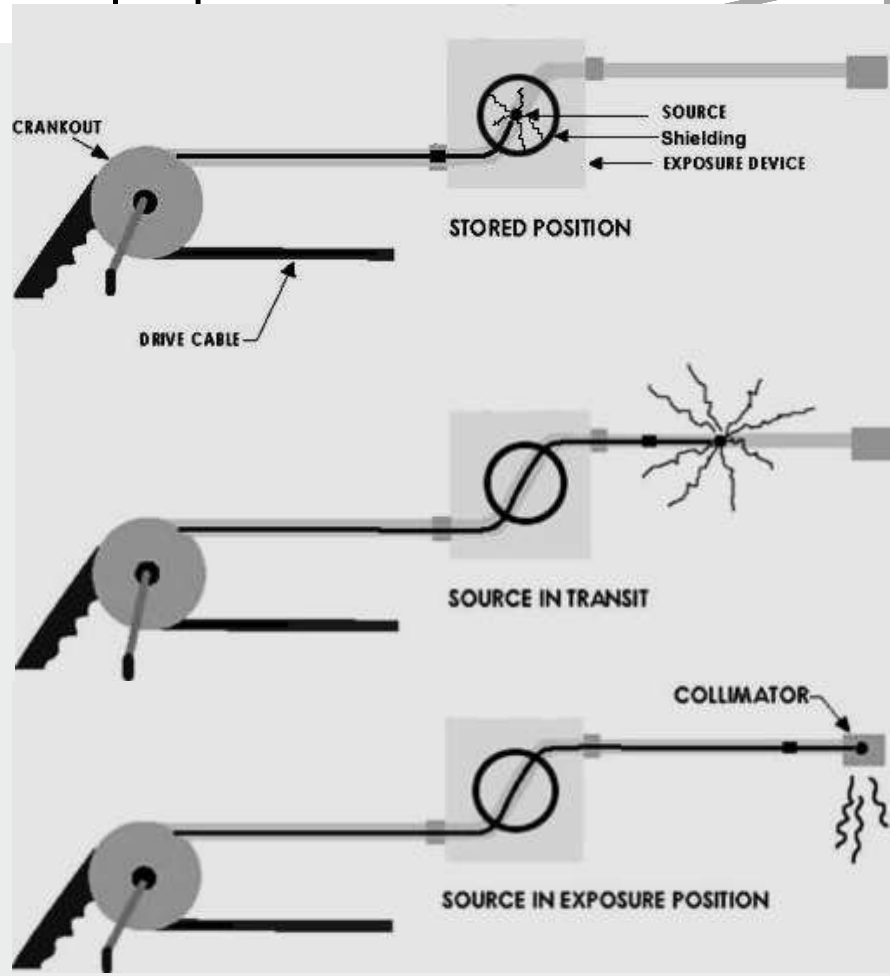
Radiographic testing (RT) - Equipment

Gamma Ray Equipment

The first gamma ray source used in industrial radiography was the radium.

The major component in a gamma ray system is the exposure device, which has shields that contain an S-tube in which the iridium source is maintained inside a stainless steel capsule and is securely locked into place when not in use.



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Radiographic testing (RT) - Equipment

Radiographic testing accessories :

- Film and cassettes
- Lead screens
- Lead numbers and letters
- Penetrometers (image quality indicators)
- Densitometers
- High-intensity film illuminators
- Processing equipment (manual or automatic)
- Film hangers (for manual processing)
- Collimators (especially for use with radioactive sources)

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Radiographic testing (RT) - Variables

Of all the nondestructive testing methods described, radiography certainly has the most variables. These variables include:

1. Energy;
2. Exposure time;
3. mA (x-ray) or curies (gamma ray);
4. Material type and density;
5. Material thickness;
6. Type of film;
7. Screens used;
8. Film processing (procedure development time and temperature, etc.);
9. Film density;
10. Distance from the radiation source to the object;
11. Distance from the object to the film;
12. Physical size of the target (x-ray) or source (gamma ray).

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Radiographic testing (RT)

Radiographic Image Quality

- **Contrast**
  - **Subject Factors**
    - Absorption differences in the subject
    - Wavelength of the primary radiation
    - Secondary radiation form scatter
  - **Film Factors**
    - Type of film (grain size)
    - Chemistry of the film processing chemicals
    - Concentrations of the film processing chemicals
    - Development time
    - Amount of the film agitation
    - Overall film density
- **Definition**
  - **Geometrical Factors**
    - Size of the source (focal-spot size)
    - Source to film distance
    - Specimen to detector(film) distance
    - Abruptness of specimen thickness changes
    - Movement of the specimen during the exposure
  - **Film Factors**
    - Type of film(grain size)
    - Mottling due to the use of a fluorescent screen
    - Wavelength of the primary radiation
    - Development time
    - Other film processing factors

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Radiographic testing (RT)

Advantages

- Both surface and internal discontinuities can be detected;
- Significant variations in compositions can be detected;
- It has very few limitations;
- Direct access to the surface is not required;
- Very minimal or no part preparation is required;
- Permanent test record is obtained;
- Good portability especially for gamma-ray sources

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Radiographic testing (RT)

Disadvantages

- Hazardous to operators and other nearby personnel
- High degree of skill and experience for exposure and interpretation is required;
- The equipment is very expensive ;
- The process is generally slow;
- Sensitive to flow orientation;
- Depth of the discontinuity is not indicated;
- It requires a two side access to the component.

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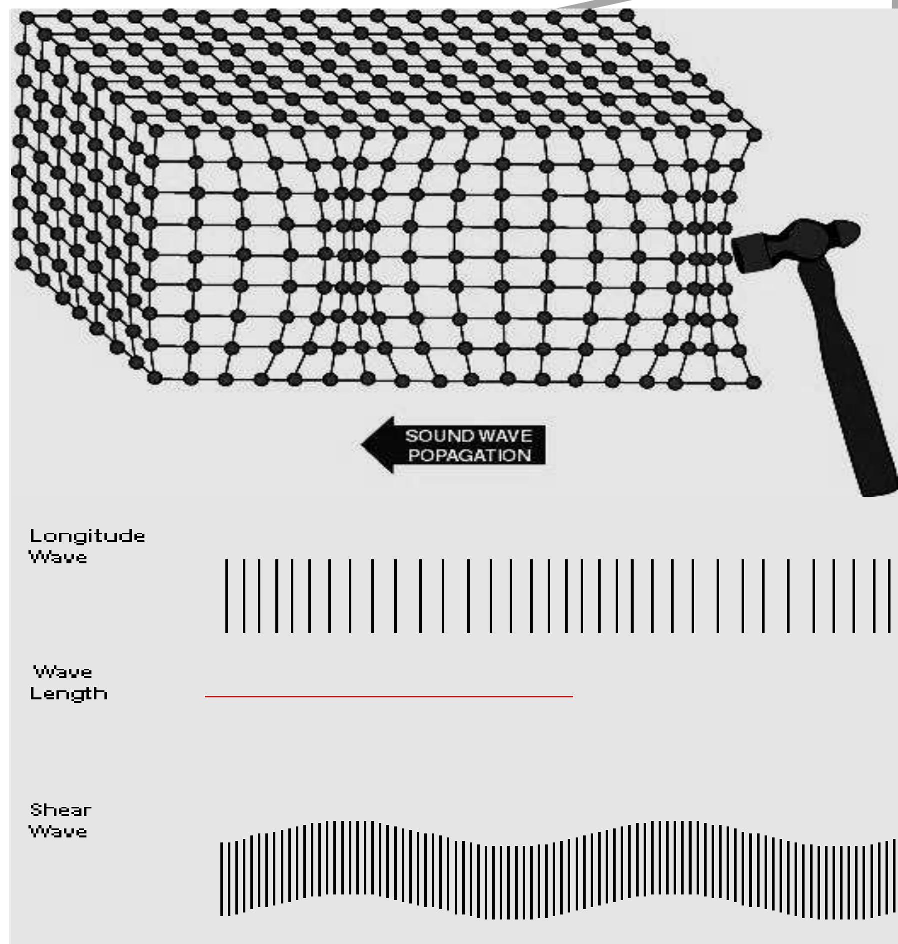
Ultrasonic testing (UT) - Basic Principle

Sound is produced by a vibrating body and travels in the form of a wave. Sound waves travel through materials by vibrating the particles that make up the material.

The pitch of the sound is determined by the frequency of the wave (vibrations or cycles completed in a certain period of time).

Ultrasound is a sound with a pitch too high to be detected by the human ear



Ultrasonic testing (UT) - Basic Principle

Ultrasonic waves are very similar to light waves by the fact that they can be reflected, refracted, and focused.

Reflection and refraction occurs when sound waves interact with interfaces of differing acoustic properties.

Ultrasonic reflections from the presence of discontinuities or geometric features enables detection and location.

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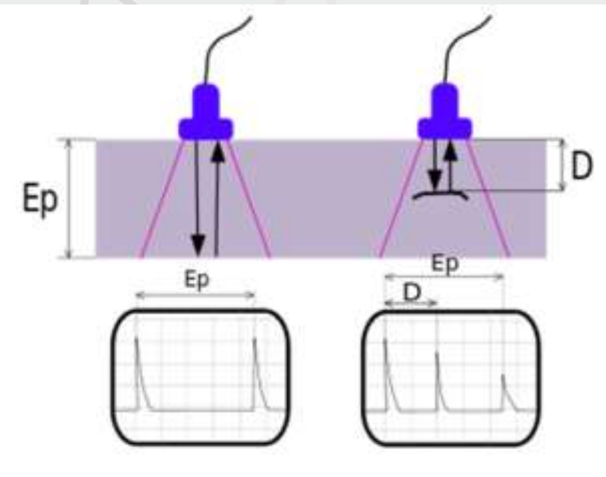
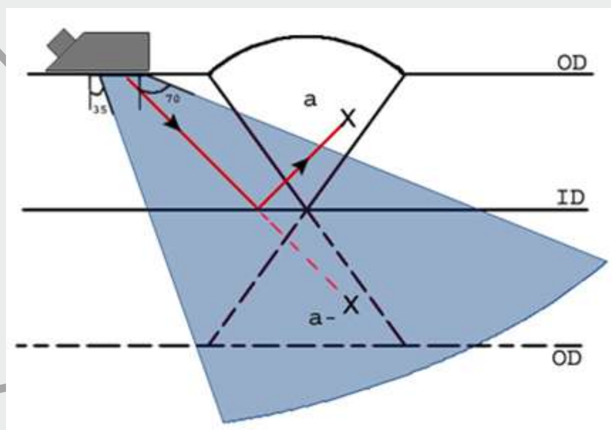
Ultrasonic testing (UT) – Basic Principle





Ultrasound is generated with a transducer. A piezoelectric element in the transducer converts electrical energy into mechanical vibrations (sound), and vice versa. The transducer is capable of both transmitting and receiving sound energy.

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Ultrasonic testing (UT)

Reflection and transmission of sound waves

Sound energy may be reflected, refracted, scattered, absorbed or transmitted while interacting with a material. Reflection takes place in the same way as for light, i.e. angle of incidence equals angle of reflection.

At any interface between two media of different acoustic impedances a mismatch occurs causing the major percentage of the wave to be reflected back, the remainder being transmitted.

There are two main cases:

- Reflection and transmission at normal incidence;
- Reflection and transmission at oblique incidence.

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Ultrasonic testing (UT)

Type of waves

No.	Wave types in solids	Particle vibration
1	Longitudinal	Parallel to wave direction
2	Transverse (Shear)	Perpendicular to wave direction
3	Surface – Rayleigh	Elliptical orbit – symmetrical mode
4	Plate Wave – Lamb	Component perpendicular to surface (extensional wave
5	Plate wave – Love	Parallel to plane layer, perpendicular to wave direction
6	Stoneley (Leaky Rayleigh Waves	Wave guided along interface
7	Sezawa	Antisymmetric mode

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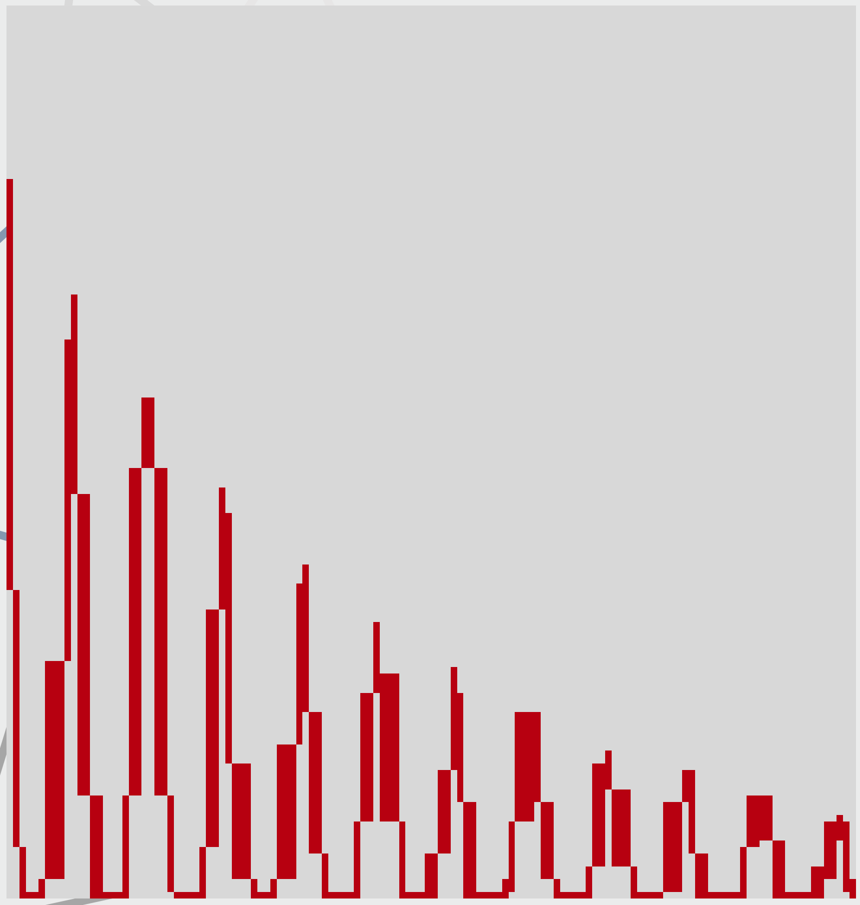
Ultrasonic testing (UT)



Attenuation of Sound Waves

The combined effect of scattering and absorption is called **attenuation**.

Scattering is the reflection of the sound in directions other than its original direction of propagation.

Absorption is the conversion of the sound energy to other forms of energy. Ultrasonic attenuation is the decay rate of the wave as it propagates through material.

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Ultrasonic testing (UT)

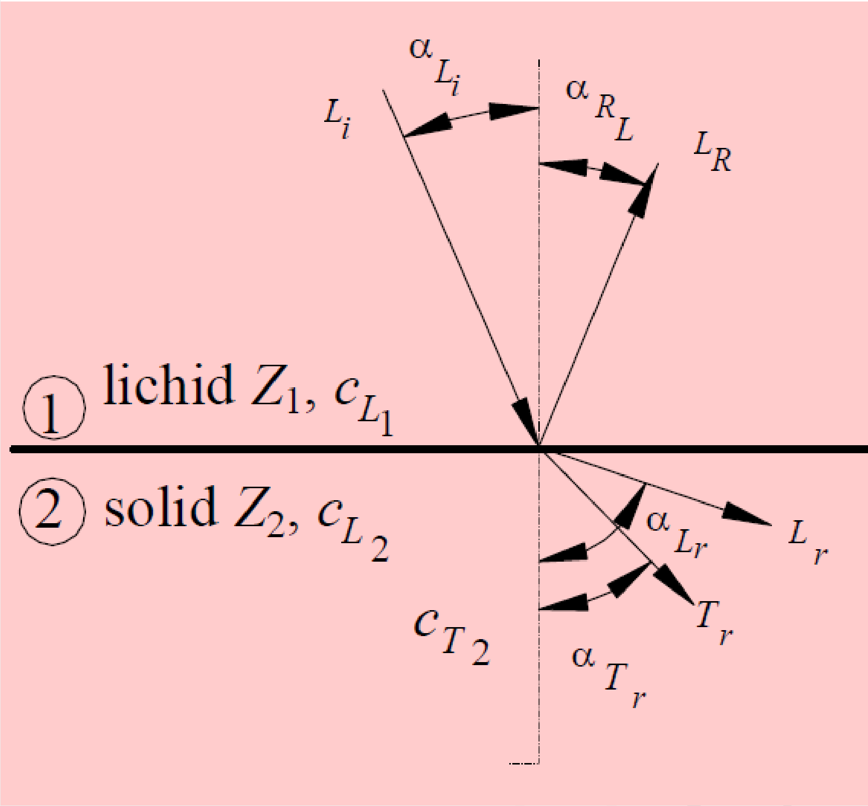
Refraction and Snell's Law

When an ultrasonic wave passes through an interface between two materials at an oblique angle, and the materials have different indices of refraction, both reflected and refracted waves are produced.

$$\frac{\sin\theta_1}{V_{L_1}}=\frac{\sin\theta_2}{V_{L_2}}$$

Where:

- V_{L1} is the longitudinal wave velocity in material 1.
- V_{L2} is the longitudinal wave velocity in material 2.



Ultrasonic testing (UT) - Equipment

Equipment for ultrasonic testing is very diversified. Proper selection is important to ensure accurate inspection data as desired for specific applications.

In general, there are three basic components that comprise an ultrasonic test system:

- Instrumentation
- Transducers
- Calibration Standards

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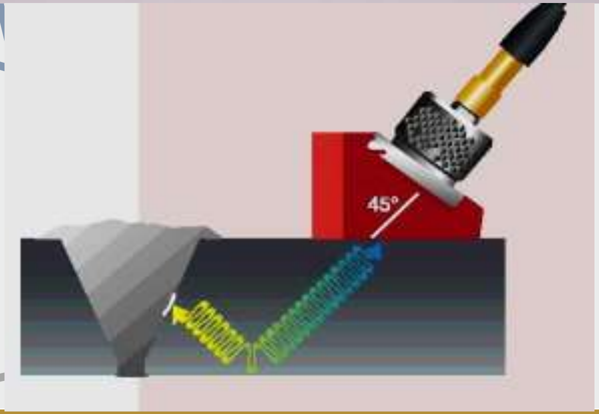
Ultrasonic testing (UT)



Transducers are manufactured in a variety of forms, shapes and sizes for various applications.

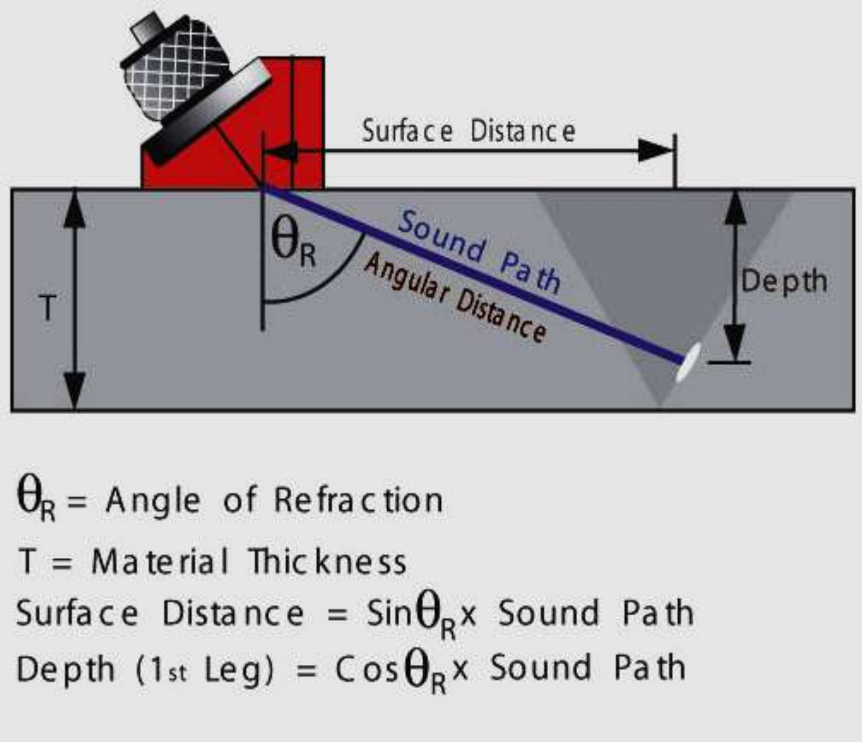
Transducers are categorized in a number of ways which include:

- Contact or immersion
- Single or dual element
- Normal or angle beam

Ultrasonic testing (UT)

Angle beam transducers and wedges are typically used to introduce a refracted shear wave into the test material.

The angled sound path allows the sound beam to be reflected from the back wall to improve detectability of flaws in and around welded areas. They are also used to generate surface waves for use in detecting defects on the surface of a component.



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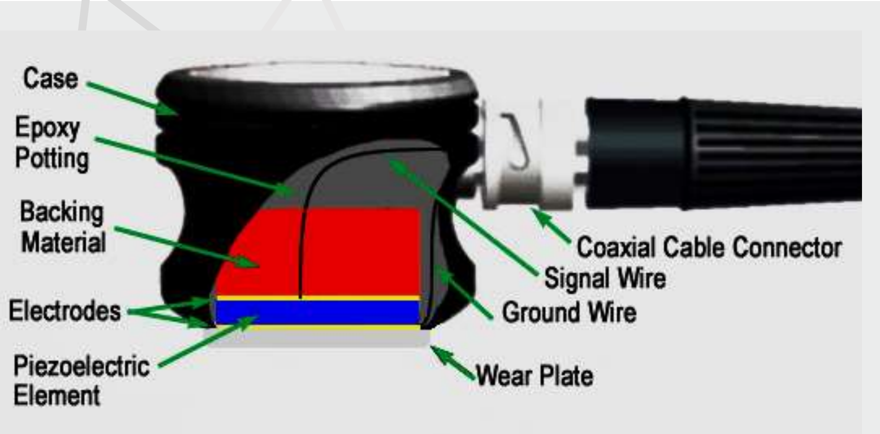
Ultrasonic testing (UT)



Contact transducers are designed to withstand rigorous use, and usually have a wear plate on the bottom surface to protect the piezoelectric element from contact with the surface of the test article.

Many incorporate ergonomic designs for ease of grip while scanning along the

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Ultrasonic testing (UT)

- **Calibration Standards**

Calibration is an operation of configuring the ultrasonic test equipment to known values.

Ultrasonic testing (UT)

Flaw detectors are instruments designed primarily for the inspection of components for defects.

However, the signal can be evaluated to obtain other information such as material thickness values.

Both analog and digital display.

Offers the user options of getting horizontal sweep and amplitude threshold.

Ultrasonic testing (UT)

Advantages

- Sensitive to small discontinuities both surface and subsurface.
- Depth of penetration for flaw detection or measurement is superior to other methods.
- Only single-sided access is needed when pulse-echo technique is used.
- High accuracy in determining reflector position and estimating size and shape.
- Minimal part preparation required.
- Electronic equipment provides instantaneous results.
- Detailed images can be produced with automated systems.
- Has other uses such as thickness measurements, in addition to flaw detection.

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Ultrasonic testing (UT)

Disadvantages

- Surface must be accessible to transmit ultrasound.
- Skill and training is more extensive than with some other methods.
- Normally requires a coupling medium to promote transfer of sound energy into test specimen.
- Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
- Linear defects oriented parallel to the sound beam may go undetected.
- Reference standards are required for both equipment calibration, and characterization of flaws.

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Useful Topic Related Links

Nondestructive testing

Ultrasonic testing

Penetrant inspection

Radiographic Testing

Visual Test

Ultrasonic testing

Magnetic Particle Inspection

Visual Testing

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I.4. Quality assurance and qualification in welding

I.4.4. Specification and qualification of welding procedures

RAPORT DE CALIFICARE A PROCEDURII DE SUDARE (WPQR)
WELDING PROCEDURE QUALIFICATION RECORD (WPQR)

Calificarea procedurii de sudare - Certificat de testare
Welding procedure qualification - Test certificate

Specificatia procedurii de sudare / *Manufacturer's Welding Procedure* Nr. Referinta : / *Reference No.*	2016-1	Inspectia Nr.: / *Inspection No.*	2016-WPQR-021
		Examinator : / *Examiner*	....
Producator: / *Manufacturer*	....		

Adresa: / *Address*	Bucuresti, ROMANIA
Cod/Standard testare: / *Code/Testing Standard*	**EN ISO 15614-1 / 2004 + A1 / 2008 + A2 / 2012**
Data sudarii : / *Date of Welding*	**25.04.2016**
Domeniul de calificare: / *Range of qualification*	**Conform cu / *According* to EN ISO 15614-1 / 2004 + A1 / 2008 + A2 / 2012**
Procedeu de sudare : / *Welding Process*	**135**
Tipul imbinarii: / *Joint Type*	**Racord "situat pe" cu penetratie completa,** *"Set-on" Branch Connection with full penetration,* **Multi-strat - *Multi-run weld* (ml);**
Material(e) de baza : / *Parent metal (s)*	**EN 10210-1,2:2006 : S355J2H (Grupa-*Group* 1.2 cf-*acc* CEN ISO/TR 15608) / EN 10025-1,2:2004 : S355J2+N (Grupa-*Group* 1.2 cf-*acc* CEN ISO/TR 15608)**
Grosime material (mm): / *Material Thickness (mm)*	**8,0 mm / 8,0 mm** **Grosime MB pt. - *thickness BM for* 3,0 ÷ 16,0 mm**
Diametrul exterior (mm): / *Outside Diameter (mm)*	**Ø114,3 (≥ 57,15)**
Material de adaos: / *Filler Material*	**EN ISO 14341-A: G 42 3 M21 3Si1: BOEHLER SG 2**
Gaz / ~~Flux~~ / *Gas / ~~Flux~~* - De protectie/*Shielding*:	**18%CO2+82%Ar:M21 cf.-*acc.* EN ISO 14175**
- Suport la radacina/*Backing*:	---
Tip current / Polaritate: / *Type of Welding Current / Polarity*	**DC / +**
Pozitia de sudare : / *Welding Position*	**PB**
Temperatura de preincalzire: / *Preheat Temperature*	**Min. 5 °C**
Temperatura intre straturi: / *Interpass Temperature*	**Max. 250 °C**
Tratament termic dupa sudare: / *Post-Weld Heat Treatment*	---
Alte informatii : / *Other Information*	---

Confirmam ca probele au fost pregatite, sudate si testate in mod corespunzator, in conformitate cu cerintele codului/standardului de testare indicat mai sus.

We hereby certify that the test welds were prepared, welded and tested satisfactorily in accordance with the requirements of the code/testing standard indicated above.

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Aim & Objectives

Module Aim:	The module specifies how a preliminary welding procedure specification is qualified by welding procedure tests
Number of hours:	1 hour e-learning and 1 hour self-study
Learning Outcomes:	• Welding procedure test • Range of qualification for welding procedures • Welding procedure qualification record (WPQR)
ECVET:	4 (for Training Units Nº 4)

Lecture Outline

The lecture provides a short introduction of the conditions for the execution of welding procedure tests and the range of qualification for welding procedures for all practical welding operations within a range of variables.

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Specification and qualification of welding procedures

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ISO 15609

The standard ISO 15609 specifies requirements for the content of welding procedure specifications for arc welding processes.

Technical content of welding procedure specification (WPS)

A Welding Procedure Specification (pWPS/WPS) shall provide all the necessary information required to make a weld.

Welding procedure specifications cover a certain range of material thickness and also cover a range of parent materials and even welding consumables.

Ranges and tolerances, according to the relevant standard of the series and to the manufacturer's experience, shall be specified where appropriate.

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ISO 15609

Related to the manufacturer

- Identification of the manufacturer;
- Identification of the WPS;
- Reference to the Welding Procedure Qualification Record (WPQR) or other documents as required .

Related to the parent material

- Parent material type
  - Designation of the material(s), and reference standard(s);
  - Number(s) of the group(s) as given in CR ISO/TR 15608.
- Material dimensions
  - Thickness ranges of the joint;
  - Outside diameter ranges for pipes.

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ISO 15609

Common to all welding procedures

- Welding process
  - Welding process(es) used in accordance with EN ISO 4063.
- Joint design
  - A sketch of the joint design/configuration and dimensions or reference to standards which provide such information.
  - Weld run sequence given on the sketch if essential for the properties of the weld.
- Welding position
  - Applicable welding positions in accordance with EN ISO 6947.
- Joint preparation
  - Joint preparation methods, cleaning, degreasing, including methods to be used;
  - Jigging, fixtures and tack welding.

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ISO 15609

Common to all welding procedures

- Welding technique
  - Weaving if applicable

    a) For manual welding maximum width of the run.

    b) For mechanized and automatic welding maximum weaving or amplitude, frequency and dwell time of oscillation.
  - Torch, electrode and/or wire angle.
- Back gouging
  - The method to be used.
  - Depth and shape.
- Backing
  - The method and type of backing, backing material and dimensions.
  - For gas backing, gas in accordance with EN 439.
- Welding consumables
  - Designation, make (manufacturer and trade name).
  - Dimensions (size).
  - Handling (baking, exposure to atmosphere, re-drying, etc.)..

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ISO 15609

Common to all welding procedures

- Electrical parameters
  - Type of current (alternating current (AC) or direct current (DC)) and polarity.
  - Pulse welding details (machine settings, program selection) if applicable.
  - Current range.
- Mechanized and automatic welding
  - Travel speed range.
  - Wire/strip feed speed range.
- Preheat temperature
  - The minimum temperature applied at the start of welding and during welding.
  - If pre-heating is not required the lowest work piece temperature prior to welding.
- Interpass temperature
  - Maximum and if necessary minimum interpass temperature.

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ISO 15609

Common to all welding procedures

- Preheat maintenance temperature
- Post-heating for hydrogen release
  - Temperature range.
  - Minimum holding time.
- Post-weld heat-treatment
- Shielding gas
- Heat input

ISO 15609

Specific to a group of welding processes

- Process 111 (Manual metal arc welding)
  - the run-out length of electrode consumed or travel speed.
- Process 12 (Submerged arc welding)
  - For multiple electrode systems the number and configuration of wire electrodes and polarity.
  - Distance contact tube/work piece : The distance from contact tip nozzle to the surface of the work piece.
  - Flux: Designation, manufacturer and trade name.
  - Additional filler metal.
  - Arc voltage range.

ISO 15609

Specific to a group of welding processes

- Process 13 (Gas-shielded metal arc welding)
  - Shielding gas flow rate and nozzle diameter.
  - Number of wire electrodes.
  - Additional filler material.
  - The distance from the contact tip/contact tube to the surface of the workpiece.
  - Arc voltage range.
  - Mode of metal transfer.

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ISO 15609

Specific to a group of welding processes

- Process 14 (Gas-shielded arc welding with non-consumable tungsten electrode)
  - Tungsten electrode: the diameter, and codification in accordance with EN 26848.
  - Shielding gas flow rate and nozzle diameter.
- Process 15 (Plasma arc welding)
  - Plasma gas parameters, e.g. composition, nozzle diameter, flow rate.
  - Shielding gas flow rate and nozzle diameter.
  - Type of torch.
  - Distance contact tube/work piece: The distance from the nozzle to the surface of the work piece.

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ISO 15614

The standard ISO 15614 specifies how a preliminary welding procedure specification is qualified by welding procedure tests.

It is applies to production welding, repair welding and build-up welding.

The primary purpose of welding procedure qualification is to demonstrate that the joining process proposed for construction is capable of producing joints having the required mechanical properties for the intended application.

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ISO 15614 - Test piece

The welded joint to which the welding procedure will relate in production shall be represented by making a standard test piece or pieces.

For level 1: Any butt joint test qualifies all joint configurations.

For level 2: Where the joint requirements and/or dimension of the test piece are not covered by the standard test pieces the use of ISO 15613 shall be required.

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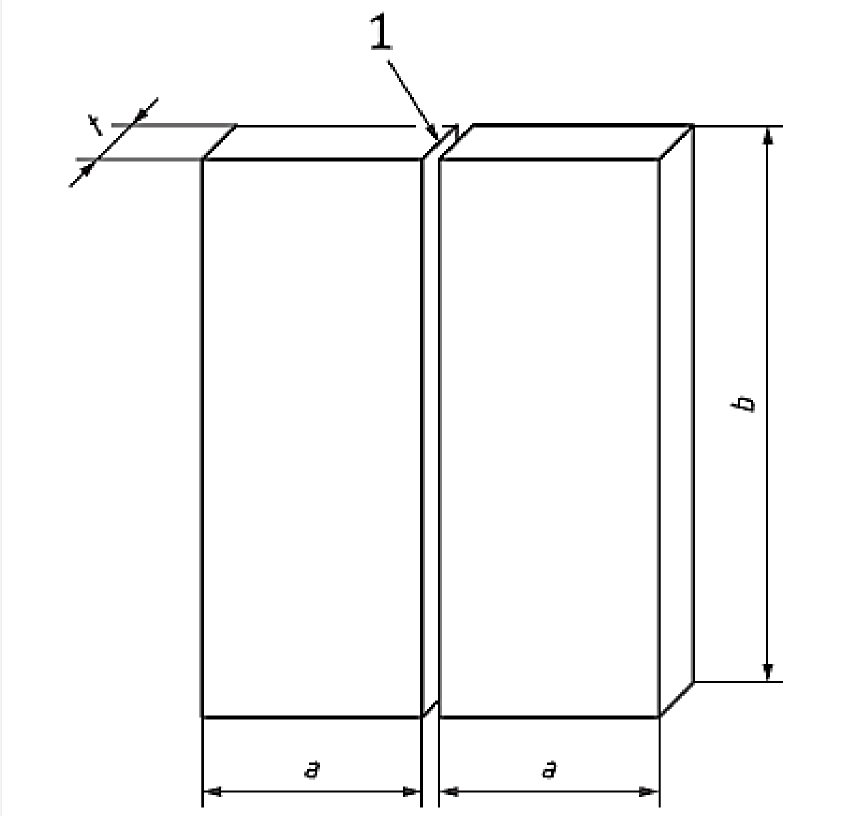
ISO 15614 - Test piece

Test piece for a butt joint in plate with full penetration

Key

- 1 - joint preparation and fit-up as detailed in the preliminary welding procedure specification (pWPS)
- *a* - minimum dimension 150 mm
- *b* - minimum dimension 350 mm
- *t* - material thickness



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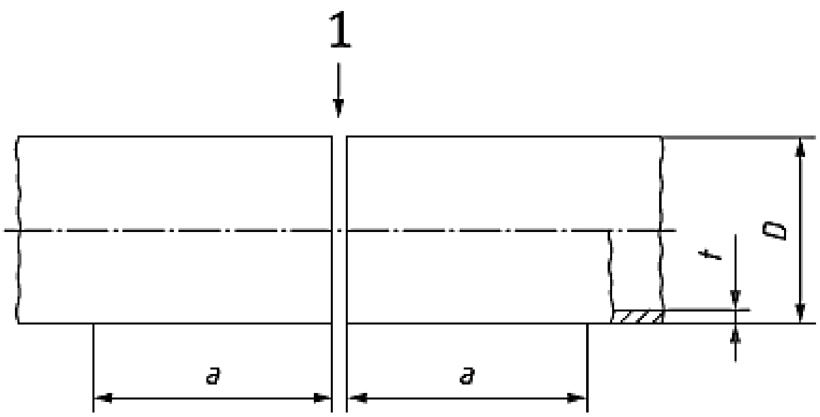
ISO 15614 - Test piece



Test piece for a butt joint in pipe with full penetration

Key

- 1 - joint preparation and fit-up as detailed in the preliminary welding procedure specification (pWPS)
- *a* - minimum dimension 150 mm
- *D* - outside pipe diameter
- *t* - material thickness

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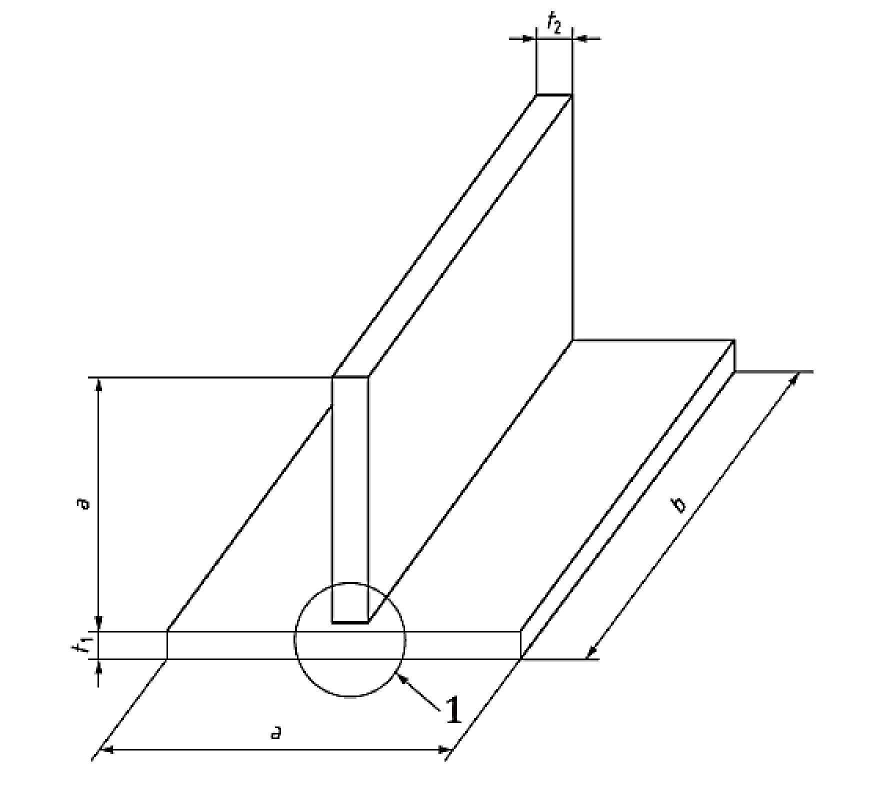
ISO 15614 - Test piece

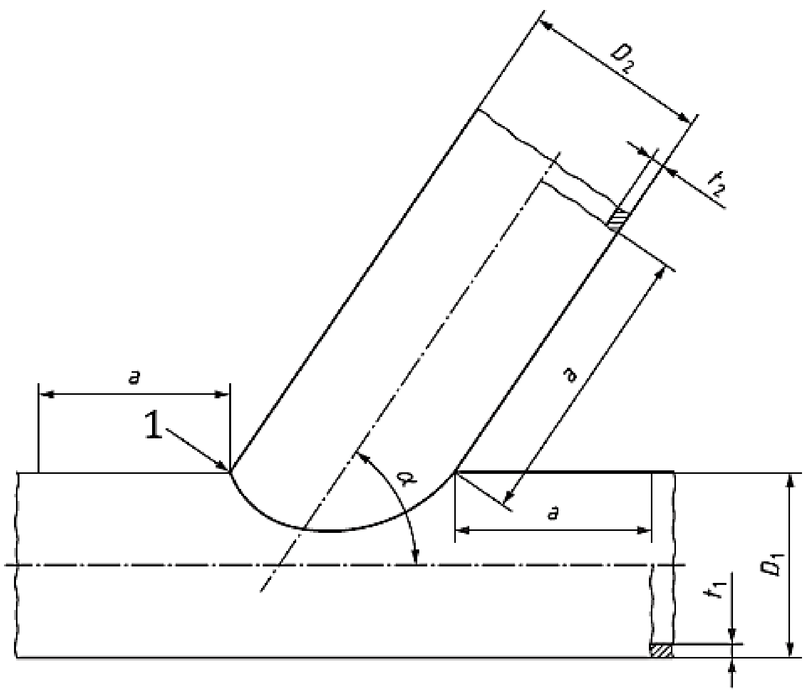
Test piece for a T-joint

Key

- 1 - joint preparation and fit-up as detailed in the preliminary welding procedure specification (pWPS)
- *a* - minimum dimension 150 mm
- *b* - minimum dimension 350 mm
- t_1, t_2- material thickness



ISO 15614 - Test piece



Test piece for a branch connection

Key

- 1 - joint preparation and fit-up as detailed in the preliminary welding procedure specification (pWPS)
- α - branch angle
- a - minimum dimension 150 mm
- D_1 -outside diameter of main pipe
- D_2 outside diameter of branch pipe
- t_1 - main pipe material thickness
- t_2- branch pipe material thickness

2016-1-RO01-KA202-024508

ISO 15614 - Examination and testing

For level 1: Examination and testing of the test pieces

Test piece	Type of test	Extent of testing	Footnote
Butt joint with full penetration	Visual testing Transverse tensile test Transverse bend test	100 % 2 specimens 4 specimens	a
Fillet welds	Visual testing Macroscopic examination	100 % 2 specimens	b

a) For bend tests

b) Where mechanical properties are required by an application standard, it shall be tested accordingly. If an additional test piece is needed, the dimensions should be sufficient enough to allow testing of the mechanical properties. For this additional test piece, the welding parameter range, parent material group, filler metal and heat treatment are required to be the same.

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ISO 15614 - Examination and testing

For level 2: Examination and testing of the test pieces (1)

Test piece	Type of test	Extent of testing	Footnote
Butt joint with full penetration	Visual testing	100 %	—
	Radiographic or ultrasonic testing	100 %	a
	Surface crack detection	100 %	b
	Transverse tensile test	2 specimens	—
	Transverse bend test	4 specimens	c
	Impact test	2 sets	d
	Hardness test	required	e
	Macroscopic examination	1 specimen	—
T- joint with full penetration Branch connection with full penetration	Visual testing	100 %	
	Surface crack detection	100 %	b
	Ultrasonic or radiographic testing	100 %	a, g
	Hardness test	required	e
	Macroscopic examination	2 specimens	

2016-1-RO01-KA202-024508

ISO 15614 - Examination and testing

For level 2: Examination and testing of the test pieces(2)

Test piece	Type of test	Extent of testing	Footnote
Fillet weld	Visual testing	100 %	
	Surface crack detection	100 %	b
	Hardness test	required	e
	Macroscopic examination	2 specimens	

a)Ultrasonic testing shall not be used for t < 8 mm and not for material groups 8, 10, 41 to 48.
b)Accessible weld surfaces: penetrant testing or magnetic particle testing. For non-magnetic materials, penetrant testing.
c)For bend tests.
d) One set in the weld metal and one set in the HAZ for materials ≥12 mm thick and having specified impact properties required by technical delivery conditions and/or if appropriate according to the service conditions. Application standards may require impact testing below 12 mm thick.
e) Not required for parent metals: sub-group 1.1, groups 8 and 41 to 48 and dissimilar joints between these groups, except for dissimilar joints between sub-group 1.1 and group 8.
f) Where mechanical properties are required by an application standard, it shall be tested accordingly. If an additional test piece is needed, the dimensions should be sufficient enough to allow testing of the mechanical properties.
g) For outside diameter ≤50 mm, no ultrasonic testing is required, but radiographic testing is required provided that the joint configuration will provide valid results. For outside diameter >50 mm and where it is not technically possible to carry out ultrasonic testing, a radiographic testing shall be carried out provided that the joint configuration will provide valid results.

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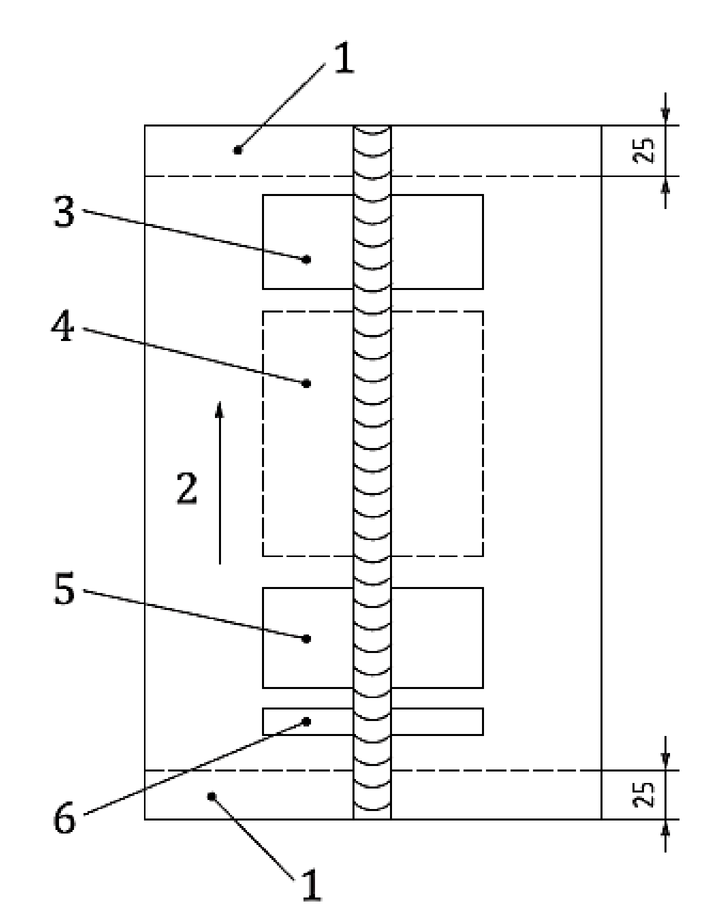
ISO 15614 - Examination and testing

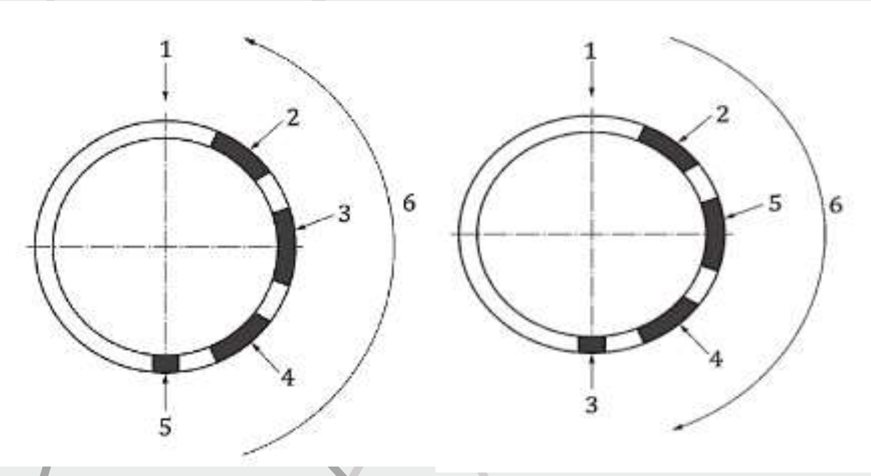
Location of test specimens for a butt joint in plate

Key

- 1 discard 25 mm
- 2 welding direction
- 3 area for:
  - — 1 tensile test specimen
  - — bend test specimens
- 4 area for:
  - — impact and additional test specimens if required
- 5 area for:
  - — 1 tensile test specimen
  - — bend test specimens
- 6 area for:
  - — 1 macro test specimen
  - — 1 hardness test specimen



ISO 15614 - Examination and testing



Location of test specimens for a butt joint in pipe

Key

- 1 end of weld
- 2 area for:
  - — 1 tensile test specimen
  - — bend test specimens
- 3 area for:
  - — impact and additional test specimens if required
- 4 area for:
  - — 1 tensile test specimen
  - — bend test specimens
- 5 start of weld; area for:
  - — 1 macro test specimen
  - — 1 hardness test specimen (taken from the start of weld)
- 6 weld direction

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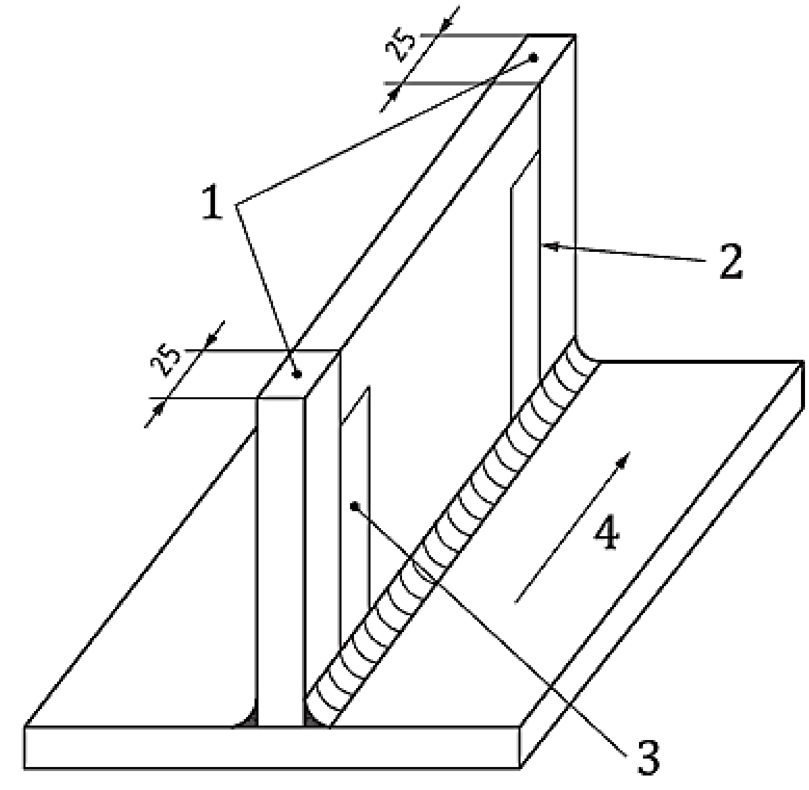
ISO 15614 - Examination and testing

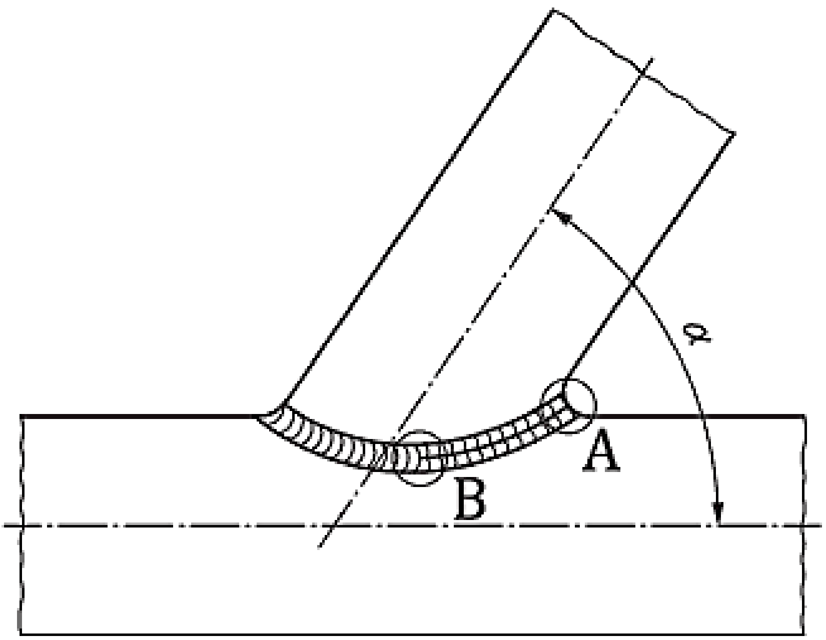
Location of test specimens in a T-joint

Key

- 1 discard 25 mm
- 2 macro test specimen
- 3 macro and hardness test specimen
- 4 welding direction



ISO 15614 - Examination and testing



Location of test specimens for a branch connection on pipe

Key

- A - macro and hardness test specimen to be taken
- B - macro test specimen to be taken
- α - branch angle

ISO 15614 - Examination and testing

Acceptance levels for imperfections (1)

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≤3mm	C
1.21	5214	Excessive throat thickness	No specific requirements	C
-	-	All imperfections	No specific requirements	B

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ISO 15614 - Examination and testing

Re-testing

- If the test piece fails to comply with any of the requirements for NDT, one further test piece shall be welded and subjected to the same examination. If this additional test piece does not comply with the requirements, the welding procedure test has failed.
- In the case of failure of any destructive test specimen, except for macroscopic examination, two additional test specimens may be removed from the original test piece for each test specimen that failed if adequate material is available. The test specimens shall be taken as close as possible to the original specimen location.
- Each additional test specimen shall be subjected to the same tests as the initial test specimen that failed. If any of the additional test specimens do not comply with the requirements, the welding procedure test shall be considered failed.

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ISO 15614 - Range of qualification

Range of qualification for steel groups and sub–groups[a,b,c]

Test piece material A	Test piece material B										
	1	2	3	4	5	6	7	8	9	10	11
1	1-1	-	-	-	-	-	-	-	-	-	-
2	1-1 2-1	1-1 2-1 2-2	-	-	-	-	-	-	-	-	-
3	1-1 2-1 3-1	1-1 2-1 2-2 3-1 3-2	1-1 2-1 2-2 3-1 3-2 3-3	-	-	-	-	-	-	-	-
4	4-1	4-1 4-2	4-1 4-2 4-3	4-1 4-2 4-3 4-4	-	-	-	-	-	-	-

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ISO 15614 - Range of qualification

Range of qualification for steel groups and sub–groups^{a,b,c}

Test piece material A	Test piece material B										
	1	2	3	4	5	6	7	8	9	10	11
5	5-1	5-2	5-3	5-4	5-1 5-2 5-5	-	-	-	-	-	-
6	6-1	6-1 6-2	6-1 6-2 6-3	6-1 6-2 6-3 6-4	6-1 6-2 6-3 6-4 6-5	6-1 6-2 6-3 6-4 6-5 6-6	-	-	-	-	-
7	7-1	7-1 7-2	7-2 7-3	7-4	7-5	7-5 7-6	7-7	-	-	-	-
8	8-1	8-1 8-2	8-1 8-2 8-3	8-4	8-1 8-2 8-4 8-5	8-1 8-2 8-4 8-5 8-6	8-7	8-8	-	-	-

2016-1-RO01-KA202-024508

ISO 15614 - Range of qualification

Range of qualification for steel groups and sub–groups[a,b,c]

Test piece material A	Test piece material B										
	1	2	3	4	5	6	7	8	9	10	11
9	9-1	9-1 9-2	9-1 9-2 9-3	9-4	9-5	9-6	9-7	9-8	9-9	-	-
10	10-1	10-1 10-2	10-1 10-2 10-3	10-4	10-1 10-2 10-3 10-4 10-6	10-1 10-2 10-4 10-6	10-7	10-8	10-9	10-10	
11	11-1 1-1	11-1 11-2	11-1 11-2 11-3	11-4	11-5	11-6	11-7	11-8	11-9	11-10	1-1 11-1 11-11

a) Test piece materials in groups 1, 2, 3 and 11 qualify the equal or lower specified minimum yield strength steels (independent of the material thickness).
b) Test piece materials in groups 4, 5, 6, 8 and 9 qualify steels in the same sub-group and any lower sub-group within the same group.
c) Test piece materials in groups 7 and 10 qualify steels in the same sub-group.

ISO 15614 - Range of qualification

Range of qualification for butt welds material thickness and deposited metal thickness

Thickness of test piece t	**Range of qualification**			
	Parent material thickness			Deposited weld metal thickness for each process s
	Level 1	Level 2		
		Single run	Multi-run	
t ≤ 3	0,5 t to 2 t			max. 2 s
3 < t ≤ 12	1,5 to 2 t 2	0,5 t (3 min) to 1,3 t	3 to 2 t^{a}	max. 2 s^{a}
12 < t ≤ 20	5 to 2 t	0,5 t to 1,1 t	0,5 t to 2 t	max. 2 s
20 < t ≤ 40	5 to 2 t	0,5 t to 1,1 t	0,5 t to 2 t	max. 2 s when s < 20 max. 2 t when s ≥ 20
40 < t ≤ 100	5 to 200	-	0,5 t to 2 t	max. 2 s when s < 20 max. 200 when s ≥ 20
100 < t ≤ 150	5 to 200	-	50 t to 2 t	max. 2 s when s < 20 max. 300 when s ≥ 20
t > 150	5 to 1,33 t	-	50 to 2 t	max. 2 s when s < 20 max. 1,33 t when s ≥ 20

a)For level 2: when impact requirements are specified but impact tests have not been performed, the maximum thicknessof qualification is limited to 12 mm.

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ISO 15614 - Range of qualification

For level 2: Range of qualification for material thickness and throat thickness of fillet welds

<table>
<tr><th rowspan="3">Thickness of test piece
t</th><th colspan="3">Range of qualification</th></tr>
<tr><th rowspan="2">Material thickness</th><th colspan="2">Throat thickness</th></tr>
<tr><th>Single run</th><th>Multi-run</th></tr>
<tr><td>t ≤ 3</td><td>0,7 t to 2 t</td><td rowspan="3">0,75 a to 1,5 a</td><td rowspan="3">No restriction</td></tr>
<tr><td>3 > t < 30</td><td>3 to 2 t</td></tr>
<tr><td>t ≥ 30</td><td>≥ 5</td></tr>
<tr><td colspan="4">Where a fillet weld is qualified by means of a butt weld test, the throat thickness range shall be based on the thickness of the deposited weld metal.
NOTE: a is the nominal throat thickness as specified in pWPS for the test piece.
In case of different material thicknesses, the range of qualification of both thicknesses of the test pieces shall be calculated separately.</td></tr>
</table>

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ISO 15614 - Range of qualification

For level 2: Range of qualification for pipe and branch connection diameters

Diameter of the test piece	Range of qualification
D	≥ 0,5 D
NOTE 1 : For hollow section other than circular (for example, elliptic), D is the dimension of the smaller side. NOTE 2 : D is the outside diameter for the pipe of a butt weld or the outside diameter of the branch pipe for a branch connection (see Figure 4, outside diameter D 2).	

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ISO 15614 - Welding procedure qualification record (WPQR)

The WPQR is a statement of the results of assessing each test piece including re-tests.

For level 1: A WPQR format shall be used to record details and level for the welding procedure and the test results, in order to facilitate uniform presentation and assessment of the data.

For level 2: A WPQR format shall be used to record details, range of qualification and level for the welding procedure and the test results, in order to facilitate uniform presentation and assessment of the data.

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Useful Topic Related Links

[Welding Procedure Specification - general information]

[Welding procedure specification - example]

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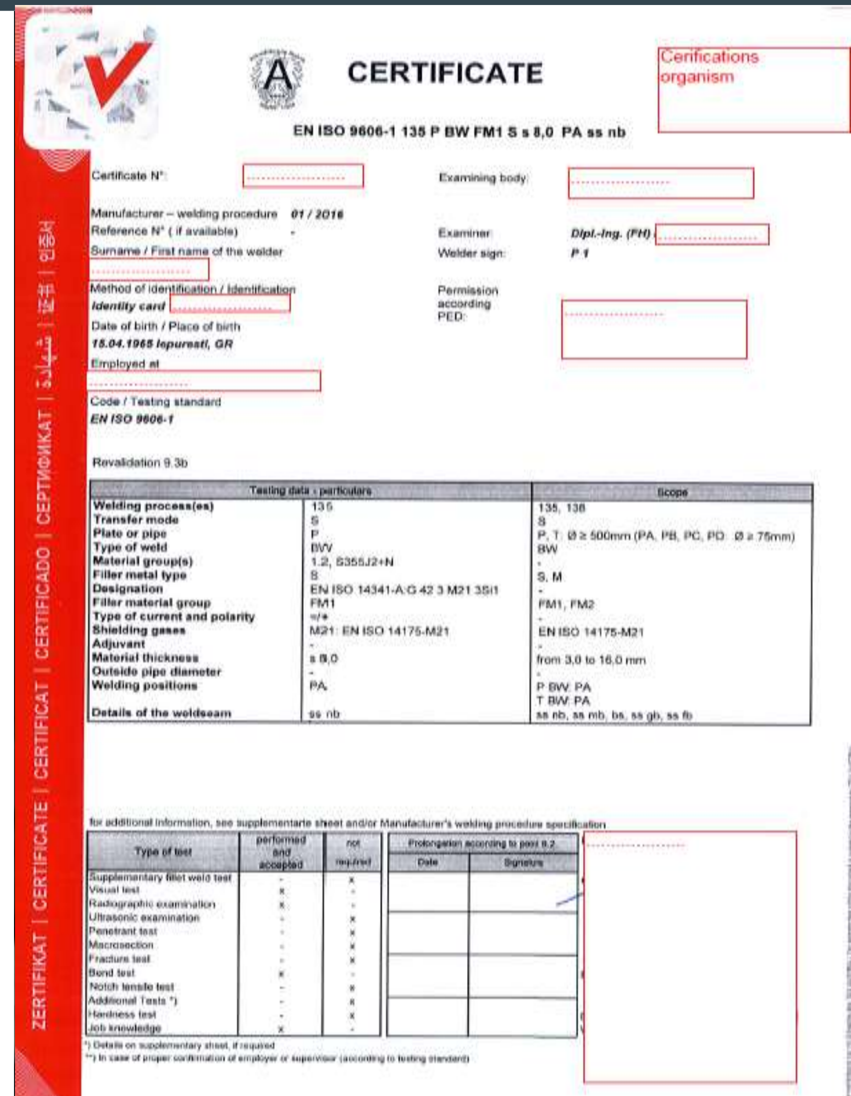
I.4. Quality assurance and qualification in welding

I.4.5. Welders qualification standard



ZERTIFIKAT | CERTIFICATE | CERTIFICAT | CERTIFICADO | СЕРТИФИКАТ | شهادة | 証书 | 인증서

CERTIFICATE

Cerifications organism

EN ISO 9606-1 135 P BW FM1 S s 8,0 PA ss nb

Certificate N°: ....

Examining body: ....

Manufacturer – welding procedure *01 / 2016*

Reference N° (if available) -

Examiner: *Dipl.-Ing. (FH)* ....

Surname / First name of the welder ....

Welder sign: *P 1*

Method of identification / Identification *Identity card* ....

Permission according PED: ....

Date of birth / Place of birth *15.04.1965 Iepuresti, GR*

Employed at ....

Code / Testing standard *EN ISO 9606-1*

Revalidation 9.3b

Testing data - particulars		Scope
Welding process(es)	135	135, 138
Transfer mode	S	S
Plate or pipe	P	P, T: Ø ≥ 500mm (PA, PB, PC, PD: Ø ≥ 75mm)
Type of weld	BW	BW
Material group(s)	1.2, S355J2+N	-
Filler metal type	S	S, M
Designation	EN ISO 14341-A:G 42 3 M21 3Si1	-
Filler material group	FM1	FM1, FM2
Type of current and polarity	=/+	-
Shielding gases	M21: EN ISO 14175-M21	EN ISO 14175-M21
Adjuvant	-	-
Material thickness	s 8,0	from 3,0 to 16,0 mm
Outside pipe diameter	-	-
Welding positions	PA	P BW: PA T BW: PA
Details of the weldseam	ss nb	ss nb, ss mb, bs, ss gb, ss fb

for additional information, see supplementarte sheet and/or Manufacturer's welding procedure specification

Type of test	performed and accepted	not required
Supplementary fillet weld test	-	x
Visual test	x	-
Radiographic examination	x	-
Ultrasonic examination	-	x
Penetrant test	-	x
Macrosection	-	x
Fracture test	-	x
Bend test	x	-
Notch tensile test	-	x
Additional Tests *)	-	x
Hardness test	-	x
Job knowledge	x	-

Prolongation according to point 9.2	
Date	Signature

....

*) Details on supplementary sheet, if required

**) In case of proper confirmation of employer or supervisor (according to testing standard)

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Aim & Objectives

Module Aim:	Provide basic knowledge about welders qualification
Number of hours:	1 hour e-learning and 1 hour self-study
Learning Outcomes:	• Essential variables and range of qualification • Examination and testing • Acceptenace requirement for test pieces • Period of validity
ECVET:	4 (for Training Units Nº 4)

Lecture Outline

This lecture deals with presenting the theoretical aspects of the qualification test of welders for the fusion welding of steels.

It provides a set of technical rules for a systematic qualification test of the welder, and enables such qualifications to be uniformly accepted regardless of the type of product, location and examiner/examining body.

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I.4.5. Welders qualification standard

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Field of application ISO 9606-1

- This part of ISO 9606 specifies the requirements for qualification testing of welders for fusion welding of steels.
- It provides a set of technical rules for a systematic qualification test of the welder, and enables such qualifications to be uniformly accepted regardless of the type of product, location and examiner or examining body.
- When qualifying welders, the emphasis is placed on the welder's manual ability to manipulate the electrode, welding torch or welding blowpipe, thereby producing a weld of acceptable quality.
- The standard does not cover fully mechanized and automated welding processes.

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Essential variables and range of qualification

The qualification of welders is based on essential variables. For each essential variable, a range of qualification is defined. If the welder has to weld outside the range of welder qualification, a new qualification test is required. The essential variables are :

- welding process(es);
- product type(metal sheet or pipe)
- welding type (butt welding and fillet welding);
- the group of filler materials;
- type of the filler material
- dimensions (the material thickness and outer diameter of the pipe);
- welding position;
- detail(s) related to the welding (root support, gas root protection, flow root protection, fusible insertion, single-side welding, both sides welding, single layer, multiple layers, welding to the left, welding to the right).

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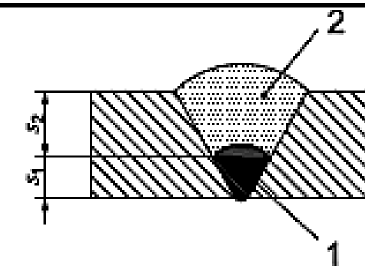
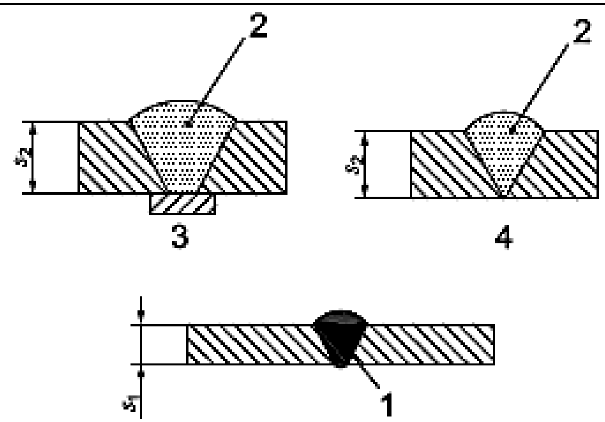
Welding processes

Each test normally qualifies only one welding process. A change of welding process requires a new qualification test.

Exceptions are as follows:

- a change from solid wire electrode 135 to a metal cored electrode 138, or vice versa, does not require requalification ;
- a change from solid wire electrode 121 to a tubular cored electrode 125, or vice versa, does not require requalification ;
- welding with 141, 143 or 145 qualifies for 141, 142, 143 and 145, but 142 only qualifies for 142;
- qualifying the welder for dip (short-circuit) transfer mode (131, 135 and 138) shall qualify him for other transfer modes, but not vice versa.

A welder can be qualified for two or more welding processes by welding a single test piece (multi-process joint) or by two or more separate qualification tests.

Welding process used for test piece	Deposited thickness range qualified according to Table 6	
	Single process joint	Multi-process joint
 1 welding process 1 (ss nb) 2 welding process 2 (ss mb)	for welding process 1: $s = s_1$ for welding process 2: $s = s_2$	$s = s_1 + s_2$
 1 welding process 1 2 welding process 2 3 welding with backing (ss mb) 4 welding without backing (ss nb)	for welding process 1: s_1 for welding process 2: s_2	for $s = s_1 + s_2$ welding process 1 only for welding of the root area

NOTE See 4.3.1 for definitions of the variables.

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Product type

The qualification test shall be carried out on plate, pipe or other suitable product form. The following criteria are applicable:

- test piece welds with outside pipe diameter $D > 25$ mm cover welds in plates;
- test piece welds in plates cover welds in fixed pipe of outside pipe diameter $D \geq 500$.
- test piece welds in plates cover welds in rotating pipes of outside pipe diameter $D \geq 75$ mm for welding positions PA, PB, PC, and PD.

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Type of weld

The qualification test shall be carried out as butt or fillet welding. The following criteria are applicable.

- Butt welds cover butt welds in any type of joint except branch connections ;
- Butt welds do not qualify fillet welds or vice versa;
- Butt welds in pipes qualify branch joints with an angle ≥ 60° and the same range of qualification as in Tables 1 to 12;
- For applications where the type of weld cannot be qualified by means of either a butt or fillet or for branch connections of less than 60°, a specific test piece should be used to qualify the welder, when specified (e.g. by the product standard).

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Filler material grouping

The parent material used in a qualification test should be from any suitable material from ISO/TR 15608, material groups 1 to 11.

Group	Filler material for welding of	Examples of applicable standards
FM1	Non-alloy and fine grain steels	ISO 2560, ISO 14341, ISO 636, ISO 14171, ISO 17632
FM2	High-strength steels	ISO 18275, ISO 16834, ISO 26304, ISO 18276
FM3	Creep-resisting steelsCr<3,75%	ISO 3580, ISO 21952, ISO 24598, ISO 17634
FM4	Creep-resisting steels3,75 <Cr< 12%	ISO 3580, ISO 21952, ISO 24598, ISO 17634
FM5	Stainless and heat-resisting steels	ISO 3581, ISO 14343, ISO 17633
FM6	Nickel and nickel alloys	ISO 14172, ISO 18274

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Filler material grouping

Welding with a filler material in one group qualifies the welder for welding with all other filler materials within the same group, as well as other groups.

Range of qualification for filler material

Filler material	**Range of qualification**					
	FM1	FM2	FM3	FM4	FM5	FM6
FM1	x	x	-	-	-	-
FM2	x	x	-	-	-	-
FM3	x	x	x	-	-	-
FM4	x	x	x	x	-	-
FM5	-	-	-	-	x	-
FM6	-	-	-	-	x	x

x indicates those filler materials for which the welder is qualified.
- indicates those filler materials for which the welder is not qualified.

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Filler material type

Welding with filler material qualifies for welding without filler material, but not vice versa.

Welding process	Type of covering used in the test	Range of qualification		
		A,RA,RB,RC,RR,R 03,13,14,19,20,24,24,27	B 15,16,18,28,45,48	C 10,11
111	A,RA,RB,RC,RR,R 03,13,14,19,20,24,24,27	x	-	-
	B 15,16,18,28,45,48	x	x	-
	C 10,11	-	-	x

x indicates those filler materials for which the welder is qualified.
- indicates those filler materials for which the welder is not qualified.

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Filler materials

Range of qualification for filler material

Welding consumables used in the test	Range of qualification			
	S	M	B	R, P, V, W, Y, Z
Solid wire (S)	×	×	—	—
Electrode core (M)	×	×	—	—
Electrode core (B)	—	—	×	×
Electrode core (R, P, V, W, Y, Z)	—	—	—	×

x indicates those filler materials for which the welder is qualified.
- indicates those filler materials for which the welder is not qualified.

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Dimensions

The welder qualification test of butt welds is based on the deposited thickness and outside pipe diameters.

For test pieces of different outside pipe diameters and deposited thicknesses, the welder is qualified for:

- the thinnest to the thickest deposited and/or parent metal thickness qualified;
- the smallest to the largest diameter qualified

Dimensions

Range of qualification of deposited thickness for butt welds

Deposited thickness of test piece s	Range of qualification(a,b)
$s < 3$	s to 3^{c} or s to$2s^{c}$ whichever is greater
$3 \leq s < 12$	3 to $2s^{d}$
$s \geq 12^{e,f}$	$\geqq 3^{f}$

a For single process and the same type of filler material, s, is equal to parent material t.
b For branch joints, the range of qualification for deposited thickness is:
— for set-on branch, see, for example, Figure 1 a), the deposited thickness of the branch
— for set-through and set-in branches, see, for example, Figure1 b) and c), the deposited thickness of the main pipe or shell.
c For oxyacetylene welding (311): s to 1,5s
d For oxyacetylene welding (311): 3 to 1,5s
e The test piece has to be welded in at least 3 layers f For multi-processes, s is the deposited thickness for each process.

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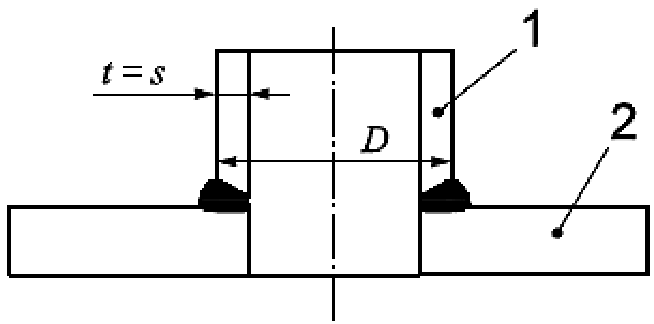
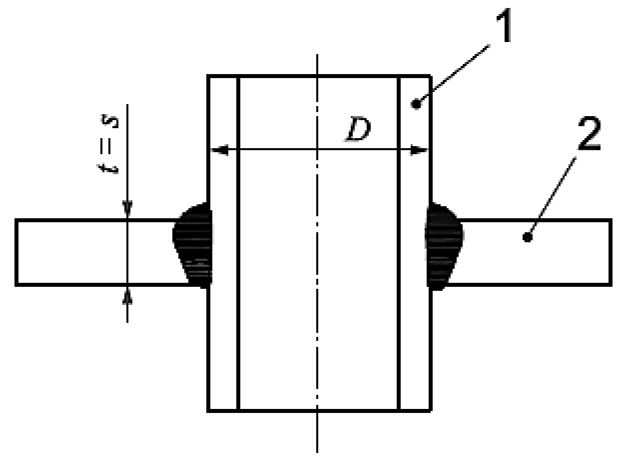
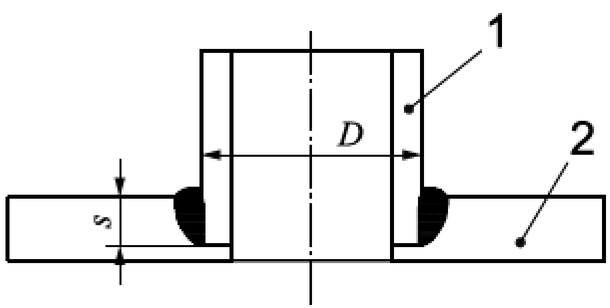
Dimensions



a) Set-on



b) Set-through



c) Set-in

Key

D	outside pipe diameter
s	deposited thickness or fused metal thickness in butt welds
t	material thickness of test piece (plate or wall thickness)
1	branch
2	main pipe or shell

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Dimensions

Range of qualification for outside pipe diameter

Outside pipe diameter of test piece D	Range of qualification
D ≤ 25	D to 2D
D > 25	≥ 0,5D (min. 25 mm)
For non-circular hollow sections, D is the dimension of the smaller side.	

Range of qualification of material thickness for fillet welds

Material thickness of test piece t	Range of qualification
t < 3	t to 2t, 3 3, whichever is greater
t ≥ 3	≥ 3

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Welding positions

Range of qualification for welding positions for butt welds

Testing position	Range of qualification				
	PA Flat	PC Horizontal	PE Overhead	PF Vertical up	PG Vertical down
PA	×	—	—	—	—
PC	×	×	—	—	—
PE (plate)	×	×	×	—	—
PF (plate)	×	—	—	×	—
PH (pipe)	×	—	×	×	—
PG (plate)	—	—	—	—	×
J (pipe)	×	—	×	—	×
H-L045	×	×	×	×	—
J-L045	×	×	×	—	×
NOTE See also 5.3.					

x indicates those filler materials for which the welder is qualified.
- indicates those filler materials for which the welder is not qualified.

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Welding positions

Range of qualification for welding positions for fillet welds

Testing position	Range of qualification						
	PA Flat	PB Horizontal	PC Horizontal	PD Overhead	PE Overhead	PF Vertical up	PG Vertical down
PA	×	—	—	—	—	—	—
PB	×	×	—	—	—	—	—
PC	×	×	×	—	—	—	—
PD	×	×	×	×	×	—	—
PE (plate)	×	×	×	×	×	—	—
PF (plate)	×	×	—	—	—	´	—
PH (plate)	×	×	×	×	´	´	—
PG (plate)	—	—	—	—	—	—	´
PJ (pipe)	×	×	—	×	´	—	´

NOTE See also 5.3.

x indicates those filler materials for which the welder is qualified.
- indicates those filler materials for which the welder is not qualified.

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Weld details

Range of qualification for backings and consumable inserts

Test condition	Range for qualification for backing and consumable inserts					
	No backing (ss,nb)	Material backing (ss,mb)	Welding from both sides (bs)	Gas backing (ss,gb)	Consumable insert (ci)	**Flux backing (ss,fb)**
No backing(ss,nb)	×	×	×	×	—	×
Material backing(ss,mb)	—	×	×	—	—	—
Welding from both sides(bs)	—	×	×	—	—	—
Gas backing(ss,gb)	—	×	×	×	—	—
Consumable insert(ci)	—	×	×	—	×	—
Flux backing(ss,fb)	—	×	×	—	—	×

x indicates those filler materials for which the welder is qualified.
- indicates those filler materials for which the welder is not qualified.

Weld details

Range of qualification of layer technique for fillet welds

Test piece	Range of qualification[b]	
	Single layer(sl)	Multi-layer(ml)
Single layer(sl)	x	-
Multi-layer $(ml)^a$	x	x

x indicates those filler materials for which the welder is qualified.
- indicates those filler materials for which the welder is not qualified.

a During the welding of the test piece, the examiner shall perform visual examination of the first layer in accordance with Clause 7.
b When a welder has been qualified using a multi-layer butt weld and he or she makes the supplementary fillet weld test, he or she is qualified for both multi- and single layer fillet welds.

Examination and testing

The welding of test pieces shall be witnessed by the examiner or examining body. The testing shall be verified by the examiner or examining body.

The examiner or examining body may stop the test if the welding conditions are not correct or if it appears that the welder does not have the skill to fulfill the requirements, e.g. where there are excessive and/or systematic repairs.

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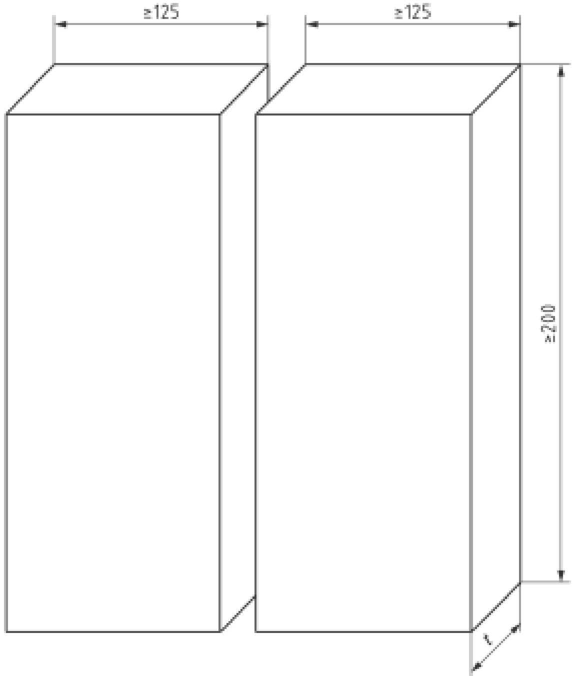
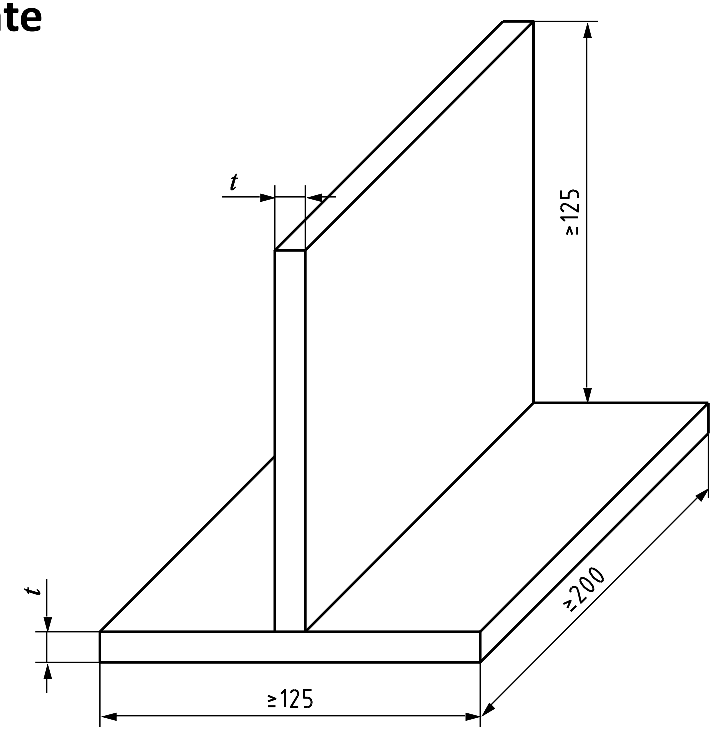
Probe

Dimensions of test piece for a butt weld in plate



Dimensions of test piece for a fillet weld on plate

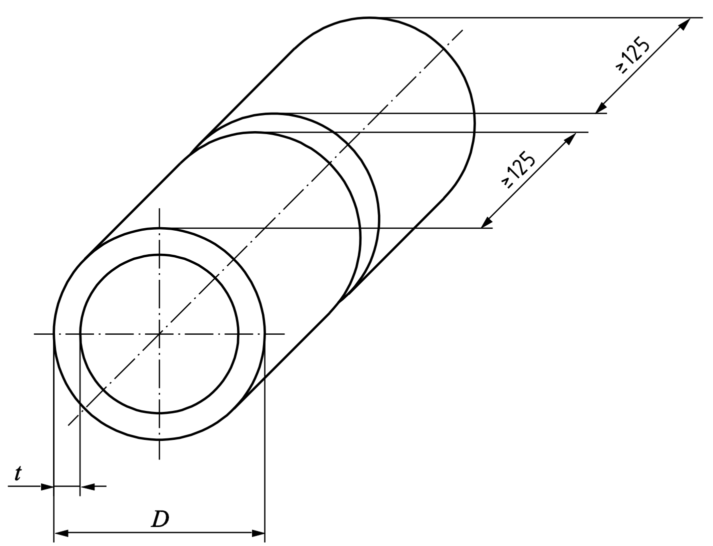


t - material thickness of test piece

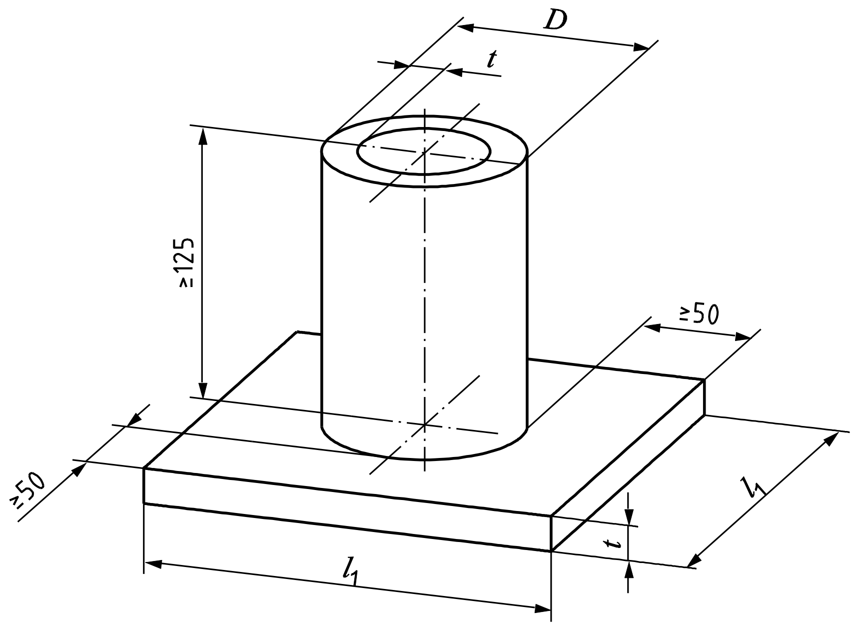
- Note - The parent material can be of dissimilar thickness.

Examination and testing

Dimensions of test piece for a butt weld in pipe



Dimensions of test piece for a fillet weld on pipe



D outside pipe diameter , *l*1- length of test piece

t material thickness of test piece (plate or wall thickness)

NOTE The parent material can be of dissimilar thickness for the pipe and plate

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Test methods

Test method	Butt weld (in plate or pipe)	Fillet weld and branch joint
Visual testing according to ISO 17637	mandatory	mandatory
Radiographic testing according to ISO 17636	mandatory (a,b,c)	not mandatory
Bend test according to ISO 5173	mandatory (a,b,d)	not applicable
Fracture test according to ISO 9017	mandatory (a,b,d)	mandatory (e,f)

a Either radiographic testing or bend or fracture tests shall be used

b When radiographic testing is used, then additional bend or fracture tests are mandatory for welding processes 131, 135, 138 and 311.

c The radiographic testing may be replaced by ultrasonic testing according to ISO 17640[19] for thicknesses ≥ 8 mm on ferritic steels only. In this case, the additional tests mentioned in footnote b are not required.

d For outside pipe diameters D ≤ 25 mm, the bend or fracture tests may be replaced by a notched tensile test of the complete test piece

e The fracture tests may be replaced by a macroscopic examination, performed according to ISO 17639[18], of at least two sections,at least one of which shall be taken from the stop/start location.

f The fracture tests on pipes may be replaced by radiographic testing.

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Acceptance requirements for test pieces

Test pieces shall be evaluated according to the acceptance requirements specified for relevant types of imperfections.

Prior to any testing, the following shall be checked:

- all slag and spatters are removed;
- no grinding on the root and the face side of the weld;
- stop and restart in the root run and in the capping run are identified;
- profile and dimensions.

If any test fails to comply with the requirements of this part of ISO 9606, the welder may be given the opportunity to repeat the qualification test once without further training.

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Period of validity

The welder's qualification begins from the date of welding of the test piece(s), provided that the required testing has been carried out and the test results obtained were acceptable. The certificate needs to be confirmed every 6 months otherwise the certificate(s) become(s) invalid.

Confirmation of the validity

The qualifications of a welder for a process shall be confirmed every 6 months by the person responsible for welding activities or examiner/examining body. This is confirming that the welder has worked within the range of qualification and extends the validity of the qualification for a further 6 month period.

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Period of validity

Revalidation shall be carried out by an examiner/examining body.

The skill of the welder shall be periodically verified by one of the following methods.

a) The welder shall be retested every 3 years.

b) Every 2 years, two welds made during the last 6 months of the validity period shall be tested by radiographic or ultrasonic testing or destructive testing and shall be recorded. The acceptance levels for imperfections shall be as specified in Clause 7. The weld tested shall reproduce the original test conditions except for thickness and outside diameter. These tests revalidate the welder's qualifications for an additional 2 years.

Period of validity

A welder's qualifications for any certificate shall be valid as long as it is confirmed and provided all the following conditions are fulfilled:

- the welder is working for the same manufacturer for whom he or she qualified, and who is responsible for the manufacture of the product;
- the manufacturer's quality programme has been verified in accordance with ISO 3834-2 or ISO 3834-3;
- the manufacturer has documented that the welder has produced welds of acceptable quality based on application standards.

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Period of validity

Revocation of qualification

When there is a specific reason to question a welder's ability to make welds that meet the product standard quality requirements, the qualifications that support the welding he or she is doing shall be revoked. All other qualifications not questioned remain valid.

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Welder's qualification certificate

The certificate shall be issued under the sole responsibility of the examiner or examining body.

The examiner or examining body is responsible for verifying that all essential variables are addressed in this certificate

The following non-essential variables shall be recorded on the certificate:

- type of current and polarity;
- parent material group/subgroup;
- shielding gas.

In general, for each test piece, a separate welder's qualification test certificate shall be issued. If more than one test piece is welded, a single welder's qualification test certificate can be issued that combines the ranges of qualification of the individual test pieces. All essential variables for all tests shall be recorded on the combined certificate.

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Useful Topic Related Links

Welder certification – general information

Welder certification - example

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I.5. Technical drawing used in welding field

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Aim & Objectives

Module Aim:	To equip students with the skills required to understand, and read technical drawings used in the welding field.
Number of hours:	e-learning: 2h, self-study: 4h
Learning Outcomes:	• Learn about the importance of drawings as a technical language. • Understand the different types of technical drawings which are utilised in engineering. • Learn on how mechanical engineering components and assemblies are represented on different technical drawing layouts.
ECVET:	

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Lecture Outline

- Drawings as a technical language
- Types of drawings
- Drawing layouts
- Drawing views
- Further reading

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I.5. Technical drawing used in welding field

Introduction

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Drawing as a language

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- What are drawings generated for?
  - Communicate ideas
  - Express ideas
  - Manufacturing purposes
  - Documentation
- "…a perfect drawing communicates an exact requirement or specification which cannot be misinterpreted"

[Simmons & Maguire, 2004]

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Drawing as a language

- Over the years many standards (e.g. JIS, BS, ASME, ISO) relating to technical drawing have been developed and established.
- Drawings are used in various domains (electrical and mechanical engineering, architecture)

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Advantages of Computer Aided Drafting:

Image License

- absolute accuracy can be maintained.
- editing processes (e.g. copy, move, rotate, mirror and erase) drawing entities.
- drawings are stored easily.
- drawings can be quickly reproduced.
- parts of drawings can be saved and used in other drawings.

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Why we need to learn Eng. Drawing?

- Engineering drawing is a graphical language – it's useless to generate drawings with CAD without being able to interpret them!!
- What if you do not have a computer available and you still want to communicate your ideas with someone else?

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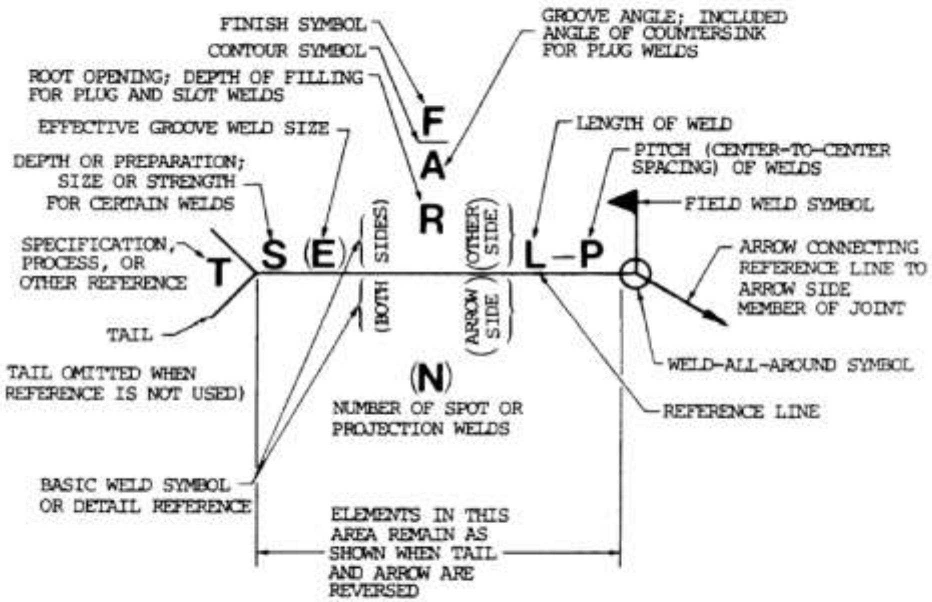
Welding Drawing Symbols

- In welding we use specific drawing symbols and notations.
- The symbolic representation of joints as per EN ISO 2553 have been outlined in Module 1, sub-topic 1.4



By Milton H Hamilton, Gordon R. Sullivan - US Army Training Circular 9-237, Public Domain, https://en.wikipedia.org/w/index.php?curid=33358263

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I.5. Technical drawing used in welding field

Types of Drawing

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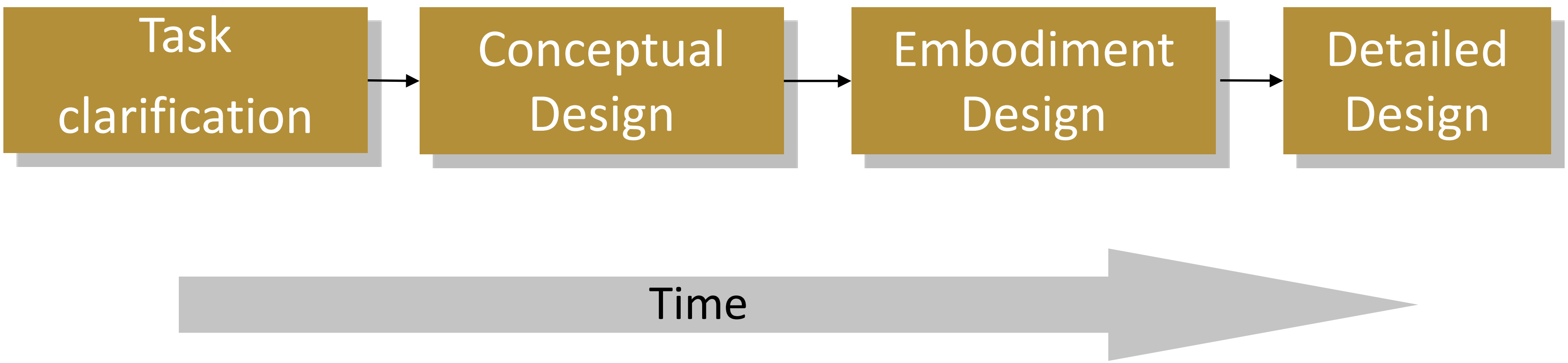
Engineering Design Process



The engineering design process is made up of different stages. As time goes by the design advances from conceptual, embodiment and finally to detailed design.

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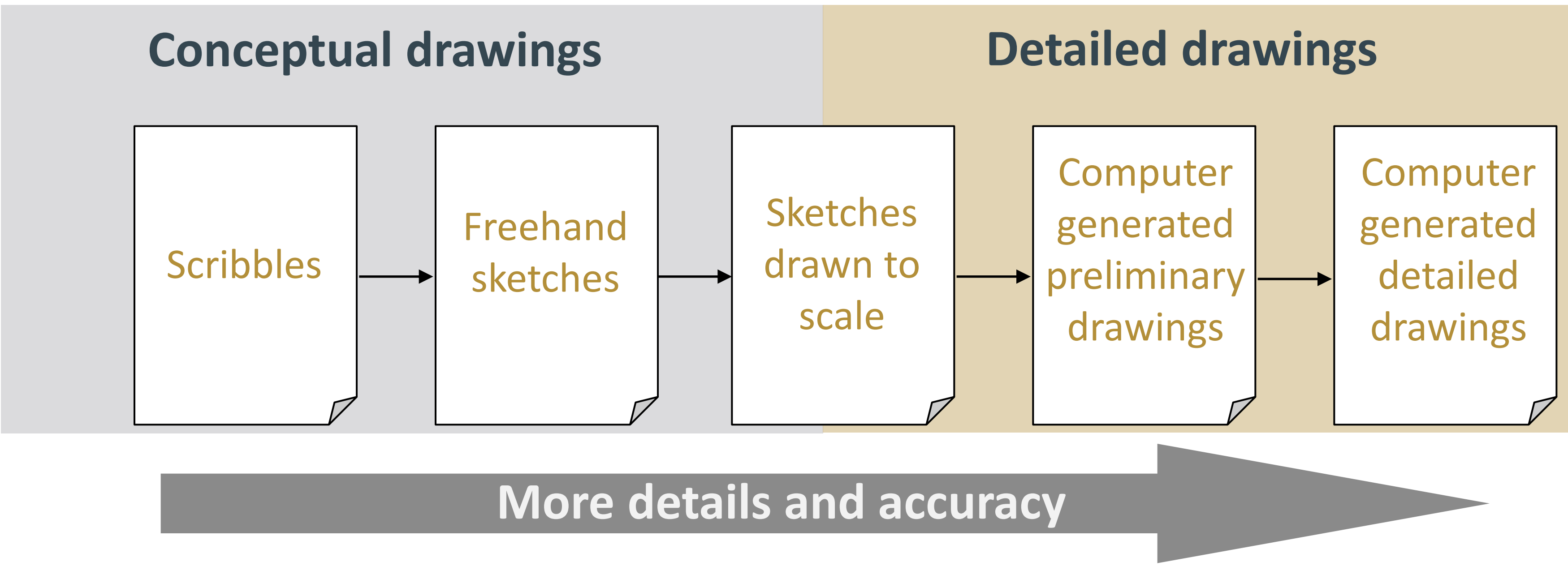
Engineering Design Process



Similarly as the engineering design process progresses, so do technical drawings evolve from preliminary sketches to detailed CAD generated drawings.

Click on the above types of technical drawings to view further details about each style.

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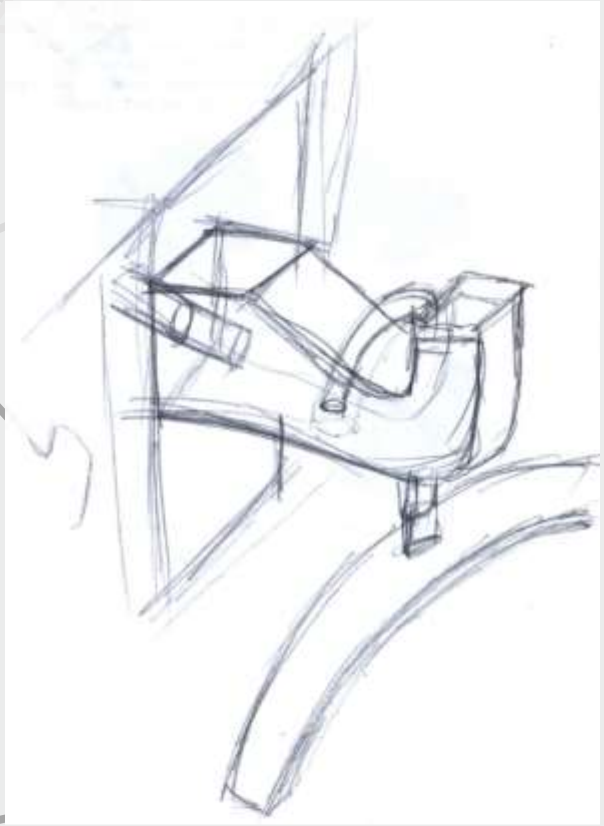
Scribbles



- Produced at the very early design stages
- Very rough drawings
- Contain extra graphical information
- No engineering standards are observed
- Lack dimensions

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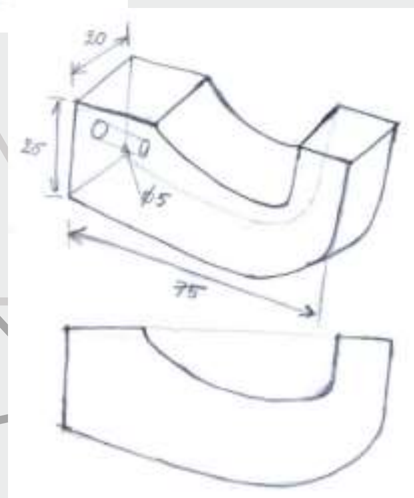
Freehand sketches



- Are less rough compared to scribbles
- May contain both geometric & non-geometric information
- Engineering standards may be adhered to
- Inaccurate drawings
- Produced without drawing instruments

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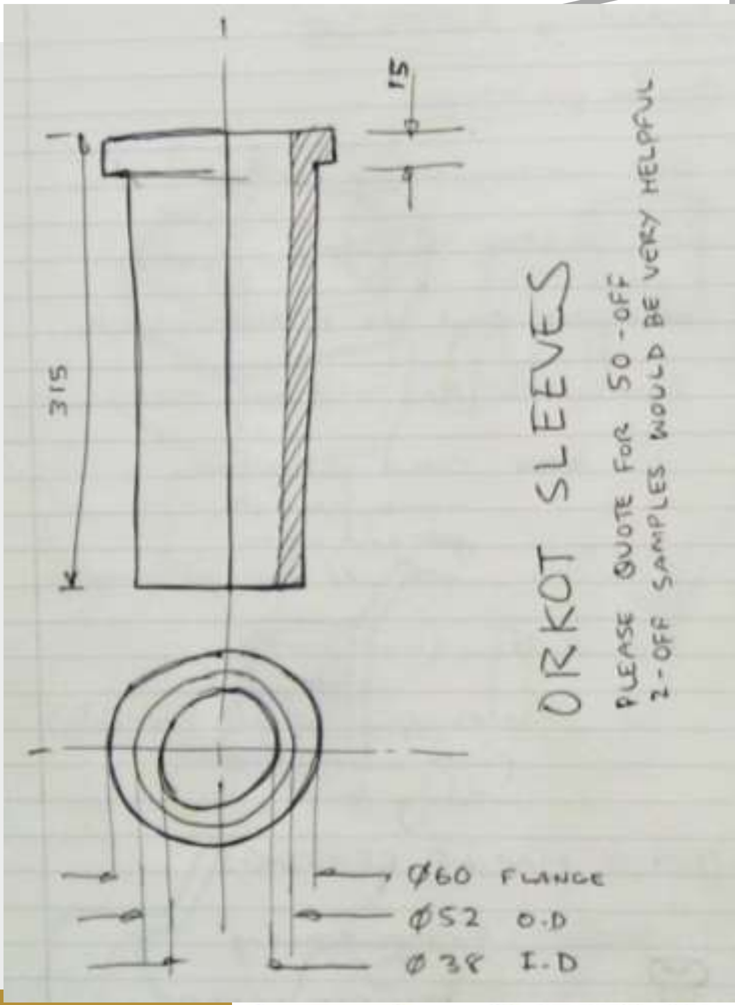
Sketches drawn to scale

- Accurate drawings compared to sketches
- Engineering standards are adhered to
- May be produced with drawing instruments
- Typically produced for the CAD operator



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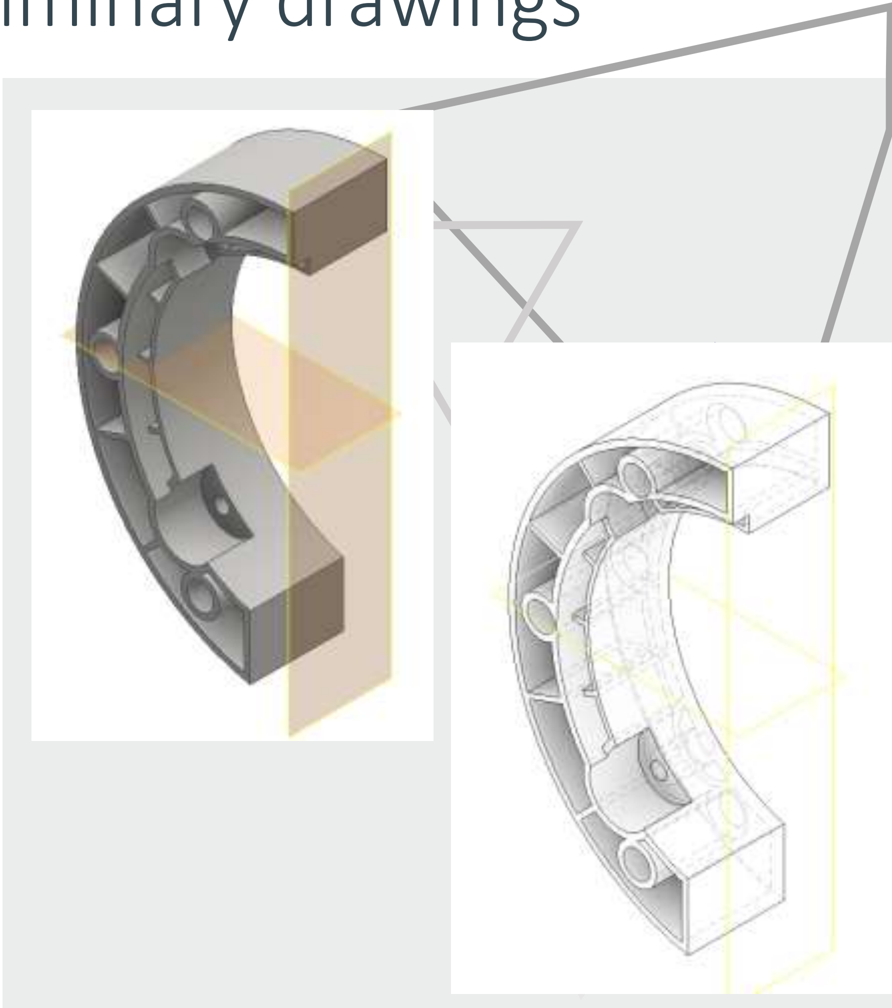
Computer-generated preliminary drawings

- Known also as design layout drawings
- Preliminary in nature, subject to modification
- Useful in order to discuss product design layouts
- May also be prepared for use with tenders



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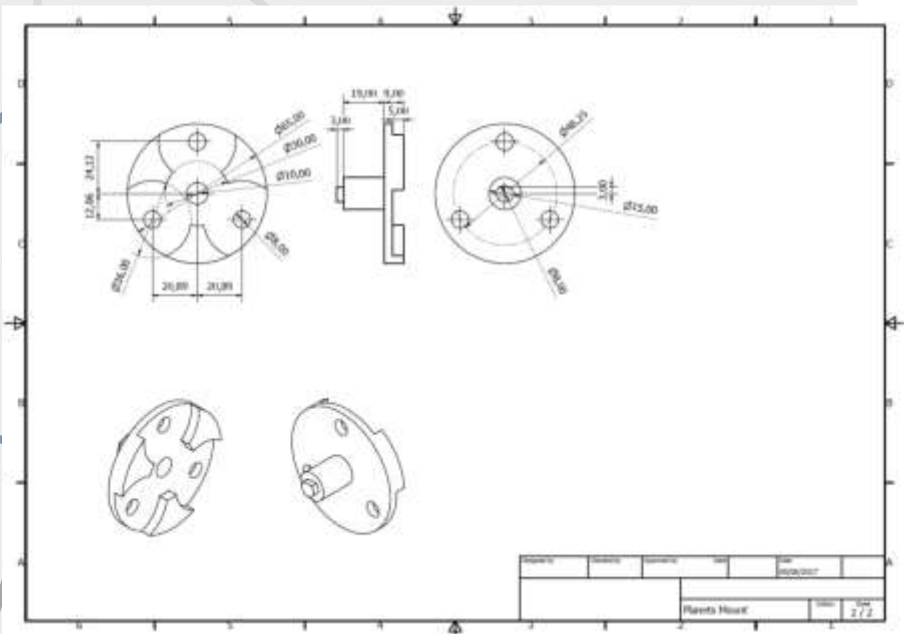
Computer-generated detailed drawings



- Contain all the details required to manufacture a product/component
- Should not contain errors
- Include details on materials, quantity to be produced etc.
- Are checked by chief designers

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I.5. Technical drawing used in welding field

Drawing Layouts

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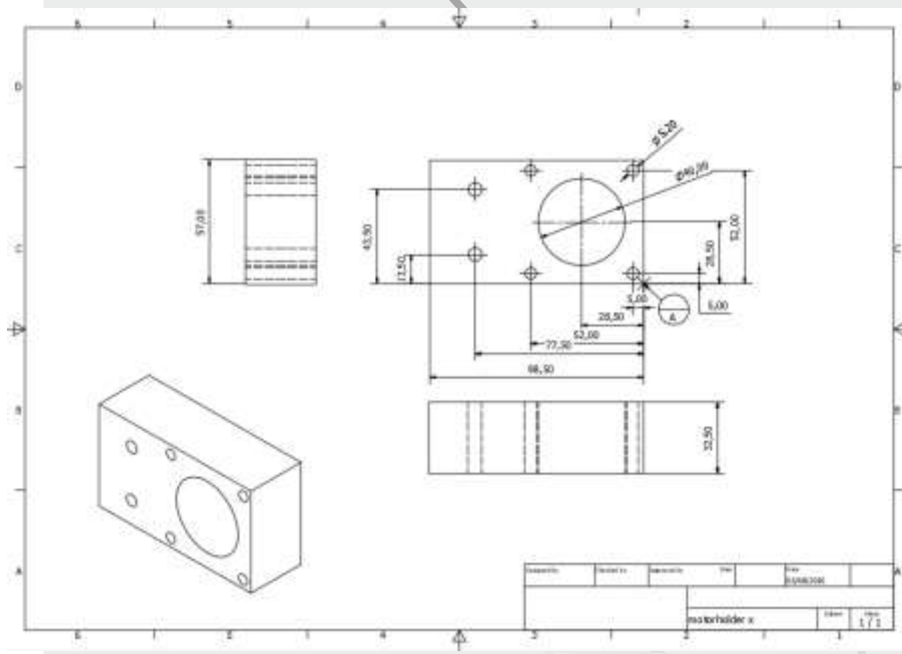
Single-part drawing

- Contains information on a component
- No. of views depend on the complexity of the component
- Typically includes tolerances
- More than one drawing may also be made for the same component (due to different processes)



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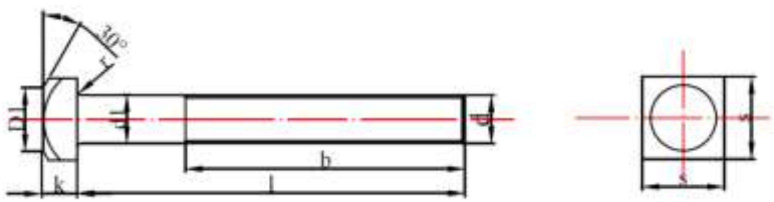
Collective single-part drawings



a	6	8	10	12	14	18	22	28	36	42	48	54
a_1	–						9	12	16	19	22	25
h_1	14						50.5	61.5	76.5	90.5	100.5	111.5
h_2	–						18	24	30	36	42	48
l	20				32		40		50		63	
c	2						3			4		

Material for: OLC 10 hardened 0.8 – 1.2 mm up to 55 – 60 HRC

As per standard (a) STAS 8322/2-69

- Drawing covers a number of components, with similar geometry but different sizes
- Used also when 1 or 2 dims on a component are variable, whilst all the others are standard
- Generally used for basically similar parts

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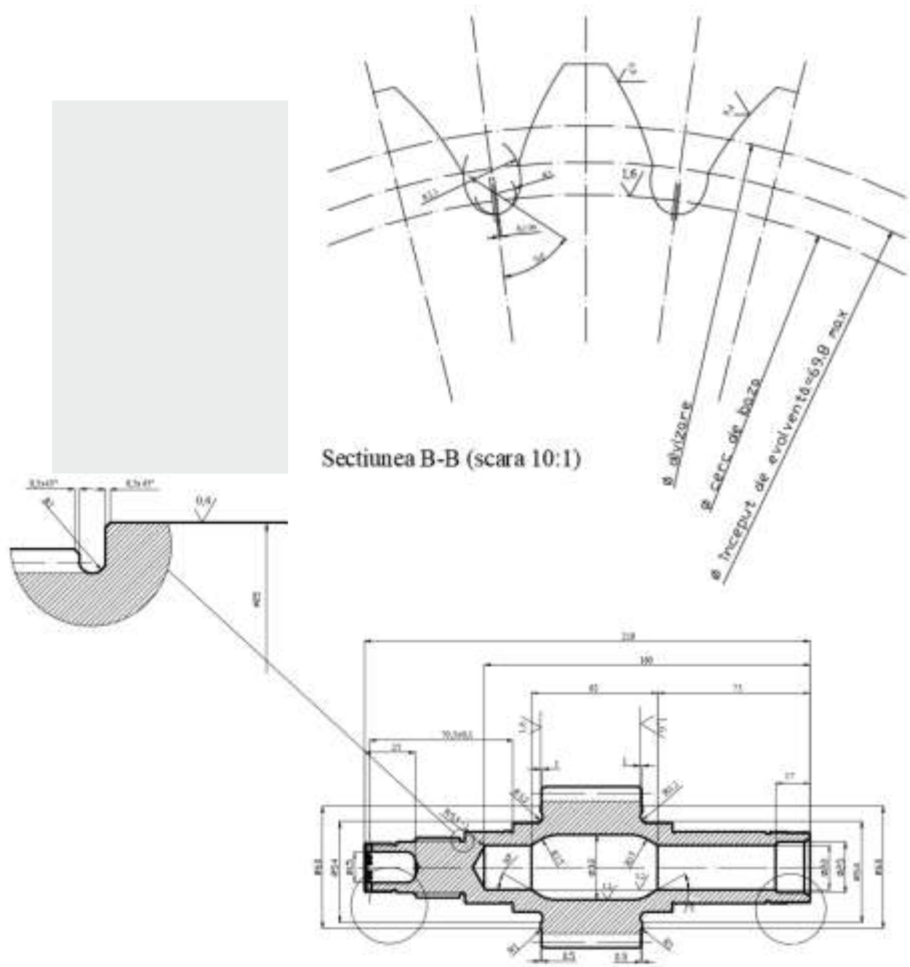
Simplified drawings

- Used to reduce time spent in detailing symmetrical components and repeated parts
- Allow for enlarged scales to clarify the shape of a feature and leave adequate space for dimensions
- Used also to show knurling



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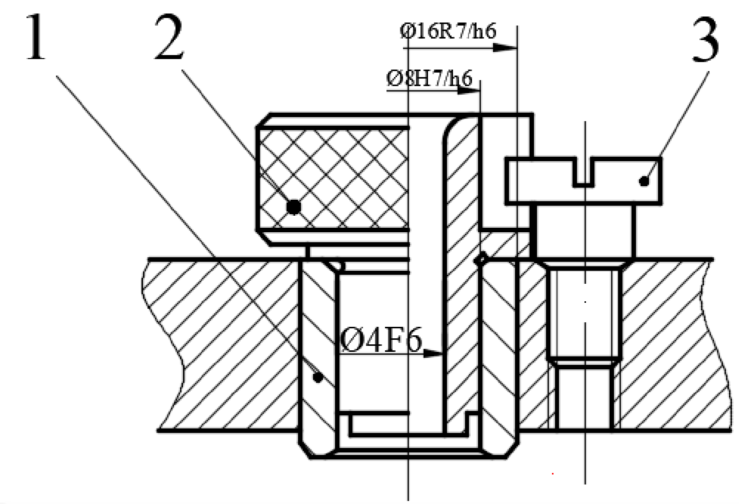
Assembly drawings

- Sub-assembly drawings (e.g. clutch)
- Contains an assembly list in which all components are labelled
- Information on the quantity required of each component for assembly, its individual single-part drawing no.
- May include overall dimensions of (sub)-assembly



1	Piuliță specială	STAS 9011-71	1	OLC45 STAS 880-80	-	-
2	Bucșă schimbabilă	STAS 1228/1-75	4	OLC15 STAS 880-80	-	-
3	Șurub cu cap cilindric crestat M4x22	STAS 3954-87	4	OL60 STAS 500/2-80	-	-

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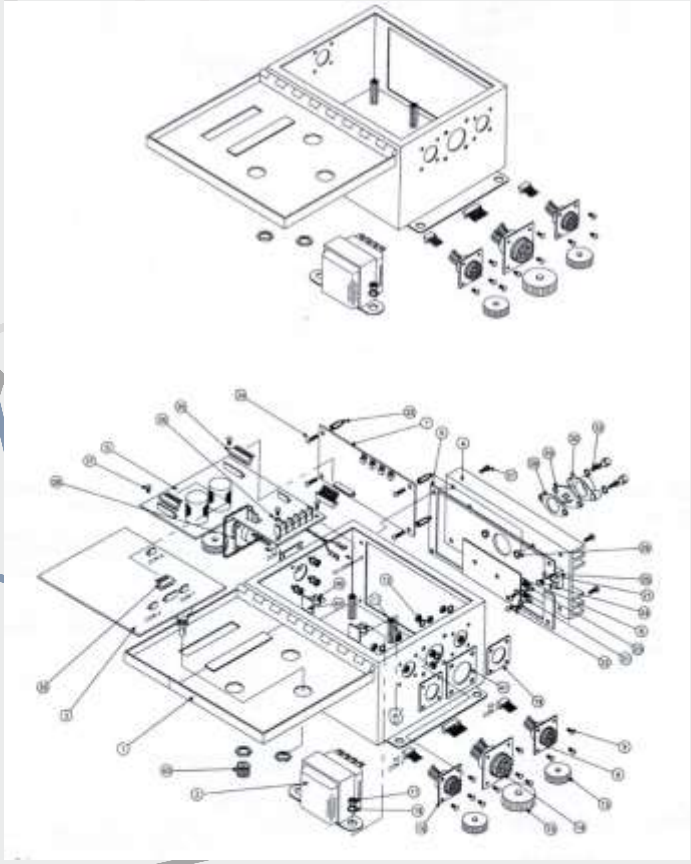
Exploded Assembly drawings



[Simmons & Maguire, 2004]

- Prepared to assist in the correct understanding of the various component positions in an assembly (e.g. machine operators, users)
- A pictorial type of projection is employed

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I.5. Technical drawing used in welding field

Drawing Views

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Drawing Views

- In most cases, a single view is not sufficient to show or represent all the necessary features which are required to fully describe a part.
- For this reason a technical drawing commonly contains several views and representations.
- These views are described as **projections**. The most common types of projections are called orthographic projections which show the components as they look from the front, right, left, top, bottom or back.
- These views are typically positioned relative to each other according to the rules of either **first-angle** or **third-angle** projection.

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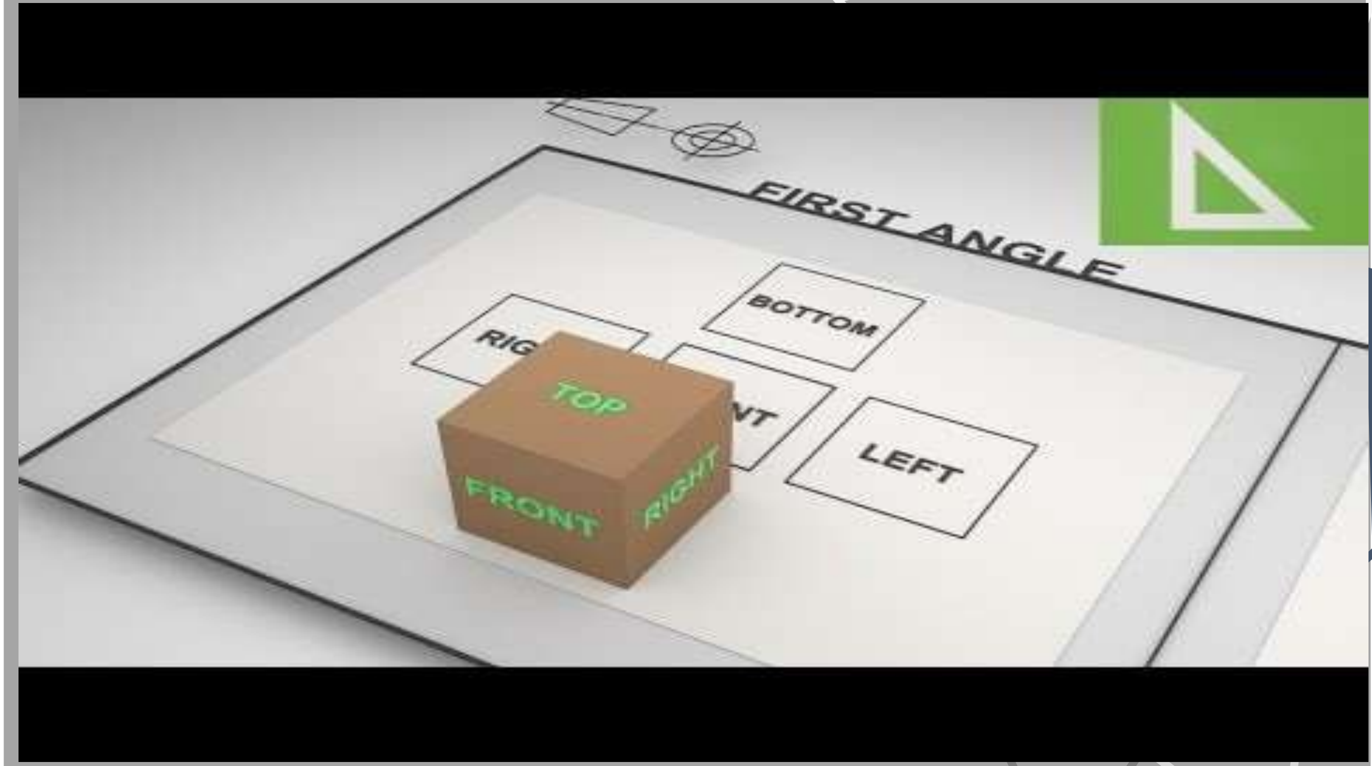
Drawing Views

Video Explaining between 1st and 3rd Angle projections



Click on the video to play

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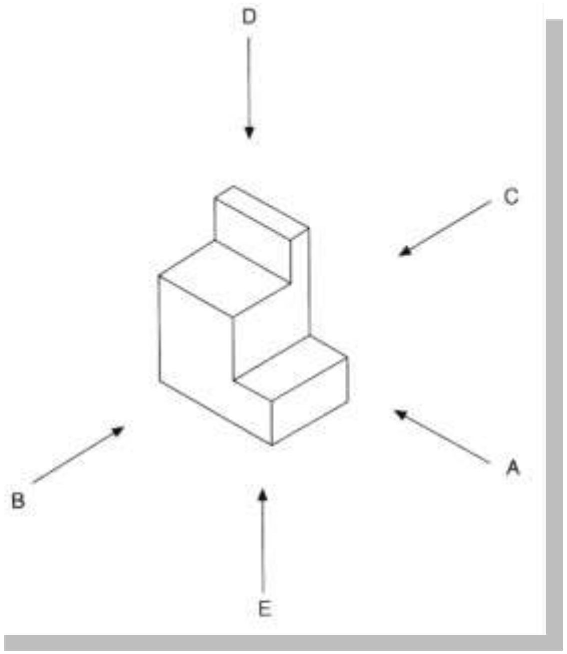
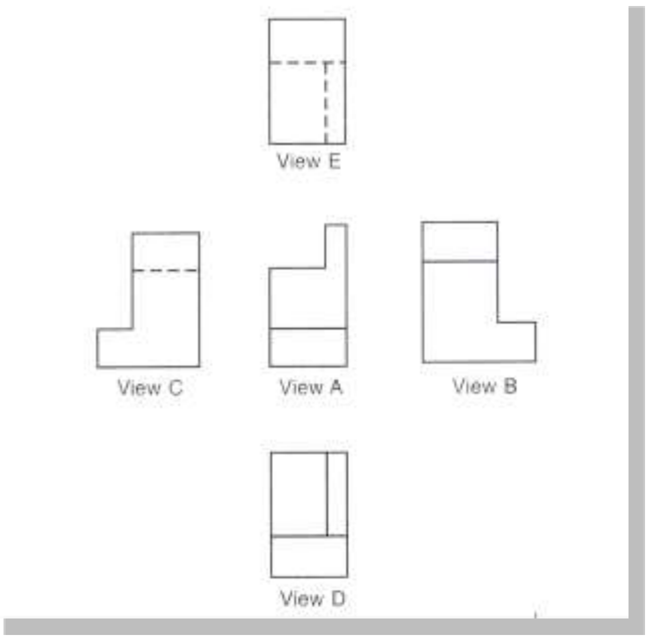
1st angle projection





- In first-angle projection, the parallel projectors originate as if radiated from **behind** the viewer and pass through the 3D object to project a 2D image onto the orthogonal plane behind it.

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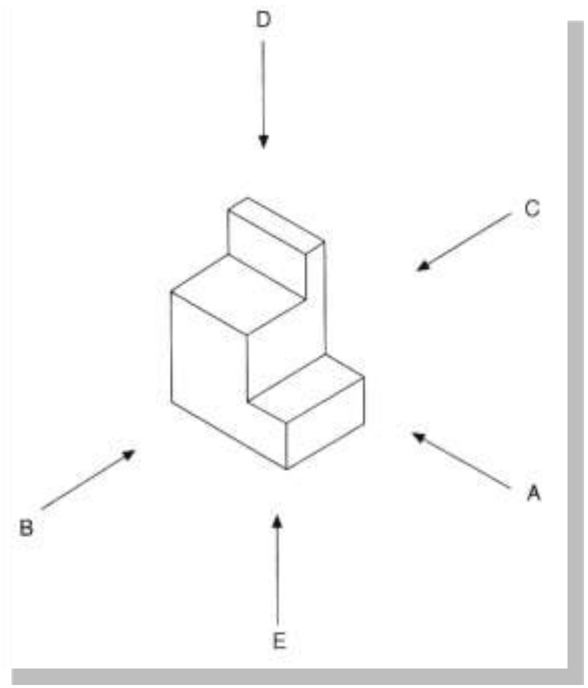
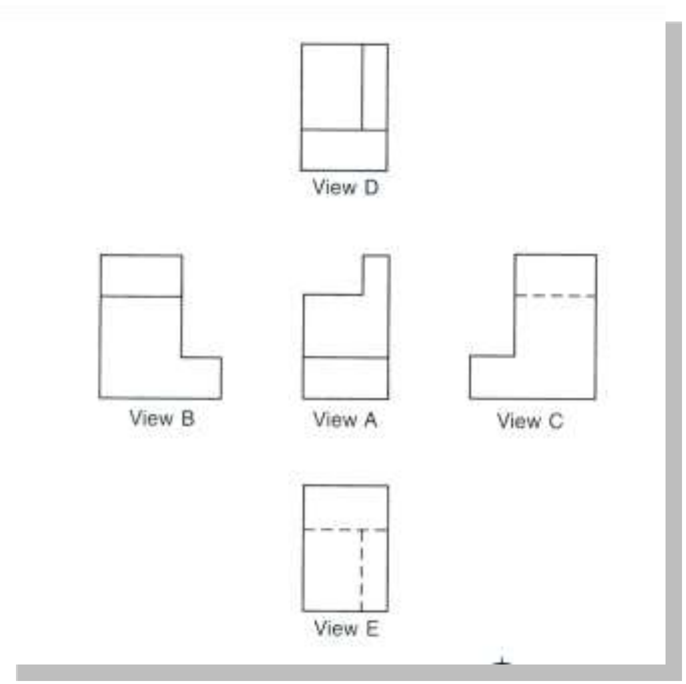
3rd angle projection





- In *third-angle projection*, the parallel projectors originate as if radiated *from the **far side** of the object* and pass through the 3D object to project a 2D image onto the orthogonal plane *in front of* it.

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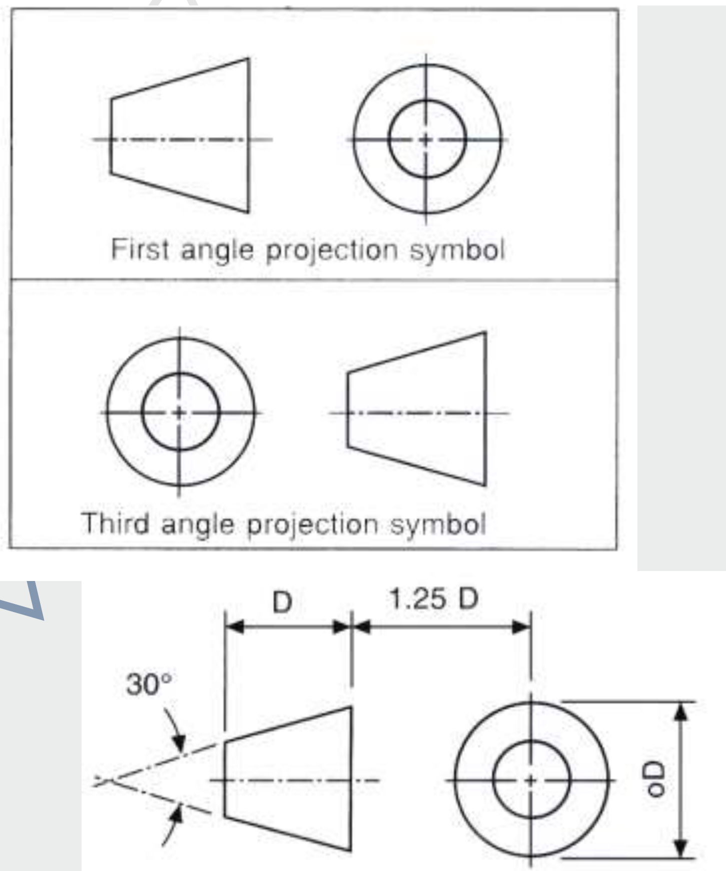
Projection symbols



- The ISO 128 Standard stipulate that both systems of projection are acceptable...
- ...but they should never be mixed on the same drawing
- Every drawing should have either symbol
- Standards specify recommended proportions of the symbols

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I.5. Technical drawing used in welding field

Conclusions and Further Reading

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What have you learnt?

- The importance of the use of drawings as a technical language in order to communicate the design and fabrication intention.
- Understood the different types of technical drawings which are utilised in engineering and how these are applied at different stages of the design process.
- How mechanical engineering components and assemblies are represented on different technical drawing layouts.

Useful Topic Related Links

[Engineering Drawing](#)

[ISO128](#)

[Autodesk Inventor Drawings](#)

[Drawings for manufacture](#)

[CAD Blocks](#)

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PART I - Basics of welding technology

I.6. Specific rules of health and safety for welding processes

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Aim & Objectives

Module Aim:	Understand different risks for health anda safety during different welding processes
Number of hours:	e-learning: 2 hours ; self study: 4 hours
Learning Outcomes:	• Knowledge of the electricity, gases, fumes, fire, radiation and noise risk factors associated with welding. • Correct interpretation of the Health and Safety regulations with respect to the above hazards.
ECVET:	

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Lecture Outline

- Electric shock
- UV and IR (heat) radiation
- Eye hazards
- Burns and fires, fire prevention, fire fighting
- Welding fumes
- Respiratory hazards
- Personal protective equipment and clothing
- Noise hazards
- Specific rules and regulations
- Exposure to electromagnetic field; standard EN 50505

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Health and safety at work

Special rules and regulations

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Specific rules and regulations

- European Directives set out minimum requirements and fundamental principles, such as the principle of prevention and risk assessment, as well as the responsibilities of employers and employees. A series of European guidelines aims to facilitate the implementation of European directives as well as European standards which are adopted by European standardisation organisations.

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Specific rules and regulations

- European directives set out the minimum standards for safety and health in the workplace. The EU directives are implemented through the national legislation of Member States.
- Member States may adopt stricter rules to protect workers but their legislation must comply with the minimum standards. As a result, national safety and health legislation varies across Europe.

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Specific rules and regulations

- Welding processes belong to production technologies that are classified according to all criteria in very dangerous for welders as well as for nearby workers, most of which are welders.
- Welders are often also present in adjacent workplaces where preparation works are carried out. This includes cutting, drilling, tacking, preheating, grinding , transport etc.

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Helth and safety in welding

Most of the hazards in welding industry arise from chemical and physical phenomena that are related to the specific welding process. These phenomena are shown as:

- mechanical injuries,
- electromagnetic fields,
- radiations,
- welding fume and gases,
- choking and poisoning
- burns and fires,
- explosions,
- noises,
- occupational diseases.

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Helth and safety in welding

- The employer must inform employees about safe work by issuing written notices and instructions.
- Only workers who have received the necessary instructions may have access to places where there is a direct danger.
- The employer must provide workplaces and work equipment (machines) with hazard signs and instructions for safe work.
- An uneducated welder can not in anyway be responsible for determining appropriate measures related to safety, environment and fire.

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Electric shock

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Electric shock

- Electric current are used mostly for powering devices. In case of improper use, electrical current can flow through the various conductive parts of electrical devices or even through the human body.
- The alternating current effects depend on:

- the route through which the electricity flows through the body,
- the time duration,
- the conductivity of the path (impedance of the body, dry or moist contact).

Electric shock

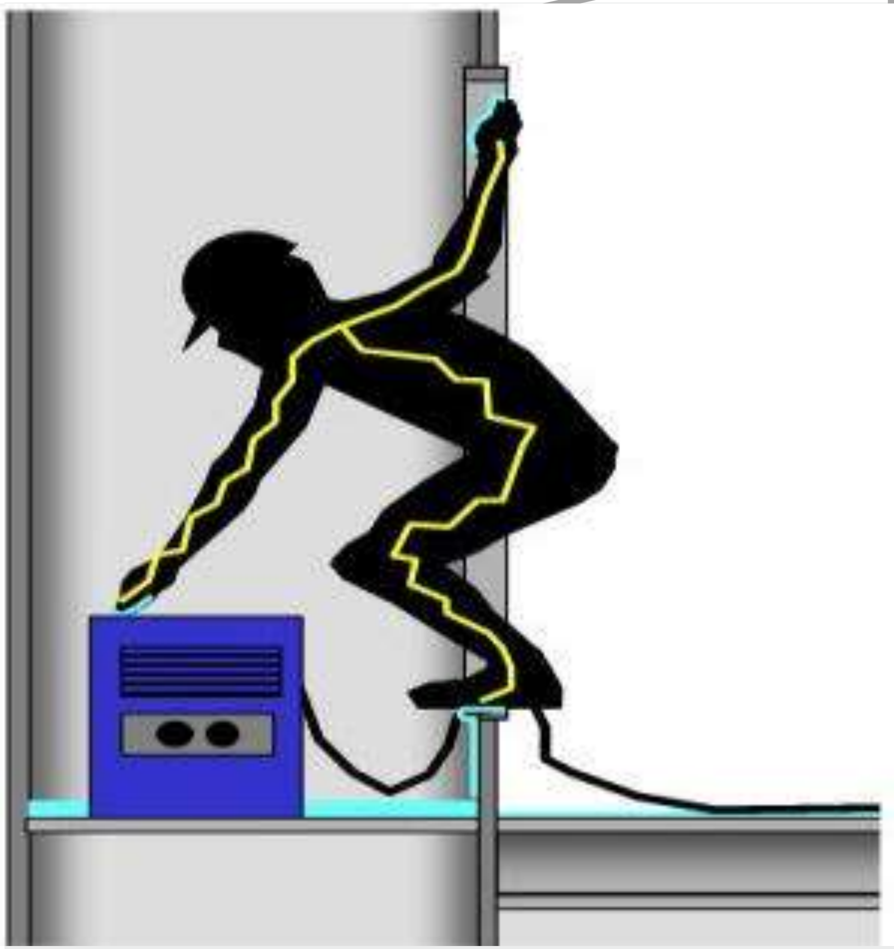
- The most common source of electrical current hazards is the high contact voltage due to the failure of the electrical insulator and the direct contact of the conductors under voltage.

- <u>Causes during welding</u>

-overlook the potential hazards in the working environment,

-carelessness during welding,

-use of unsafe welding equipment



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Electric shock

There are three negative effects of electric current on people:

- Physiological effect - which causes muscle trembling, failure of the nervous system, cardiac arrest.
- Chemical effect - which causes the disintegration of cellular fluids and blood.
- Heat effect - which causes burns.

Current	Effects
< 1 mA	No sensation; probably not notice
1 - 3 mA	Mild sensation not painful
3 – 10 mA	Muscular control could be lost or muscle clamping
30 – 75 mA	Respiratory paralysis
75 mA - 4 A	Ventricular Fibrillation
over 4 A	Tissue begins to burns. Heart muscles clamp and heart stops beating

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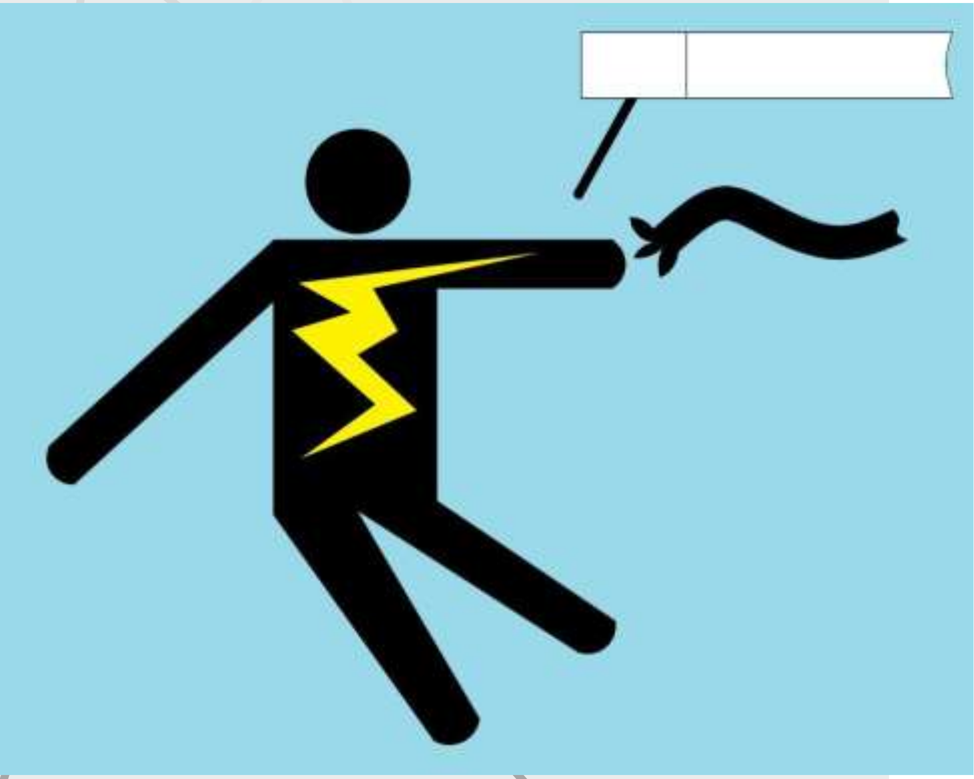
Electric shock–causes during welding

Electric shock occurs when the human body becomes part of the electric circuit. Some causes for electric shock during welding are:

- Replacing the welding electrode with bare hands without switching off the welding transformer.
- Accidentally touching the exposed conductor of the electrode holder, or the welding electrode which is connected to the electrode holder.
- Sitting or leaning on the welding workpiece, such as large machinery, steel structure and steel tanks, etc. which is connected with the welding return cable.
- Lying on the floor to weld the underside of workpiece. Staying on flooded ground to carry out welding work

Electric shock



- To enhance the safety of welding work and to prevent electric shock, the following areas should be looked into :

- Working environment ,
- Working practices ,
- Welding equipment,
- Personal protective equipment,

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UV and heat radiation

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Radiation - definition, effects

- Radiation is electromagnetic energy given off by the arc or flame that can injure eyes and burn skin. An operator sees visible light radiation. However, he does not see ultraviolet or infrared radiation. Radiation is often silent and undetected, yet injury occurs. Have all users learn about the effects of radiation.
- The effects of radiation depend on the wavelength, intensity, and length of time one is exposed to the radiant energy. Although a variety of effects is possible, the following two injuries are most common:

- Skin burns.
- Eye damage.

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Radiation-nonionizing

- Nonionizing radiation:
- ultraviolet(UV-A/B/C)
- visible light,
- infrared(IR)

- Intensity and wavelength of energy produced depend on the process, welding parameters, electrode and base metal composition, fluxes, and any coatings or plating on the base material.

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Radiation - protection

- Use welding helmet with correct shade of filter plate.
- Protect exposed skin with adequate gloves and clothing.
- Be aware of reflections from welding arcs, and protect all persons from intense reflections.
- Locate welding operations so that other workers are not exposed to either direct or reflected radiation.
- Wear safety glasses with UV protective side shields in addition to a proper welding helmet with filter plate

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Eye hazards

- The major eye and face hazards during welding and cutting include:

- arc and heat rays,
- flying metal,
- slag from chipping,
- dirt, and particles from grinding.

- Because these hazards are so common in welding and cutting environments, proper selection and consistent use of eye and face protection are vital to avoid injury and blindness.

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Eye hazards – how to avoid

- Depending on the specific work task, appropriate eye/face protection may include safety glasses with side protection (side shields or wrap-around frames), goggles, face shields, welding helmets, curtains, or combinations of the above
- Always wear safety glasses with top and side protection under your welding helmet.
- Keep eye and face protectors in place whenever the hazards are present. Not using them is the main cause of eye injury.
- Use the correct shade of filter in your welding helmet or goggles.
- Be sure eye protection devices are not damaged or missing parts, and be sure they fit properly.

Burns and fires

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Burns and fires in welding

- Welding-related fires are very common. In the worst cases, welding-related fires result in debilitating burns, blindness, or even death. To safeguard property and welding personnel from fires, it is important that all welders familiarize themselves with potential fire hazards and safety practices.

Burns and fires in welding

Safety tips that can reduce fire hazards:

1.Investigate surroundings before welding begins, (the welder should investigate and clear the welding area and their surroundings *prior* to welding)

2.Keep flammable materials far from welding areas, (the sparks and expulsion of molten metal produced by welding can travel up to 10 meters)

3. Cover holes and cracks (flying sparks and molten metal can lodge cracks, pipe holes, and other small openings in floors and partitions)

4. Always wear the appropriate personal protection equipment (Welders are directly exposed to flying sparks and molten metal. Synthetic clothing should be avoided because they are easier to ignite)

5. Always keep a fire extinguisher nearby

(When utilized, portable fire extinguishers effectively eliminate 80% of fires)

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Welding fumes

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Welding fumes

- The welding process produces visible smoke that contains harmful metal fume and gas by-products.
- Fumes are produced when a metal is heated above its boiling point.

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Welding fumes

- What is in welding fume?

Metals: Aluminum, Antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Molybdenum, Nickel, Silver, Tin, Titanium, Vanadium, Zinc.

Gases

Shielding—A rgon, Helium, Nitrogen, Carbon dioxide.

Process— Nitric oxide, Nitrogen dioxide, Carbon monoxide, Ozone, Phosgene, Hydrogen fluoride, Carbon dioxide.

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Welding fumes

Hazardous gases are genereted by:

- Gases used for arc shielding,
- Heat produced from UV radiation,
- Welding flame and the electric arc,
- Decomposition of solvents, paints and coatings on welded metals

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Welding fumes – respiratory hazards

Effects on inhaling fumes and gases depend on:

- Welding process,
- Current and arc,
- Composition of the base and filler materials,
- Ventilation system in the workshop,
- Welder‘s personal protection,
- Amount of exposure time,
- Paints and coatings.

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Welding fumes – respiratory hazards

- Acute exposure to welding fume and gases can result in eye, nose and throat irritation, dizziness and nausea. Workers in the area who experience these symptoms should leave the area immediately, seek fresh air and obtain medical attention.
- Prolonged exposure to welding fume may cause lung damage and various types of cancer, including lung, larynx and urinary tract.
- Health effects from certain fumes may include metal fume fever, stomach ulcers, kidney damage and nervous system damage.

Welding fumes – respiratory hazards

- Gases such as helium, argon, and carbon dioxide displace oxygen in the air and can lead to suffocation, particularly when welding in confined or enclosed spaces. Carbon monoxide gas can form, posing a serious asphyxiation hazard.

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Noise hazards

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Noise hazards

Noise that is too loud can cause several physical problems:

- Damage to parts of the ear or permanent hearing loss
- Headache
- Nausea
- Upset stomach
- Difficulty sleeping
- Psychological stress
- High blood pressure
- Increased abnormal heart rate

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Noise hazards

- The level of noise and the length of time you listen to the noise can influence the severity of hearing loss.
- It is important that all welders take precautions against noise.
- Welders should:

- Know which noises are above 85 dB,
- Limit time spent at the noise source,
- Wear hearing protective devices,
- Know the warning symptoms of noise-induced hearing loss

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Personal protective equipment and clothing

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Personal protective equipment and clothing

- Welding and cutting can produce hazards such as sparks, spatter, radiation (infrared, ultraviolet, and blue light), slag, heat, hot metal, fumes and gases, and even electric shock. Since these hazards may cause burns, injury, or death, it is important to wear proper PPE at all times.
- Eye and face protection (Helmet with filter lens and cover plate) .
- Head and ear protection. (A fire-resistant welder's cap or bandana and earplugs or muffs).
- Foot protection (A leather, steel-toed, high-topped boots in good condition)
- Hand protection (Dry, hole-free, insulated welding gloves in good condition).
- Body protection.(Oil-free protective clothing made of wool or heavy cotton).
- Respiratory protective equipment.( )

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Personal protective equipment and clothing

Protect all areas of your body from injury during welding or cutting by wearing the proper protective clothing and equipment.

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Useful Topic Related Links

https://osha.europa.eu/en/safety-and-health-legislation

http://www.hse.gov.uk/welding/index.htm

https://www.youtube.com/watch?v=QQyuSoBVins

https://www.youtube.com/watch?v=CUrt0h-Hnqs

https://www.youtube.com/watch?v=MVrI2kuRKdA

https://awo.aws.org/online-courses/safety-in-welding/

EN 60974-1:2012, Arc welding equipment. Welding power sources

EN 166:2002, Personal eye protection. Specifications

EN 169:2002, Personal eye-protection. Filters for welding and related techniques. Transmittance requirements and recommended use

BS EN 60974-10:2014+A1:2015, Arc welding equipment. Electromagnetic compatibility (EMC) requirements

EN ISO 11611:2015, Protective clothing for use in welding and allied processes

BS EN ISO 15011-1:2009, Health and safety in welding and allied processes. Laboratory method for sampling fume and gases. Determination of fume emission rate during arc welding and collection of fume for analysis

BS EN ISO 15012-1:2013, Health and safety in welding and allied processes. Equipment for capture and separation of welding fume. Requirements for testing and marking of separation efficiency

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