Aalto University
School of Engineering

Department of
Mechanical Engineering

Introduction to Welding Technology

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Contents

Summary

- ✓ Definition of welding
- ✓ Introduction and scope of welding technology
- ✓ Joining mechanisms governing welding technology
- ✓ Historical milestones of welding technology and allied techniques
- ✓ Introduction to fusion welding processes
- ✓ Introduction to brazing/soldering processes
- ✓ Introduction to solid-state welding processes with focus on friction based technology and applications
- ✓ Samples of advanced welding solutions
- ✓ Fundamental nomenclature
- ✓ Introduction to weldability concept

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Learning Outcomes

At the end of the seminar the student should be able to

1. To identify the multiphysical character of welding technology
2. To classify the main joining mechanisms in welding technology
3. To distinguish between fusion, brazing and solid-state welding
4. To identify main historical milestones of welding technology
5. To identify main fusion welding processes
6. To identify main solid-state welding processes
7. To describe the weldability concept

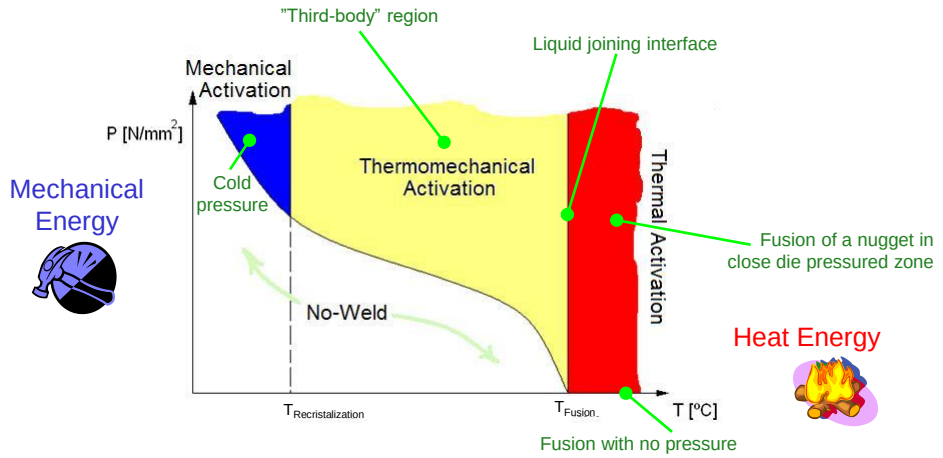
What is…?

☞**(def.) welding -** A joining process that produces coalescence of materials by…

- Applying energy: heating (Heat Energy) them to the welding temperature, **with/without** application of pressure (Mech Energy) **or** by the application of pressure alone (Mech Energy)
- **With/without** the use of filler metal
- **With/without** the use of shielding gas

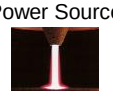
What is…?

WELDING



What is…?

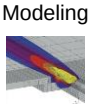
Physical / Chemical Power Sources



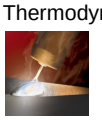
Material Science

Where *Science*

Computational Modeling



Fluid Mechanics Thermodynamics



Electrical Equipment Electronic Control

Manual Skills

and *Art*

Creativity

Innovation

WELDING

and *Business*

Product Development
Production Management
Quality Systems

meet *Technology*

Automation and Robotization

Structural Mechanics

Welding Technology

The Scope

know-how

products

Science

Application

Welding is supported by..

Fundamental Science

…and is **Attractive**

…. and **Welding** is focused on

Practical Application

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Welding Technology

The Scope… Among other joining technologies

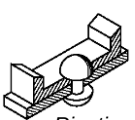
Adhesive Technology

(e.g.: epoxy; polyurethane...)

Technologies for Joining of Materials

Welding

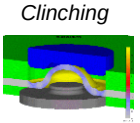
Mechanical Joints



Riveting

Threaded

Clinching



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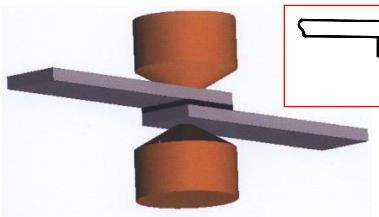
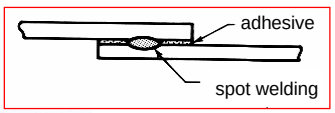
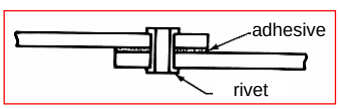
Introduction to Welding

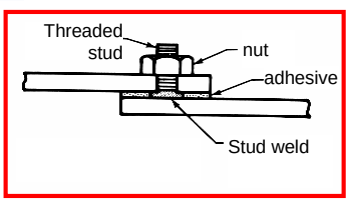
Hybrid Concepts… Are Becoming Frequent Solutions

e.g.: weld bonding









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Introduction to Welding

Related Technology… Thermal Spraying Techniques

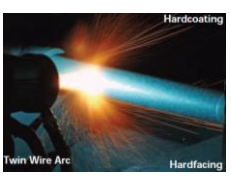
(def.) **Coating processes** in which melted /heated materials are sprayed onto a surface

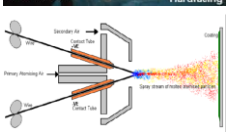
Plasma spraying (PSP)

P_{atm}

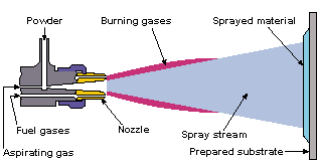
Vacuum

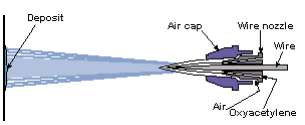
Arc spraying (ASP)





Flame spraying (FLSP)





Thermal spraying can provide thick coatings [20μm .. to several mm], over a large area at high deposition rate as compared to other coating processes such as: electroplating, physical and chemical vapor deposition

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Introduction to Welding

Related Technology… Cutting Techniques

Mechanical cutting

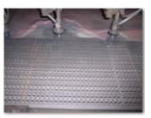
Thermal cutting

Water jet cutting

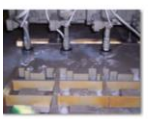
Custom Waterjet Cut Gears

Customized Movie Ticket Window

1.25 Inch Corten Steel Gear Waterjet Cut



10 ga Steel Waterjet Cut



2 Inch 4130 Steel Waterjet Cutting

Waterjet Cut Grid

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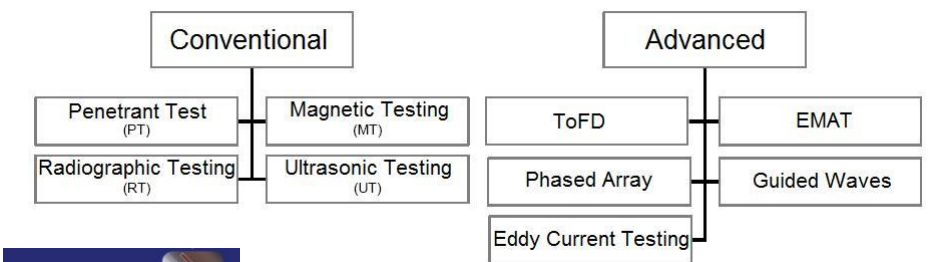
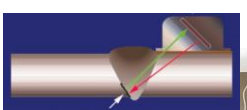
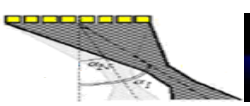
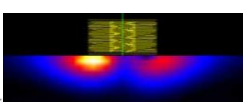
Introduction to Welding

Related Technology… NDT Techniques









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Introduction to Welding

Classification… but many others exists

Welding Process Classification

Fusion Welding

- ✓ Includes partial fusion of Base Material, with /without application of pressure, with/without filler metal added to weld pool

Brazing and Soldering

- ✓ No fusion of base material components which are joined by inserting melted filler metal in the overlap joint configuration

Solid State Welding

- ✓ Joining is obtained by solid state joining mechanisms
- ✓ In some processes, superficial melting layer is produced to then be expelled during forging
- ✓ Flash around weld zone is usual

Note: There are (many) others possible classifications

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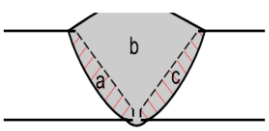
Introduction to Welding

Dilution Rate… Formulation Supporting the Classification

- ☞ Autogeneous – No filler material
- ☞ Homogeneous – Filler metal similar to base material
- ☞ Heterogeneous – Filler metal dissimilar to base material



% Base Metal Dilution =

$$\frac{a + c}{a + b + c} \times 100\%$$

Dilution rate [DR] – (Def.) Contribution of Base Material into Weld Metal. Where the Weld Metal is made of Base Materials + Filler Metal:

- ✓ DR = 0 to 100 %
- ✓ DR = 0 % - Brasing and soldering
- ✓ DR = 100 % - Autogeneous conditions

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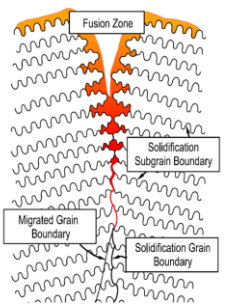
Joining Mechanism

…in Fusion Welding

☞**Epitaxial Solidification by Nucleation and grain growth**

- Oriented (e.g. epitaxial) grain growth
- Segregation of elements into last zone solidifying (middle of fusion zone), that may promote nucleation effect
- Space between dendrites
- Cooling rate (e.g. welding parameters)
- Shape factor (penetration/width)

Fusion Zone Boundaries

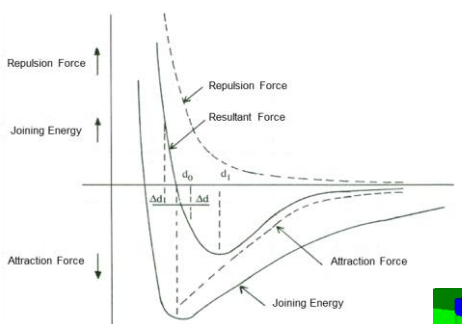


- Three types of boundaries
- Boundaries are distinguishable metallographically

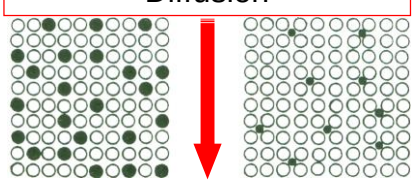
Joining Mechanisms

…Activated During Solid State Welding

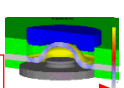
Aproximation to Interatomic Distances of Equilibrium → Atomic bonding at joining materials interfaces



Diffusion



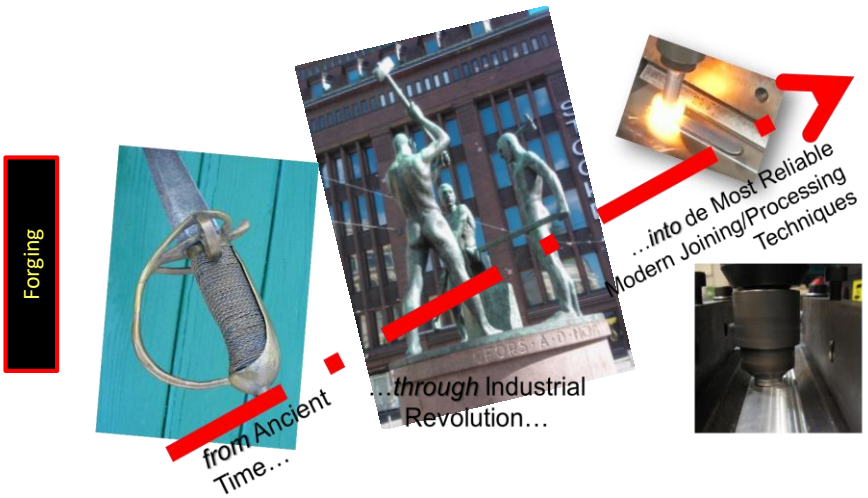
Bonding over an interferential layer which can reach up to continuous metallic conditions



Clinching → Mechanical interference

Solid State Welding

From the Origins into the Most Developed Modern Solutions



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Fusion Welding

Electric Arc Based Welding

✓ **Overview of Techniques**

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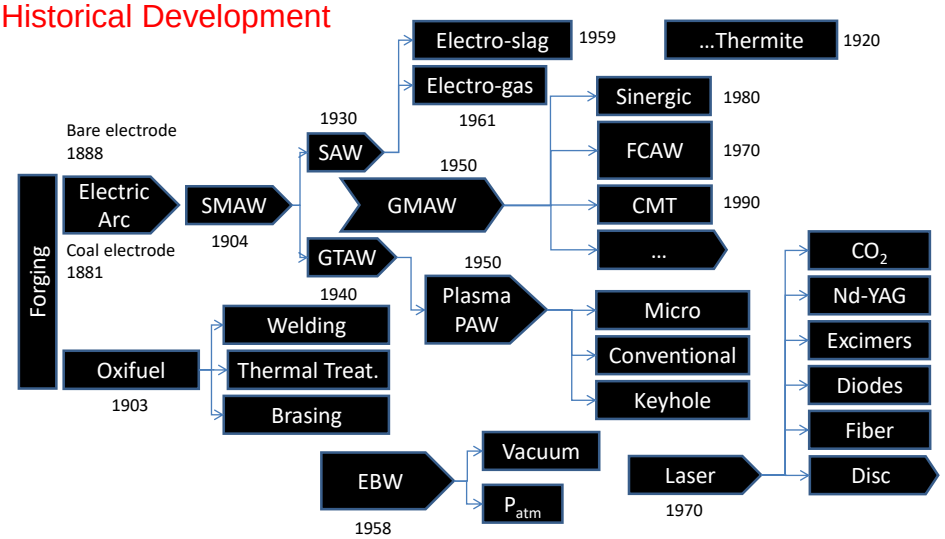
Fusion Welding Technology

Historical Development



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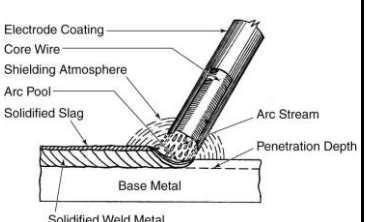
Milestones of Electric Arc Welding (1/4)

Shielded Metal Arc Welding



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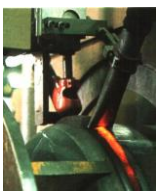
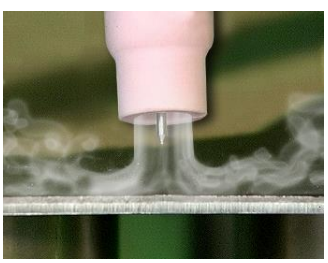
Milestones of Electric Arc Welding (2/4)

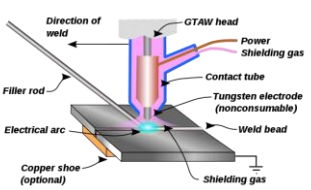
Submerged Arc Welding



Milestones of Electric Arc Welding (3/4)

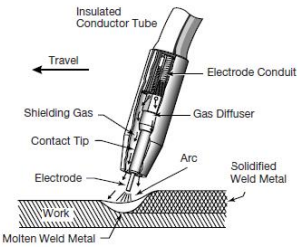
Gas Tungsten Arc Welding





Milestones of Electric Arc Welding (4/4)

Gas Metal Arc Welding



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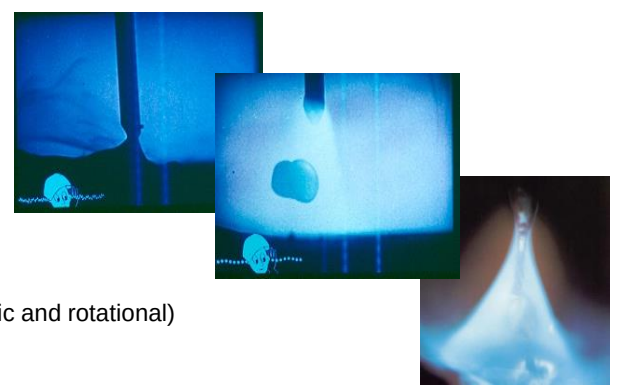
Variants of GMAW

Most Significant Transfer Modes

- **Short-circuit**
- **Globular**
- **Spray** (Axissymmetric and rotational)
- **Drop-spray** (axial spray of drop by drop in pulse current)



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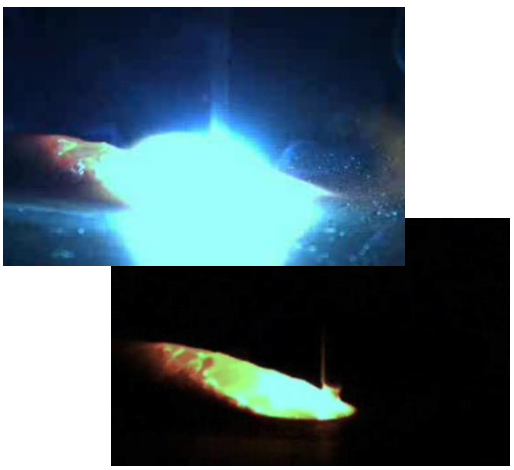
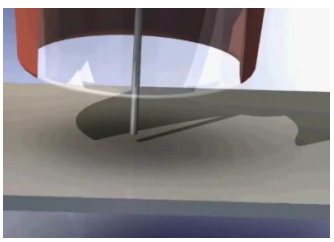
Variants of GMAW

Advanced Short-Circuit Transfer Mode: **C**old **M**etal **T**ransfer

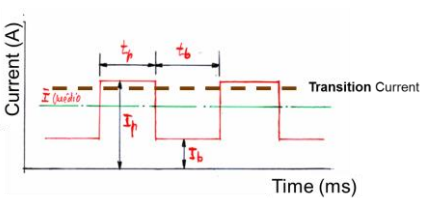




✓Oscillating wire process – wire advances and retracts at 66 Hz

Variants of GMAW

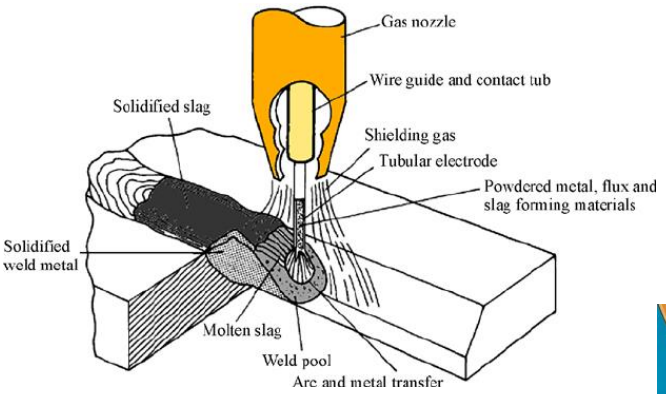
Drop-Spray Transfer Mode + Synergic Control



$$I_m = \frac{I_p t_p + I_b t_b}{t_p + t_b} \qquad HI = \eta \frac{V \cdot I_m}{v}$$

Variants of GMAW

Flux Cored Arc Welding



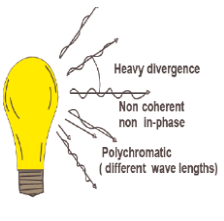
Fusion Welding

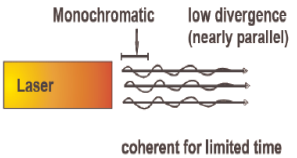
Laser Welding

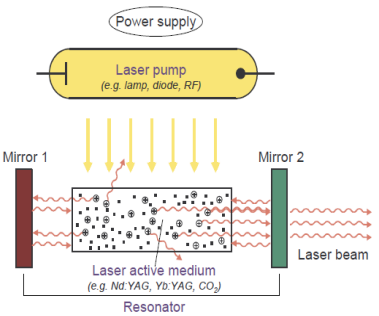
✓ **Overview of Fundaments**

Characteristics of a Laser Beam

Light
Amplification
Stimulated
Emission
Radiation







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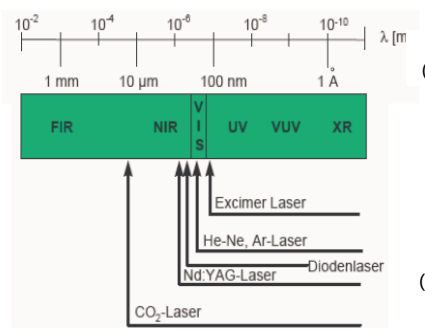
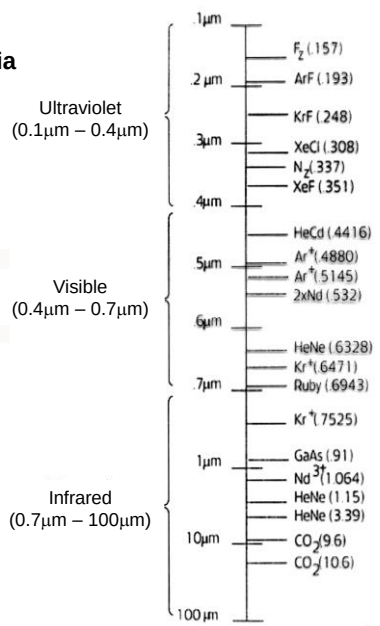
Wavelength of main active laser media

- Nd:YAG (Rod Laser) λ = 1064 nm
- Yb:YAG (Disc Laser) λ = 1030 nm
- CO_2 (Gas Laser) λ = 10600 nm





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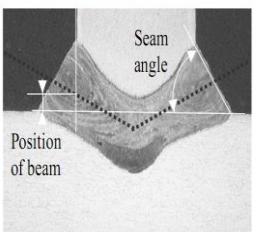
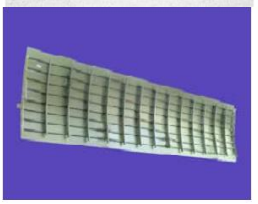
Continuous Wave Laser Welding Applications





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Fusion Welding

Electron Beam Welding

✓ Overview of Fundaments

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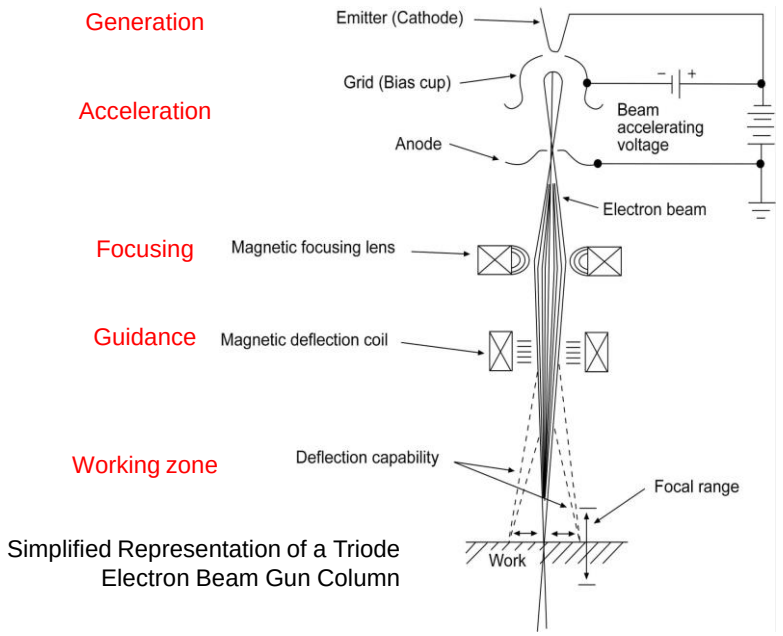

Simplified Representation of a Triode Electron Beam Gun Column

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- **Equipment:** Level of Vacuum in Gun and Working Cameras

High-vacuum chamber equipment for EBW

Variants:

✓ **High-Vacuum**: 10^{-3} to 10^{-6} Torr

✓ **Fine-Vacuum**: 25 to 10^{-3} Torr

✓ **Non-vacuum** (1 atm ≈ 760 Torr)

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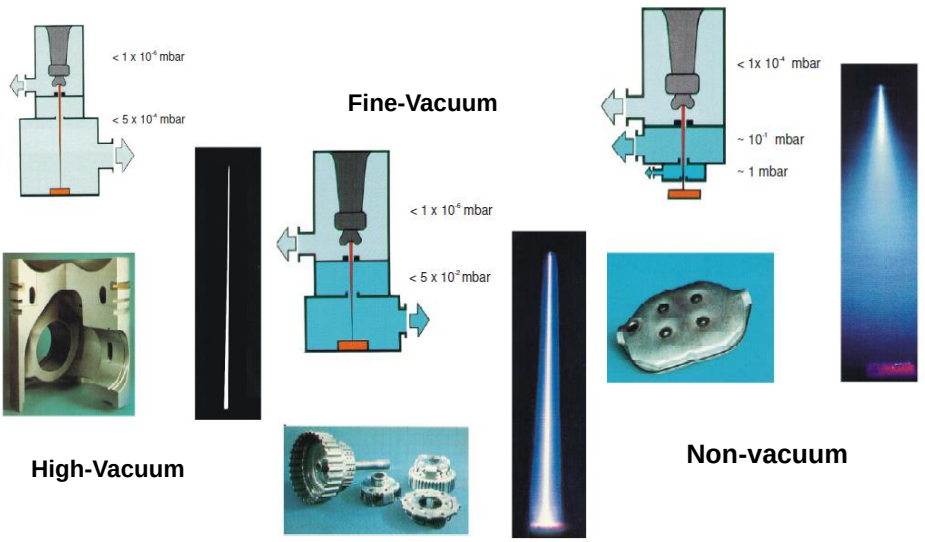
- **Equipment:** Influence of Level of Vacuum in EBW quality.



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Fusion with Pressure Welding

Resistance Welding

✓ Overview of Variants

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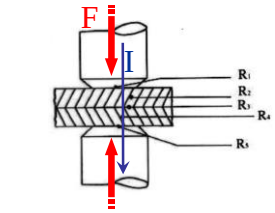
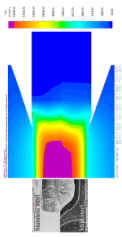
Resistance Welding

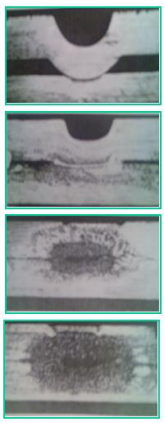
Fusion but not only… Resistance Welding Variants

Spot Welding

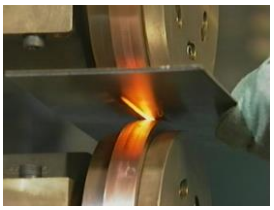




Projection Welding



Seam Welding



Flash Welding

Brasing and Soldering

Interfacial Joining of Solid Base Materials by Third-body Fusion Filler Material

Brasing and Soldering

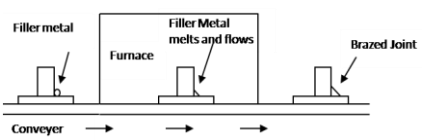
Parameter	Process	
	Soldering	**Brazing**
Joint formed	Mechanical	Metallurgical
Filler metal melt temperature, °c (°f)	<450 (<840)	>450 (>840)[a]
Base metal	Does not melt	Does not melt
Fluxes used to protect and to assist in wetting of base-metal surfaces	Required	Optional
Typical heat sources	Soldering iron; ultrasonics; resistance; oven	Furnace; chemical reaction; induction; torch; infared

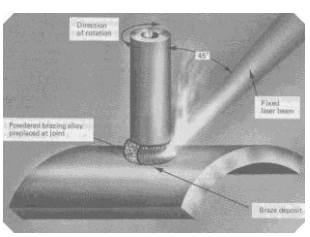
Brazing and Soldering

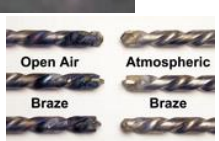
Fundaments and Application Samples

☞ **Joining Mechanisms:** Interfacial Diffusion (chemical) and/or Embedding (mechanical)

☞ **Physical Principles:** capillary (wetting and spreading) + fluidity + viscosity + vapor pressure + gravity + metallurgical interaction between Base Mat and Filler Mat







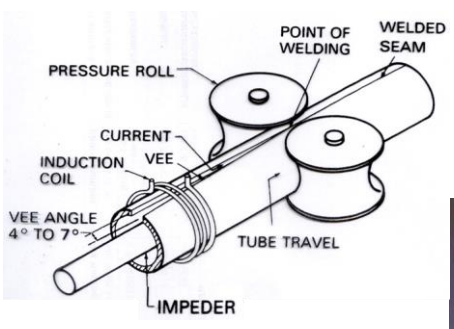
Solid State Welding and Processing Technology

Solid State Welding

✓ **Overview of Main Processes**

Overview of Solid-State Processes

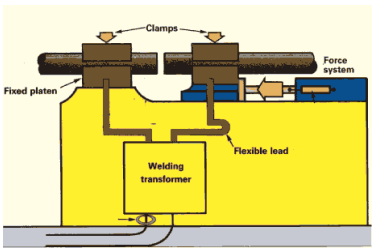
High-Frequency Welding



Sample of Frequency Ranges:
100kHz - 800kHz

Overview of Solid State Processes

Flash Welding



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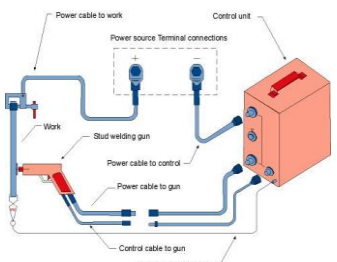
Overview of Solid State Processes

Stud Welding



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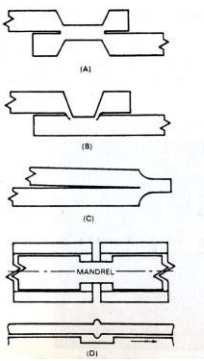
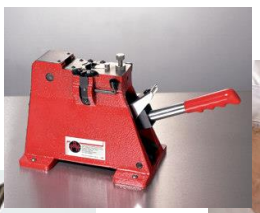
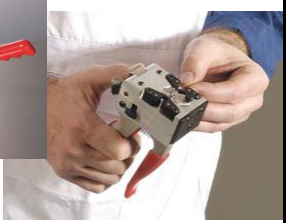
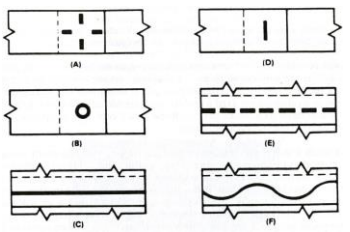
Overview of Solid State Processes

Cold Pressure Welding





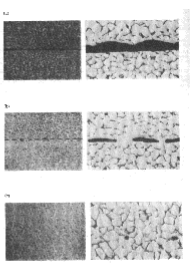




Overview of Solid State Processes

Diffusion Welding

- Initially only asperities in contact
  - pressure application causes metal-metal contact
- material diffuses across junctions
  - contact regions grow
- porosity is eventually reduced to very low levels



Bonding of Ti-alloy at 925°C

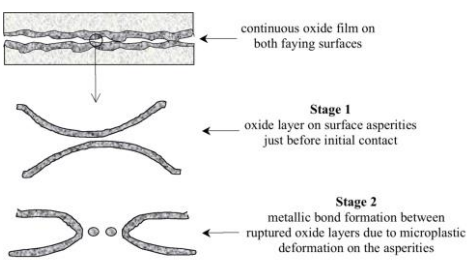
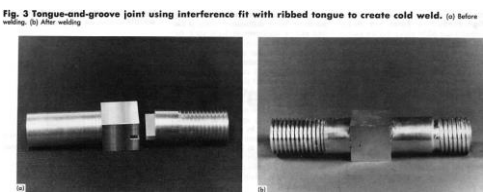
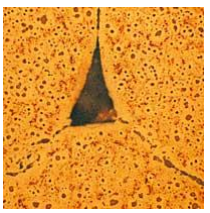


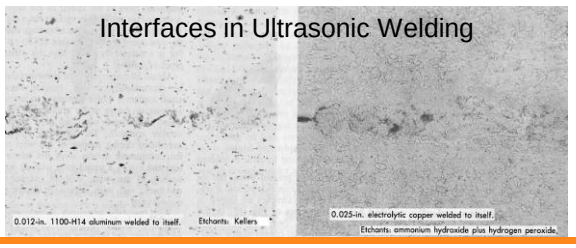
Fig. 3 Tongue-and-groove joint using interference fit with ribbed tongue to create cold weld. (a) Before welding. (b) After welding



Overview of Solid State Processes

Ultrasonic Welding





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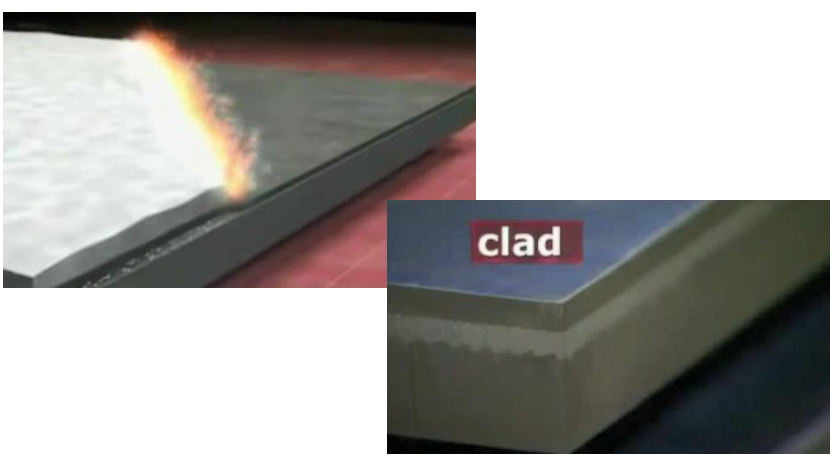
Overview of Solid State Processes

Explosion Welding



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Solid State Welding and Processing Technology

Friction Based Technology

✓ **"Third-Body" Region**

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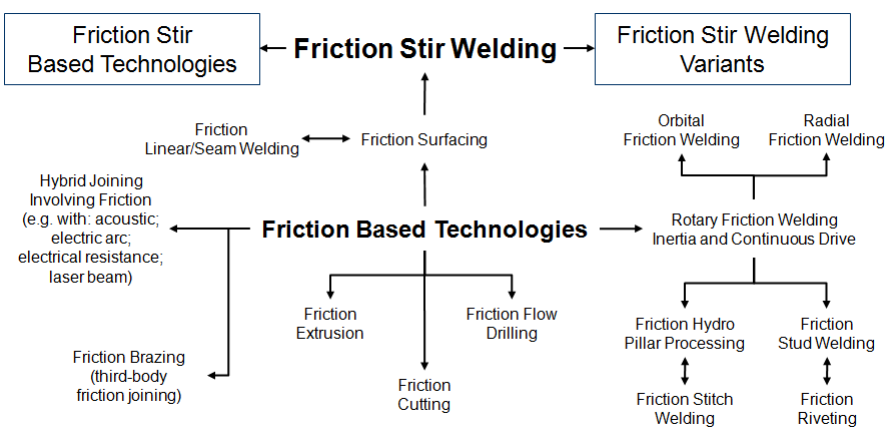
"Third-Body" Region Based Technology



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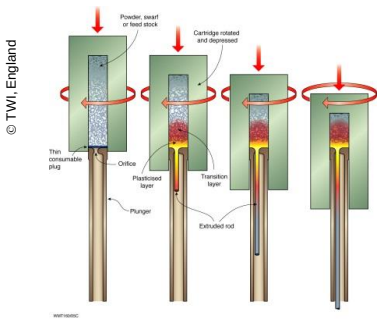
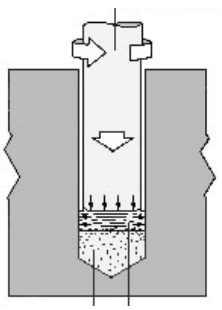
Friction Based Technology

Sample of Processes

Friction Extrusion



Friction Hydro Pillar



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Friction Based Technology

Sample of Processes

Friction Welding

Internacional Patent
2/1956 (A.I.Chudikov)

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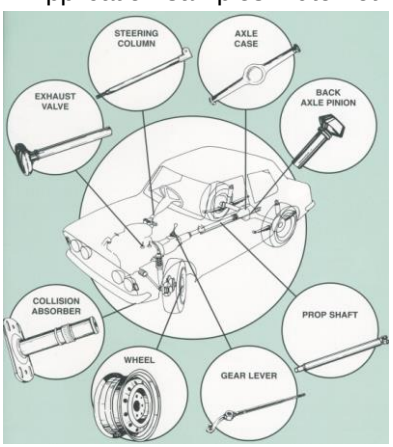
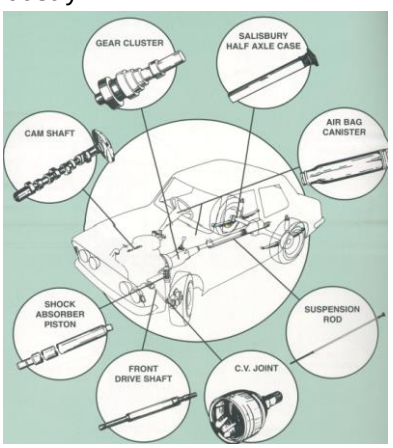
Overview of Solid State Processes

Friction Welding

☞ Application samples: Automotive industry

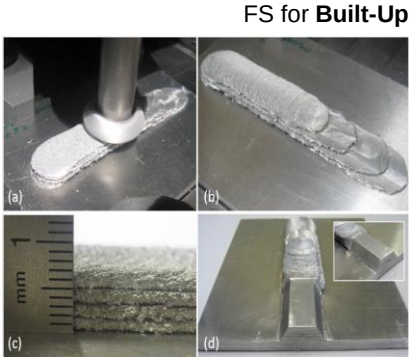




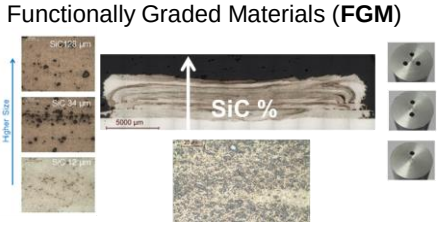
Friction Stir Based Technology

Friction Surfacing: Applications

FS for **Built-Up**



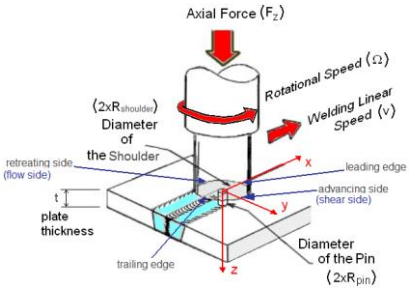
Production of
Functionally Graded Materials (**FGM**)



Overview of FSW Features

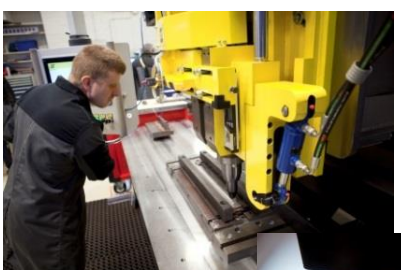
Fundaments and Parameters

☞ A breakthrough innovation in welding technology since 1995



Materials Joining and NDT

FSW @ Aalto University



☞ ESAB LEGIO™ FSW 5UT

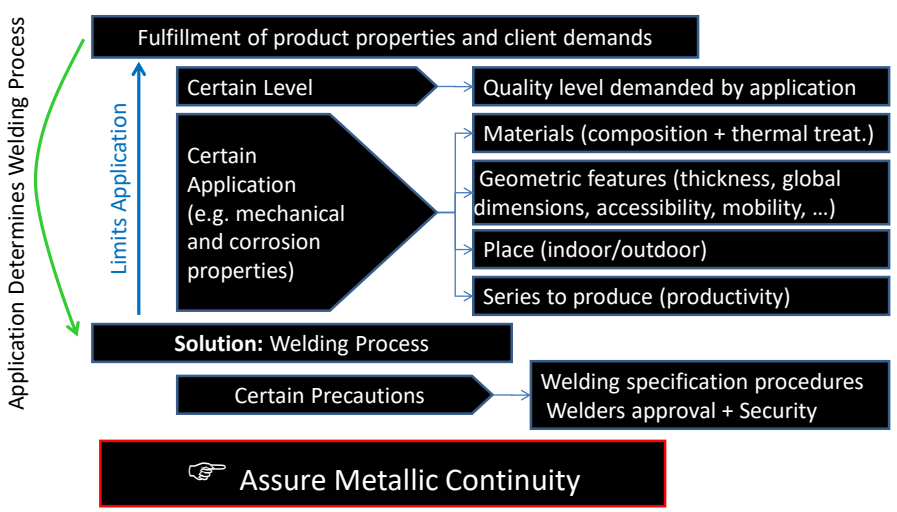
- Z-axis Control: Position + Speed + Force
- Maximum Forces: F_{z_max} = 100kN (F_{x_max} = F_{y_max} = 40kN)
- Maximum Welding Travel Speed: V_{x_max} = V_{y_max} = 4m/min
- Maximum Spindle Power = 30kW ; Maximum Spindle Speed: Ω_{max} = 3000rpm
- Work Envelope (x ; y ; z) : 2000mm x 400mm x 300mm
- Special focus on the application to: Al, Cu, HSSteels, SSteels, and Ni based alloys

Other Advanced Welding Techniques

- A-Tig Welding
- Micro-Plasma Welding
- Hot-Wire Welding and Coating
- Narrow Gap Welding (w/ TIG hot wire; MIG; SAW)
- Advanced SAW: ICE Variant
- Advanced GMAW: Synergic Control + CMT + 3D Printing
- Hybrid Laser Welding with GMAW
- Friction Stir Based Innovations: FSChannelling + FSpot Welding
- Friction Welding (conventional axisymmetric)
- Friction Based Techniques: FHydro Pillar + FRiveting
- Friction Surfacing

Weldability Concept

Towards the Correct Welding Technological Solution



Weldability Concept

Towards the Correct Welding Technological Solution

☞ Assure Metallic Continuity

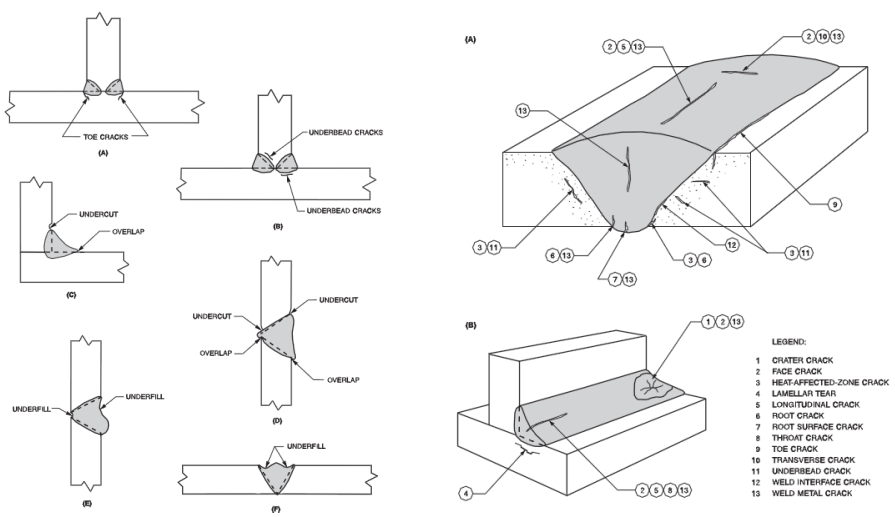
☞ Design of joints and their influence on the overall quality of the welded structure

- Type of joints
- Type of edge shape for each component
- Tolerances
- Design of joints criterion, depends on:
  - *Welding process*
  - *Material*
  - *Thickness of components*
  - *Joint accessibility*

☞ e.g.: Stress Flow in complete penetration butt joint

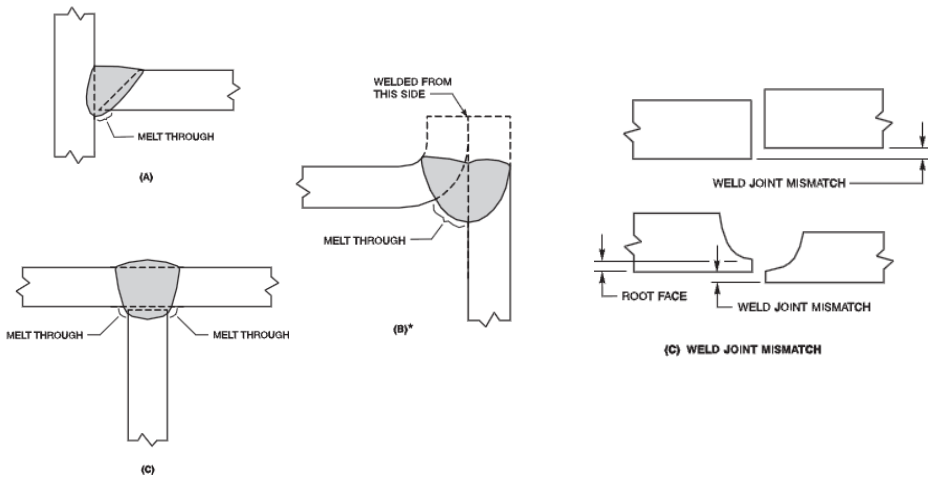
Defects in Fusion Welds

Basic Nomenclature



Defects in Fusion Welds

Basic Nomenclature



References

Literature supporting the achievement of the learning outcomes

1. J. F. Lancaster (1986) *The Physics of Welding*", 2nd ed., Pergamon Press.
2. Robert W. Messler (2004) Principles of Welding – Processes Physics, Chemistry, and Metallurgy, Jr. Wiley-VCH ed.
   - Chapter 1: Introduction to the Process of Welding (pages 1–16)
   - Chapter 5: Energy for Welding
   - Closing Thoughts

Other references

- ✓ ASM Metals Handbook – Vol. 6 – Welding Brazing and Soldering. 1993. ASM International.
- ✓ AWS Welding Handbook – Vol. 1 to 4 –9th ed. American Welding Society.