

Department of Materials Science and
Engineering



Welding



M Ű E G Y E T E M 1 7 8 2

Welding

1. Introduction

The various types of joints can be classified as shown in **Figure 1**. In terms of joint strength, joints that create continuity within the material itself are the strongest. Within this category, adhesive joints rely on adhesion; soldered joints involve adhesion combined with a diffusion layer; and welded joints rely on cohesion. Consequently, a properly executed weld yields the highest joint strength (and, not least, the highest operating temperature), as a primary metallic bond is formed between the parts being joined.

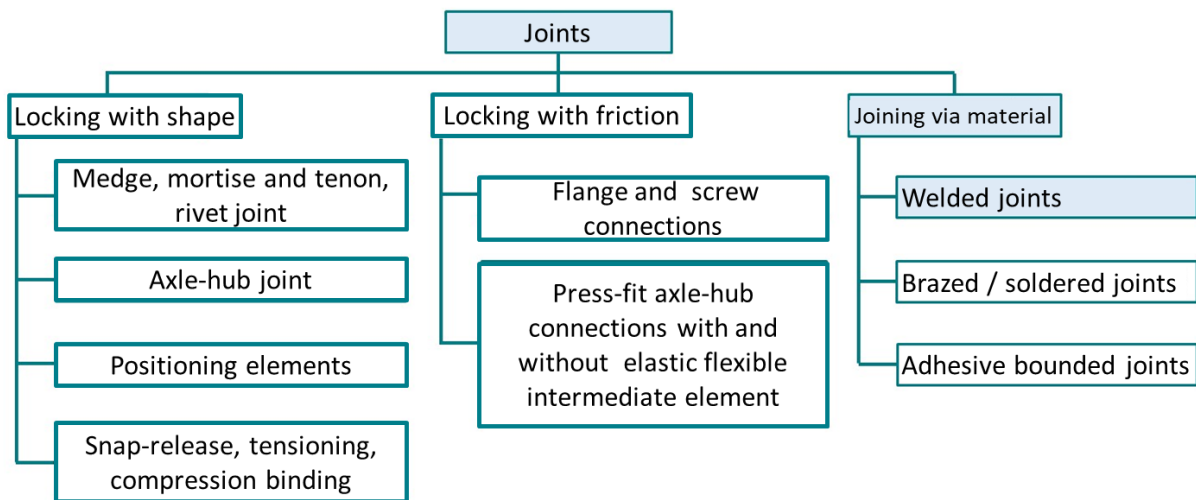


Figure1. Classification of bond types

Metallic bonding involves the transfer of valence electrons into a shared electron cloud; consequently, forming such a bond requires bringing the surfaces to be joined within the distance of a lattice parameter. The surface roughness of even a very finely (so, at a very high price) machined surface is in the micrometer range, whereas the lattice parameters of metallic elements fall within the nanometer range. Thus, during welding, a gap of at least three orders of magnitude resulting from surface roughness must be bridged.

If this problem is solved by melting the surfaces and allowing the resulting melt to crystallize between the new interfaces, the process is referred to as **fusion welding**; if, however, it is achieved through significant plastic deformation (compression) of the surfaces, it is termed **solid state** (pressure) **welding** (**Figure 2**). Pressure welding requires extensive plastic deformation of the surfaces (150–200%).

Solid state welding processes can be further categorized based on whether the welding takes place below or above the recrystallization temperature. Naturally, increasing the temperature reduces the force required for pressing the parts together (**Figure 2**) and enables the materials to be welded that are incapable of undergoing the necessary extensive deformation at room temperature.

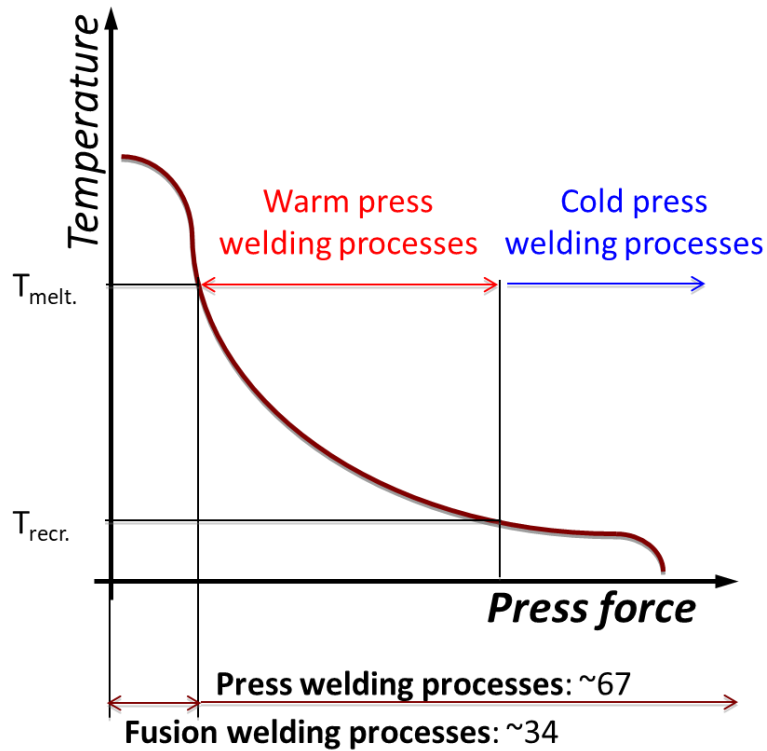


Figure 2 Classification of welding processes

Welding processes are typically classified according to the heat source, the filler material used, and the method of weld protection. Standardized names and numerical designations for welding processes are specified in the EN ISO 4063:2023 standard. General terminology regarding welding and allied processes is covered by the ISO/TR 25901-1:2020 pre-standard.

During the laboratory session, students have the opportunity to try out the process most widely used and most highly automated in large scale steel structure manufacturing: the metal active gas welding (MAG-welding).

2. About the welding processes

In Metal Inert Gas (MIG) / Metal Active Gas (MAG) welding (Process Group 13), a continuous arc is initiated between the workpiece and the wire electrodes, which is continuously fed from a spool or drum. The arc melts the surface of the workpiece(s) and the welding wire, thereby forming a weld pool. Active or inert shielding gases may be used to protect the weld. **Figure 3** illustrates the basic configuration of the equipment.

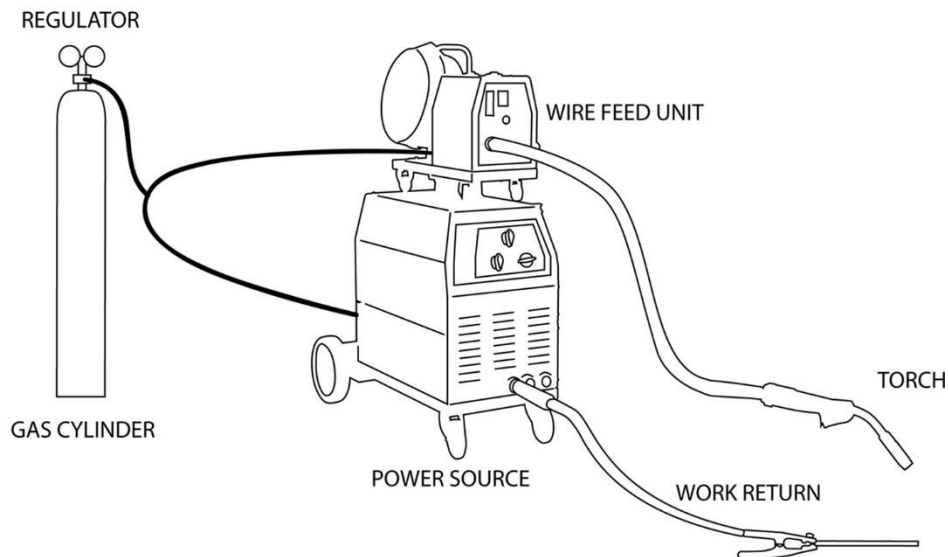


Figure 3. Schematic layout of MIG/MAG welding equipment

*/It should be noted that our laboratories operate with a central gas supply system; before welding, we must verify that the equipment is connected to the mixed gas (Corgon – 82% Ar + 18% CO₂) outlet — always the one on the right — and that the shut-off valve at the rotameter outlet is open (**Figure 4**). Do not alter the gas flow setting; leave this to the laboratory instructors if adjustments are required./* The shielding gases used may be (in accordance with the EN ISO 14175:2008 standard): CO₂ (C1), argon, or a gas mixture of argon and CO₂ (M21); therefore, the designations for the processes may be:

- Metal inert gas welding (131–133) (MIG-welding, derived from the initials of "Metal Inert Gas"). Common shielding gases: argon (Ar) or possibly helium (He).
- Metal active gas welding (135–138) (MAG-
- welding (derived from the initials of Metal Active Gas). Common shielding gases: carbon dioxide (CO₂) and carbon dioxide-argon mixtures.

Abbreviation for US English (131–138)(GMAW derived from the initials of Gas Metal Arc Welding)

Welding consumable: a wire electrode with a chemical composition matched to the base material; it may be solid or flux-cored. Typical electrode diameters are 0.8, 1.0, 1.2, and 1.6 mm. In the case of steel wire, the surface of the electrode wire may be bare (polymer-coated) or coated with copper or bronze.

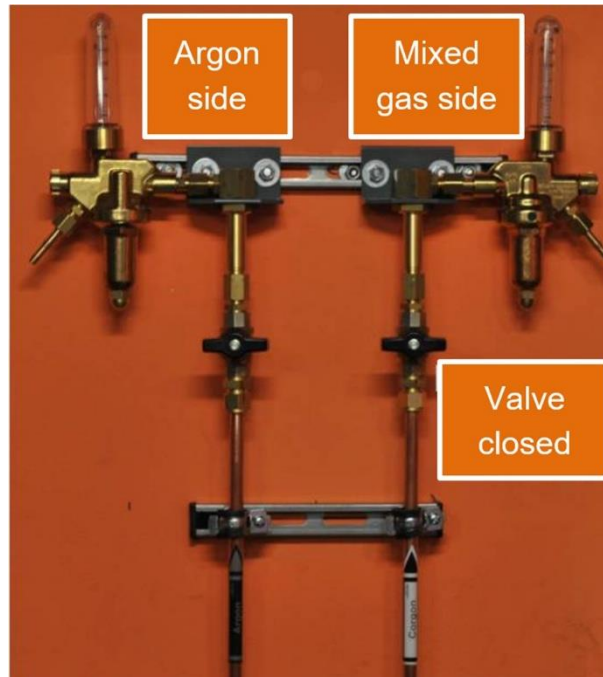


Figure 4 Rotameter-based take-off point for pure Ar and Ar+CO₂ gas mixtures

Figures 5 through 7 provide assistance in correctly selecting welding parameters such as voltage, wire feed speed (which determines the welding current), welding speed, torch distance, and torch angle.

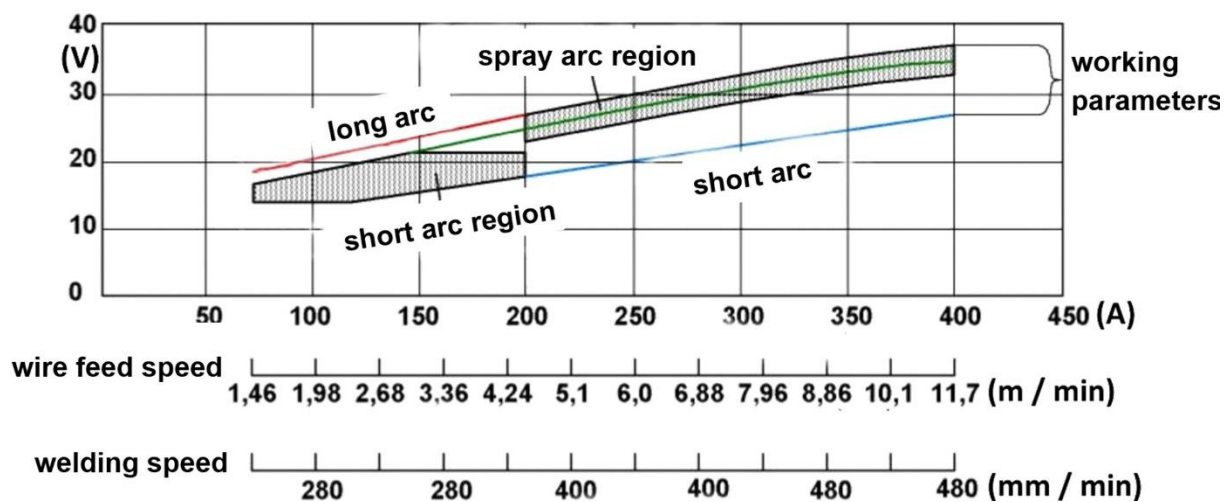


Figure 5 Guide for selecting welding parameters

Arc energy (AE) can be calculated from the welding current, voltage, and welding speed:

$$AE \text{ (kJ/mm)} = \frac{U \text{ (V)} \cdot I \text{ (A)} \cdot 60}{v_{\text{heg}} \left(\frac{\text{mm}}{\text{min}} \right) \cdot 1000}$$

where U is the welding voltage, I is the welding current, and v_{weld} is the welding speed. From this, the heat input (HI) — the amount of heat actually introduced into the material — can be calculated. This is a crucial parameter, as it determines the extent to which the weld and its surrounding area undergo "heat treatment." The heat input is:

$$HI (kJ/mm) = \eta \cdot AE (kJ/mm)$$

where η is typically 0.8 (0.9), depending on the process variant, arc type, and shielding gas.

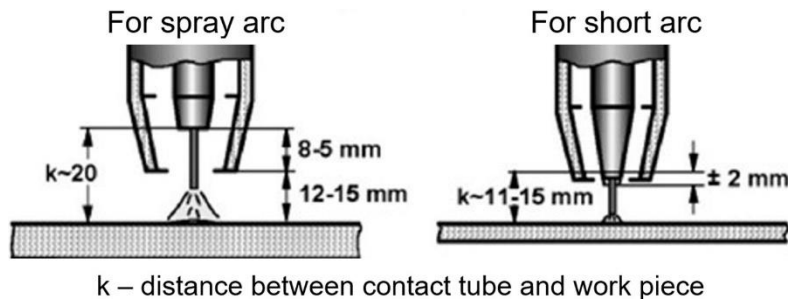


Figure 6 Guide for selecting the correct working distance

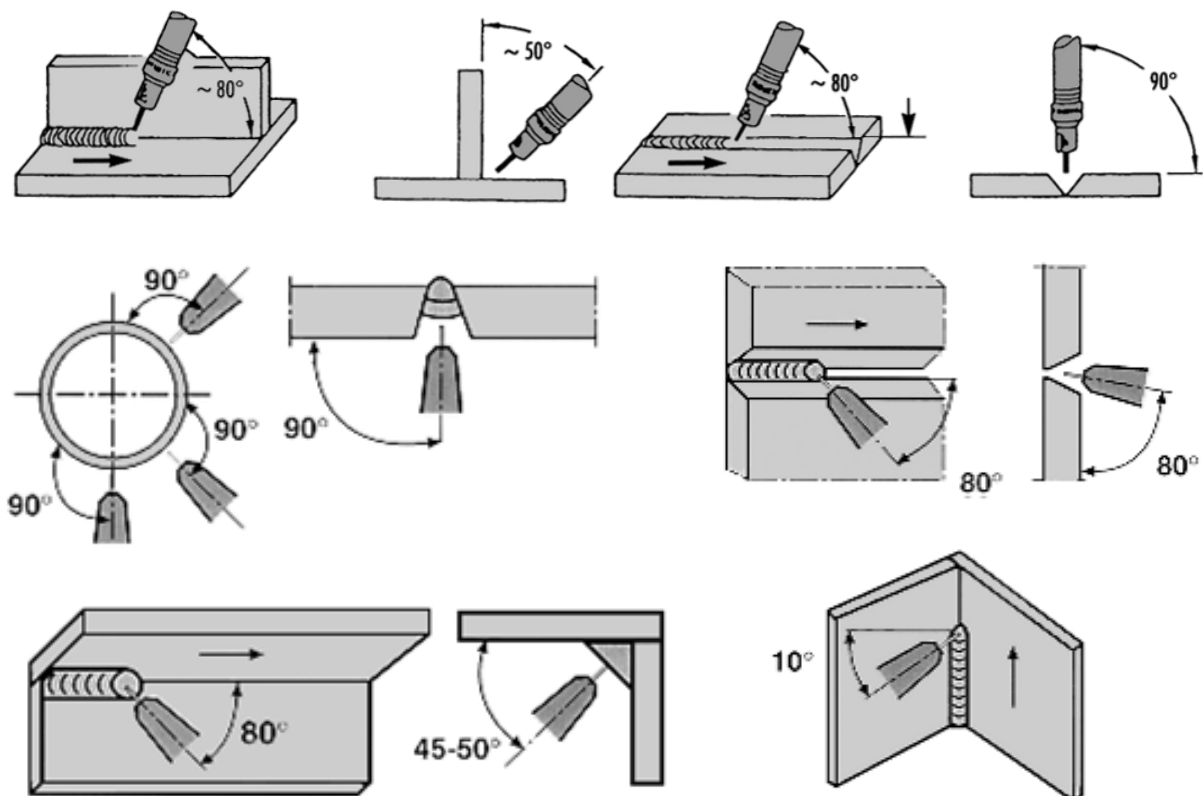


Figure 7 Guide for selecting the correct torch hold for various weld positions

As shown in **Figure 7**, this welding process is also suitable for welding in various positions (generally applicable to steel in all positions, depending on the wire and shielding gas combination).

Figure 8 illustrates the welding positions and their standard letter designations. The arrows indicate the orientation of the welding torch relative to the workpiece (PA–PE), with PG representing downhill welding and PF representing uphill welding.

When welding circumferential pipe seams, the welder traverses almost every welding position; therefore, for pipe welding, the following additional designations are used:

- PJ** – fixed pipe welded from top to bottom,
- J-L045** – fixed pipe with a 45° inclined axis welded from top to bottom,
- PH** – fixed pipe welded from bottom to top, and
- H-L045** – fixed pipe with a 45° inclined axis welded from bottom to top.

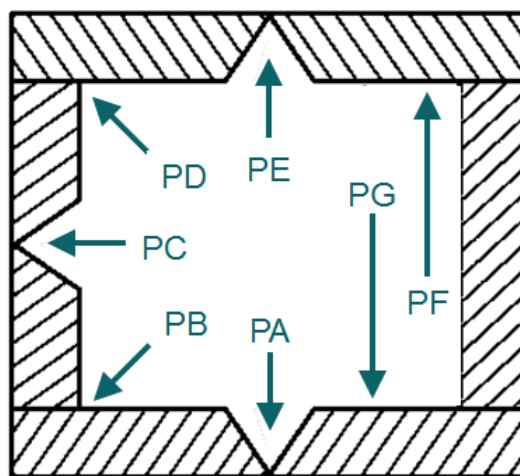


Figure 8 Letter symbols for welding positions according to the EN ISO 6947:2011 standard

All information required to produce a specific welded joint is typically documented for the welder in a Welding Procedure Specification (WPS). During the practical course, students are required to prepare two of these.

Process variants and their numerical designations according to the EN ISO 4063:2023 standard:

- 13** Gas-shielded metal arc welding
Metal inert gas (MIG) welding /Metal active gas (MAG) welding
Gas metal arc welding (GMAW), USA
- 131** MIG welding with solid wire electrode
(GMAW using inert gas and solid wire electrode, USA)
- 132** MIG welding with flux cored electrode
(Gas shielded flux cored arc welding, USA)
- 133** MIG welding with metal cored electrode
(GMAW using inert gas and metal cored wire, USA)
- 135** MAG welding with solid wire electrode
(GMAW using active gas with solid wire electrode, USA)
- 136** MAG welding with flux cored electrode
(GMAW using active gas and flux cored electrode, USA)
- 138** MAG welding with metal cored electrode
(GMAW using active gas and metal cored electrode, USA)

Welding poses a significant risk of fire and accidents; therefore, the laboratory supervisor's instructions must be strictly followed. Failure to do so will result in immediate expulsion from the laboratory!

We provide personal protective equipment in the laboratory; however, participation is not permitted without closed-toe shoes (safety shoes recommended) and long, non-flammable trousers (e.g., jeans).

3. Tasks to be completed during the Welding laboratory

0. Successful completion of the introductory test (min. 2/3 correct answers, questions are selected from the “**Questions to help you prepare**”)

Before the laboratory session begins, the instructor outlines the specific occupational and health hazards associated with the lab, the precautionary measures taken against them, and the rules of conduct within the laboratory.

During the laboratory session, students work in pairs. While one team member performs the welding, the other monitors welding parameters such as welding current, voltage, and welding time. These data are required to prepare the report—specifically, the preliminary Welding Procedure Specification (pWPS).

The lab supervisor briefly explains the safe operation of the welding machines

The laboratory supervisor explains the first part of the task and distributes the steel samples to the students.

1. Task:

Creating a weld bead parallel to the edge of a 3 mm thick S235JR steel plate using surfacing welding. Observing the effect of heat on workpiece deformation. Practicing surfacing welding on both sides of the test plate. Observing the impact of torch handling and stand-off distance on arc stability and weld bead appearance. Students do not yet need to record the parameters; this stage is for practice.

2. Task:

Joining two 3 mm thick S235JR steel sheet pieces in a T-joint configuration, followed by the creation of a fillet weld in the PB position. Observation of penetration and fusion. One student welds one side of the assembly, afterwards the other student welds the opposite side. Afterward, the students hold the welded assembly with pliers to cool it in water, measure the geometry of the finished welds, and document the results and the welding parameters on the pWPS.

3. Task:

Butt-joining 2 – 2 pieces of S 235 JR steel sheet pieces (3 mm thick) and executing the butt weld in the PA position; observing penetration and root fusion. Afterward, the students hold the welded assemblies with pliers to cool it in water, measure the geometry of the finished welds, and document the results and the welding parameters on the pWPS.

4. Students complete the necessary calculations and weld bead geometry measurements for the pWPS and finalize it, then present it to the lecturer for signature.

The instructor reviews the protocols (pWPS,) requests corrections if necessary, and signs the protocol with his/her signature, which he/she then returns to the student.

It is the student's duty and responsibility to keep the signed protocols (to eliminate any possible record keeping errors)!

Questions to help you prepare:

1. List three types of form-locking connections.
2. List three types of friction-locking connections.
3. List three types of material-locking joints!
4. Classify welding processes according to the mechanism of joint formation.
5. How is a welded joint formed in fusion welding processes?
6. How is a welded joint formed in pressure welding processes?
7. Which type of welding process is most widely used in steel structure manufacturing?
8. List three wire coatings used for the 13x welding processes!
9. List two inert shielding gases for welding!
10. What's the heat input?

Used and recommended literature:

- Manufacturing Engineering and Technology. Serope Kalpakjian. Pearson Education Limited 2023 ISBN 10: 1-292-42224-6
- Welding Metallurgy 3rd Edition. Sindo Kou, John Wiley & Sons New. Jersey, 2020 ISBN: 978-1-119-52481-6
- List of connected standards available: <https://www.mussmann.org/normung/>