ELECTRIC ARC WELDING

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ARC WELDING TECHNIQUES

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1.1. BEVELING THICK PIECES IN HORIZONTAL POSITION

Ensuring deep penetra12tion of weld metal and creating a strong joint is not always possible solely by adjusting the welding current or electrode diameter. Additionally, modifications to the cross-section of the parts to be welded should be made to create a welding groove. For ease of preparation, a V-groove is often preferred in practice. Furthermore, U, X, and J grooves can be applied either singly or on both sides for butt welds. These types of welding grooves require more preparation time and additional labor, making them generally preferred for special applications or automation-focused work.

1.1.1. Importance of Beveling

A key prerequisite for joining thick parts using electric arc welding is ensuring that the joint achieves the desired level of strength. Several factors determine the integrity of a weld joint:

- The beveling process is performed to ensure 100% penetration of the weld metal into the base material.
- Since the weld metal penetrates the base material, it increases the material's service life and mechanical strength.
- Not all thicknesses require beveling.
- The standards for beveling thickness and shape are determined by TS 3473 EN ISO 9692-1.
- Pieces up to 8 mm thick do not require beveling if welded on both sides.
- For pieces thicker than 10 mm, double-sided beveling must be performed, which may include double V, double U, or X grooves.

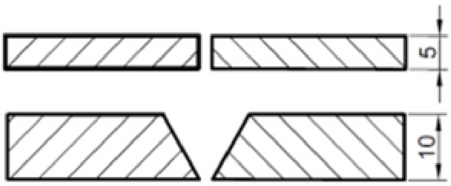

Figure 1.1: Butt Joint Without Beveling and V-Groove Beveling.

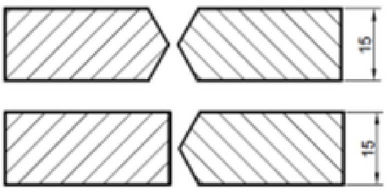

Figure 1.2: Double-Sided V-Groove and Single-Sided K-Groove Beveling.

1.1.2. Beveling Methods

Beveling can be performed using burning, melting, or machining processes. The chosen method should be cost-effective, quick, and should not alter the chemical or physical properties of the base material. Therefore, the method of beveling should be determined according to the material to be welded.

1.1.3.1. Beveling with Oxy-Gas Cutting

One of the thermal beveling methods involves cutting with an oxy-gas torch. Many metal parts can be cut and beveled with oxygen, except for some restricted materials. However, excessive heat input and oxygen consumption impose limitations on the types of materials that can be used. For instance, cutting stainless steels and brass with oxygen is not recommended.

Figure 1.3: Oxy-Gas Cutting

1.1.3.2. Beveling with Grinding Wheels

In machining applications, beveling can be performed manually or through automation. In manual applications, a grinding wheel can be used for beveling. The availability of grinding wheels in most metal workshops and the ability to perform the process quickly make this method viable for projects without additional investment. Grinding wheels used for beveling should be coarse-grained to expedite the process.

Figure 1.4 Grinfing Wheels

1.1.3.3. Beveling with Plasma Cutting

This method is preferred for cutting bevels in flat sheet metal due to its compatibility with automation. Plasma cutting allows beveling and shaping of metals that are unsuitable for oxy-gas cutting.

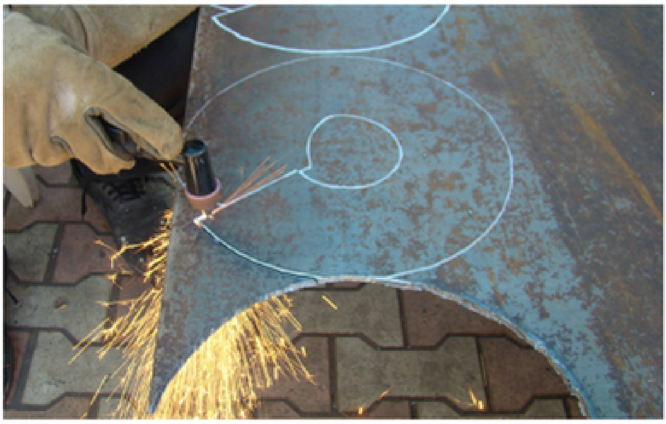

Figure 1.5: Plasma Cutting

.1.3.4. Beveling with Carbon Arc Cutting

This method involves using a carbon electrode and pressurized air. It is based on creating an arc similar to electric arc welding. This method is widely used in shipbuilding and pressure vessel manufacturing.
Since it is a melting-based cutting process, it is suitable for metals that cannot be cut with thermal methods. The system consists of two main components: the carbon electrode, which creates the melting environment, and the pressurized air system.
Additionally, carbon arc cutting is used for gouging operations, also known as grooving. Machining tools such as milling machines, lathes, and shapers can also be used for beveling. Particularly, thick sections of aluminum and similar metals can be processed using these machines in well-equipped workshops. Beveling processes for mass production can also be performed on lathes or CNC machines.

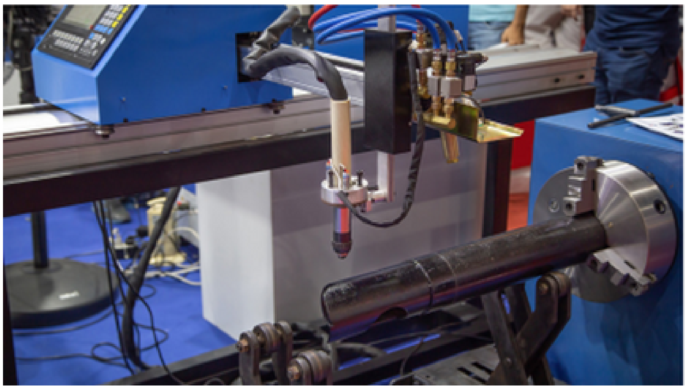

Figure 1.6: Beveling Machine for Pipes

1.1.5. Precautions During Welding

By taking certain precautions, the negative effects of distortions in welded joints can be minimized. The precautions for preventing deformations during welding are categorized into two groups:

During Design:

- The design should be suitable for the welding technique.
- Weld seams should be symmetrical.
- Weld seams should not be placed too close to each other.
- Butt joints should be preferred whenever possible.
- The workpiece should be designed to allow natural contraction during welding.

During Welding:

- An appropriate welding sequence should be followed.
- The electrode diameter and current settings should match the workpiece thickness. Excessive heat input due to large-diameter electrodes should be avoided.
- To prevent angular distortions, weld grooves should be filled with thick weld beads.
- If possible, short stitches should be applied using the skip and back-step welding techniques. Supports should be welded last whenever possible.
- Burn-through notches create stress concentrations, so their formation should be prevented.
- To prevent transverse shrinkage, parts should be clamped or tack welded firmly before welding.

Figure 1.7: Preventing Weld Shrinkage Using a Fixture.

1.2. V WELDING IN HORIZONTAL POSITION

When the thickness of the part to be welded exceeds 10 mm, a V-groove is created, and a weld seam is applied. The cost of groove preparation should be considered in many applications; however, this cost is reduced if oxygen cutting is used.

V welding alone leads to higher electrode consumption. For example, it requires more weld metal than an X-weld. Like butt welds, the root of the weld is not very resistant to bending and torsion.

In some applications, filling the V-groove with a single pass may not be feasible. In such cases, a root pass is necessary.

1.2.1. Standard Dimensions and Angles for V Welds

A V groove is created to achieve full penetration in a single-sided weld. Pieces between 6-12 mm thick are beveled with a V groove, which is generally opened at a 60-degree angle.

- α: The angle depends on the welding method, welding position, and whether back welding is possible.
- c: Root height depends on α angle and welding position.
- b: Root gap depends on α angle, welding method, and position.

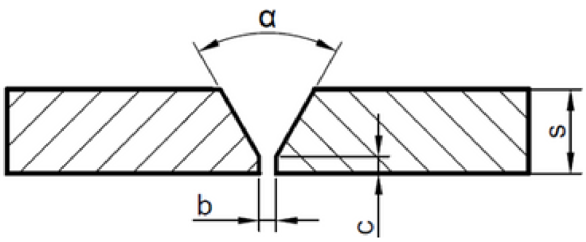

Figure 1.8: V-Groove Weld Dimensions

1.2.2. Importance of Root Pass

The root gap allows the electrode to reach the joint's bottom or root. If the root gap is too narrow, it becomes difficult to achieve full fusion, requiring a smaller electrode, which slows the process. If the root gap is too large, more weld metal is needed, increasing costs and distortions.

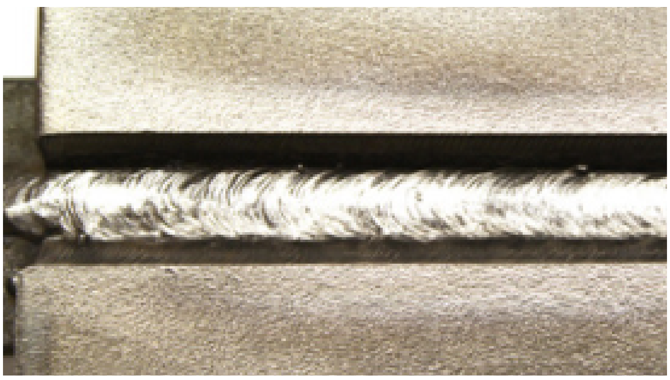

Figure 1.9: Root Pass WeldP

1.2.3. Tack Welding for V Joint Preparation

Tack welds may be applied to hold the parts in place during welding. The length and spacing of each tack weld should be specified in the fabrication drawing, welding procedure specification, or another relevant document. In fully mechanized or automated welding processes, tack weld accumulation conditions must be defined in the specification. Tack welds should be applied in a balanced sequence to minimize distortion and ensure proper assembly.

For materials thinner than 12 mm, the tack weld spacing should be at least four times the material thickness.

If the tack weld is to remain within the final weld, it must conform to the final weld profile and should be performed only by certified welders. Tack welds must not contain cracks or other unacceptable discontinuities in the weld metal and should be completely cleaned before final welding. Tack welds that contain defects such as cracks, cold laps, or crater cracks must be removed before welding. Any tack welds that are not intended to be incorporated into the final weld should be removed by machining.

1.2.4. Performing the Root Pass

The arc generated by welding current causes the heat-affected zone on the workpiece surface to melt. At the beginning of the arc, the weld metal is fluid due to the high temperature, forming what is known as the weld pool. If the electrode is struck and held in one place, the weld pool will expand and spread. If the electrode moves forward, the weld pool will move in the same direction.

The welder can adjust the electrode contact points based on the workpiece position, bevel shape, and material thickness. These adjustments, known as electrode movement, influence the shape of the weld pool, the amount of deposited weld metal, and other parameters. One of the key factors is welding speed, which affects both penetration depth and weld shape.

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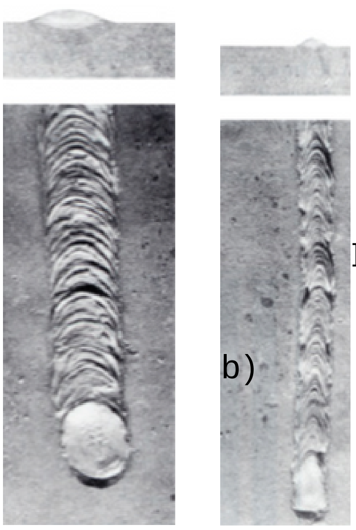

a b)

Figure 1.10: Weld Bead Appearance at Different Speeds a) Normal speed b) Higher than normal speed

Figure 1.11: Protective Coating of the Weld

tInstantaneous solidification of the weld pool is undesirable. The most crucial factor in preventing rapid solidification is the electrode coating material. Additionally, for the coating material to protect the weld bead from adverse atmospheric effects and fulfill its other functions, it must continuously and uniformly cover the weld metal. The welder must assist the coating material in covering the weld metal’s surface by holding the electrode at an angle. At the start of welding, the electrode is held perpendicular to the workpiece.

As welding progresses, the electrode is gradually tilted at predetermined angles toward the welding direction, forming an angle with the surface of the workpiece. This angle is called the electrode movement angle.

If the electrode tip is directed toward the welding direction, the angle is referred to as negative, whereas if it is directed in the opposite direction, it is termed positive. Additionally, there is another angle known as the working angle, which refers to the angle of the electrode relative to the weld bead edges. These angles vary depending on the position of the workpiece.

As the welding process continues, these steps are repeated, leading to the accumulation of weld metal on the workpiece. The structured accumulation of weld metal is called a weld bead.

1.2.5. Steps for Performing V-Groove Welding

- After the workpieces to be welded are tack-welded, the slag from the tack welds is cleaned.
- The root pass is usually performed using a Ø 2.5 mm electrode, and the root pass is then cleaned.
- Due to the narrow workspace of the root pass and to minimize defects, a Ø 2.5 mm electrode should be used.

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- The second and subsequent passes are welded using thicker .electrodes.
- Using a thicker electrode helps deposit more weld metal, saving time and labor.
- Proper cleaning must be performed after each weld pass.

- If thorough cleaning is not done after each pass, slag inclusions may occur.
- The root pass and second pass are applied to the workpiece.
- If the groove cannot be fully filled with two passes, welding continues until the groove is completely filled.

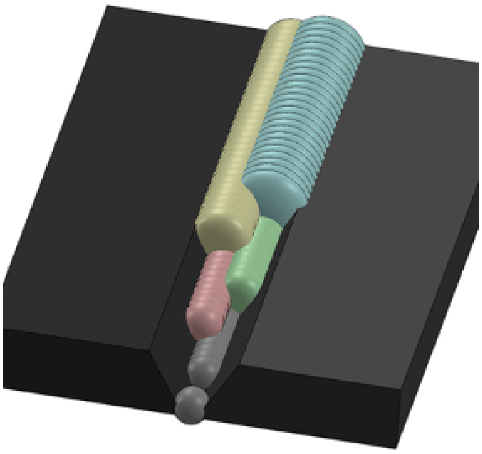

Figure 1.12: Weld Passes in V Groove Welding

1.2.6. Weld Seam Cleaning

After the root pass is completed, slag should be removed using a chipping hammer. Since the root pass is performed in a narrow area, cleaning the slag can be challenging. In cases where the weld was made too quickly, the slag may be thin and firmly attached to the groove, making it difficult to remove.

If the slag cannot be removed with a chipping hammer, it should be cleaned using chisels that can reach the surface of the root pass. Following this, a wire brush should be used to ensure a clean weld seam. If chisels and wire brushing are insufficient to remove slag deposits, the area should be thoroughly ground with a grinder. Otherwise, residual slag may become trapped under subsequent weld passes, leading to defects.

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1.3. K WELDING IN HORIZONTAL POSITION

K-groove welding is a process in which a double V-groove is made on the edges of one of the workpieces, while the other is positioned at a 90-degree angle for the welded joint.

1.3.1. Standard Dimensions and Angles of K-Groove Welding

K-groove welding can be applied to parts with thicknesses ranging from 15 to 40 mm, and the groove angle can vary between 45 and 60 degrees.

The terms and their meanings in K-groove welding are as follows:

- β: This angle depends on the welding method, welding position, and whether back welding is possible.
- s: Indicates the thickness of the workpiece.
- h: Represents the distance of the groove opening from the edge.
- b: Root gap, which depends on the α angle, welding method, and position.

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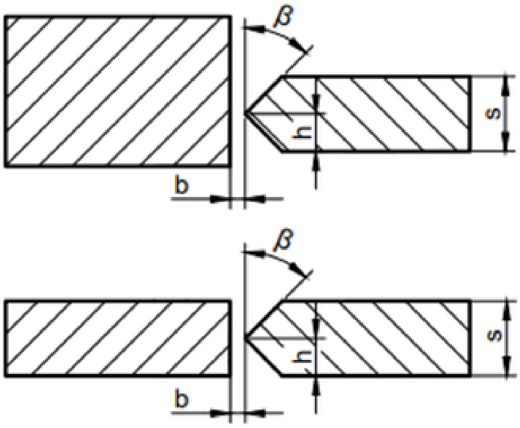

Figure 1.13: K-Groove Weld Cross-Section

1.3.2. Steps for Performing K Welding

Tack welding is performed according to the welding method.

Figure 1.14: Tack Welding in K-Groove Welding

When performing wide weld passes, appropriate electrode movement should be applied.

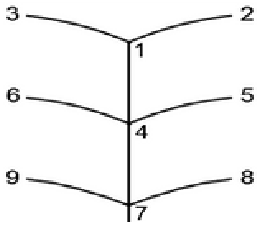

Figure 1.15: Electrode Movement for Root Pass in K-Groove Welding

- The electrode should pause slightly at each face of the groove to ensure proper fusion.
- In order to fully fuse the top edge of the groove, the final passes may be slightly oscillated.
- This is the most commonly used technique, but in some cases, limited oscillation and narrow passes may be necessary to control heat input.
- The weld bead width should be three to four times the core diameter of the electrode.
- Weld beads should vary in length between one-third to half of an electrode’s full length.
- The electrode movement should push slag away by slightly bending backward.
- Due to the thickness of the electrode covering, slag accumulation increases, making it harder to clean. Therefore, the backward movement should be slightly emphasized.
- At the same current intensity, a wide weld bead generates more heat than a narrow one, resulting in deeper penetration.
- Slag should be carefully cleaned with a pointed chipping hammer or a brush. If these are insufficient, a chisel and hammer should be used with care.
- One of the main purposes of slag is to slow down the cooling of the weld bead, preventing sudden cooling. For this reason, cleaning should not begin too early.

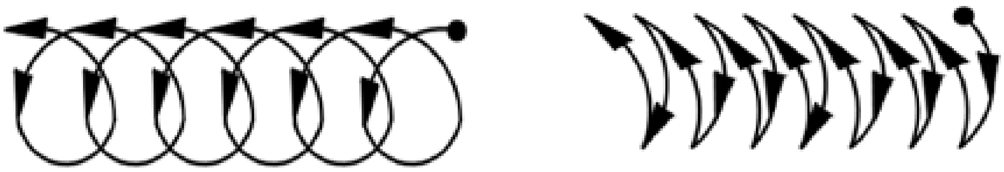

Figure 1.16: Recommended Electrode Movements for Fill Passes

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FILLER WELDING

2. LEARNING UNIT

2.1. TYPES OF BUILD-UP WELDING
2.2. SURFACE BUILD-UP WELDING
2.3. SHAFT BUILD-UP WELDING

- **2.1. TYPES OF BUILD-UP WELDING**
- Machine components such as shafts, gears, the soil-contacting surfaces of agricultural tools, the edges of earthmoving machinery, shear blades, mill crushers, friction-operated discs, and hardened surfaces are subject to wear over time due to friction.
- Repairing or replacing worn, broken, or cracked components is sometimes not feasible or economical. Therefore, build-up welding is used to restore them.
- Build-up welding refers to the process of depositing weld beads either in a single pass or by overlapping layers to restore worn machine parts to their original dimensions before wear.
- Electrodes Used in Hard Surface Build-Up Welding
- In hard surface build-up welding, primarily basic-coated electrodes and, occasionally, rutile-coated electrodes are used. These electrodes can be categorized as follows:
- Basic-coated electrodes used in build-up welding yield better results if dried at 250-300°C for two hours before use.

Very Hard Surface Electrodes: These electrodes are made of tungsten carbide. Due to their extremely hard composition, the weld bead deposited with these electrodes hardens the workpiece to the same extent. They are commonly used in the build-up welding of shear blades, discs, and knives.

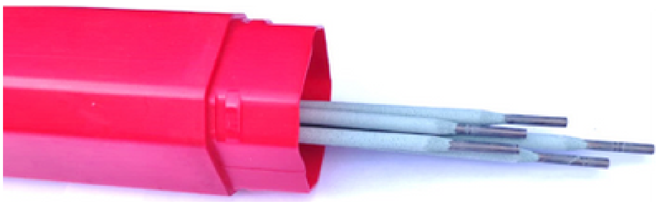


Figure 2.1: Hard Surface Electrodes

Normal Wear and Impact Electrodes: These electrodes have high carbon content and produce a hard and dense weld bead. They are suitable for surface build-up welding.

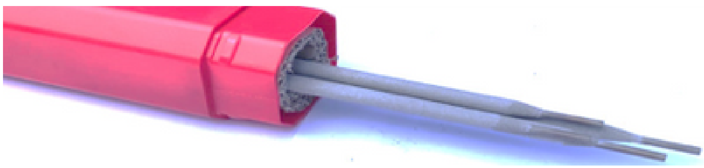


Figure 2.2 : Normal Wear and Impact Electrodes:

Moderately Hard and Impact-Resistant Electrodes: Used in applications such as chain conveyors, pins, bearings, and stone crushers.

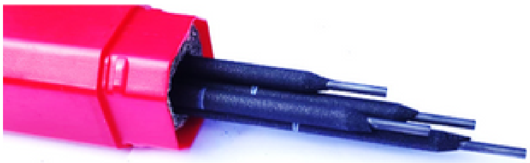


Figure 2.3 : Moderately Hard and Impact-Resistant Electrodes

Chromium-Nickel Electrodes: Primarily used for the build-up welding of stainless steel equipment in the food industry.

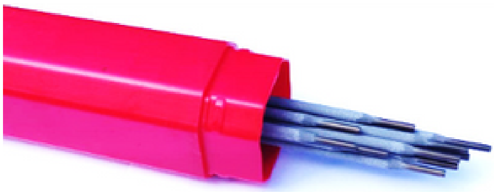


Figure 2.4 : Chromium-Nickel Electrodess

Manganese Electrodes: Used for the build-up welding of excavator teeth in earthmoving machinery, drill bits, scrapers and rippers, and rolling mill rollers.

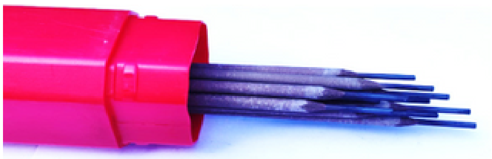


Figure 2.5 :Manganese Electrodes

Work-Hardening Electrodes: These electrodes are machinable after welding but harden during operation.

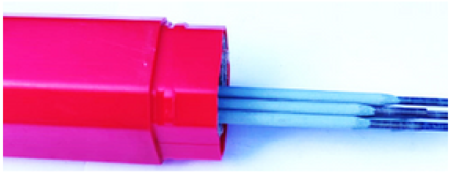


Figure 2.6 :Work-Hardening Electrodes

Heat-Treatable Hardening Electrodes: These electrodes can be hardened through heat treatment after the build-up welding process.

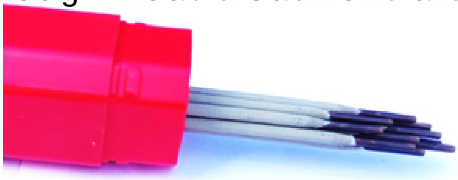


Figure 2.7 :Heat-Treatable Hardening Electrodes

Machinable Build-Up Electrodes: These are thick-coated manganese build-up electrodes with high impact absorption capacity. Their slag is easily removable, and they can be machined by chip removal.

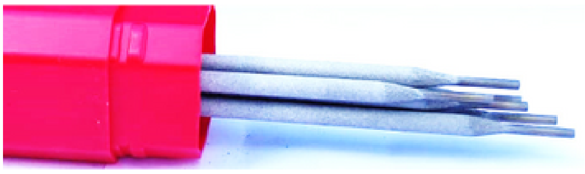


Figure 2.8 : Machinable Build-Up Electrodeses

Hard-Core Wire Electrodes: These electrodes are primarily used as filler wires in MIG-MAG and TIG-WIG welding processes. They can be made of steel, copper, aluminum, or brass.

Figure 2.9 :Hard-Core Wire Electrodes

2.2. SURFACE BUILD-UP WELDING

The types of surface build-up welding are as follows:

- Single-pass surface build-up welding
- Overlay (multi-layer) build-up welding

The general purposes of surface build-up welding can be listed as:

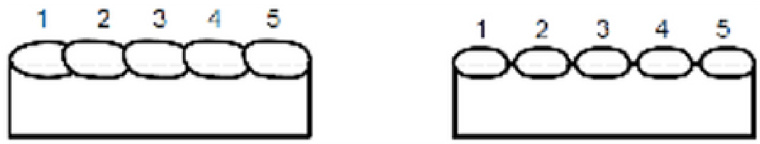
- Restoring worn surfaces to their original dimensions before wear
- Rejoining broken parts to make them functional again
- Repairing deformed surfaces to their original shape before damage

2.2.1. Single-Pass Surface Build-Up Welding

Single-pass surface build-up welding is typically applied to machine components that have not undergone excessive wear.

If the welded surfaces require high precision, they are processed using machining techniques such as turning, milling, shaping, or honing before being put into service.

However, if the application does not require fine workmanship (e.g., agricultural tools, bucket jaws), the welded surface can be used without additional machining.



a)False **b)True**

Figure 2.10 : Single-Pass Surface Build-Up Welding

2.2.2. Overlay (Multi-Layer) Build-Up Welding

Multi-layer build-up welding is applied to excessively worn or damaged keyways, broken or cracked machine components, and the edges of elements requiring high strength.

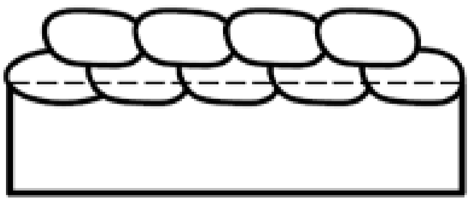


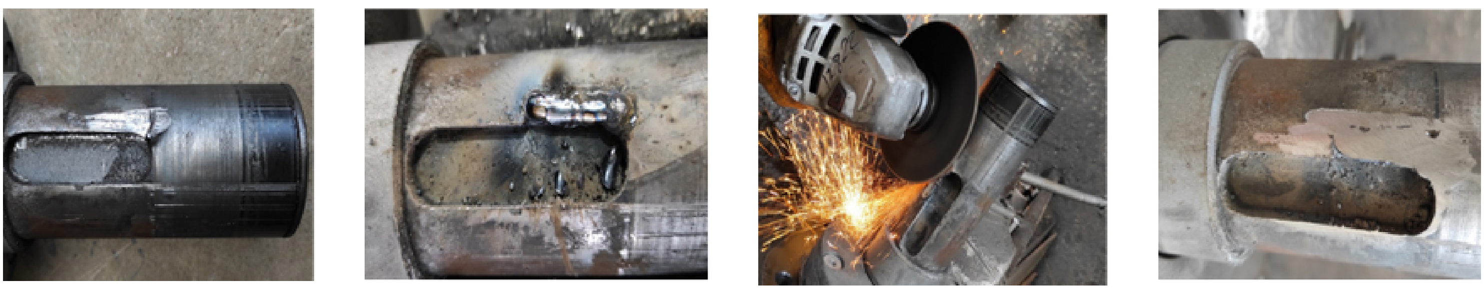
Figure 2.11 :Overlay (Multi-Layer) Build-Up Welding

2.3. SHAFT BUILD-UP WELDING

Shaft build-up welding refers to the process of filling only the worn sections of shafts using welding methods.

2.3.1. Applications of Shafts and Journals

- Used in machines to transmit power and motion while rotating, carrying components such as gears, clutches, pulleys, and flywheels.
- Found in cylindrical machine parts that are subjected to wear, deformation, and bending under load.



a) b) c) d)

Figure 2.12: Steps for Repairing a Deformed Surface

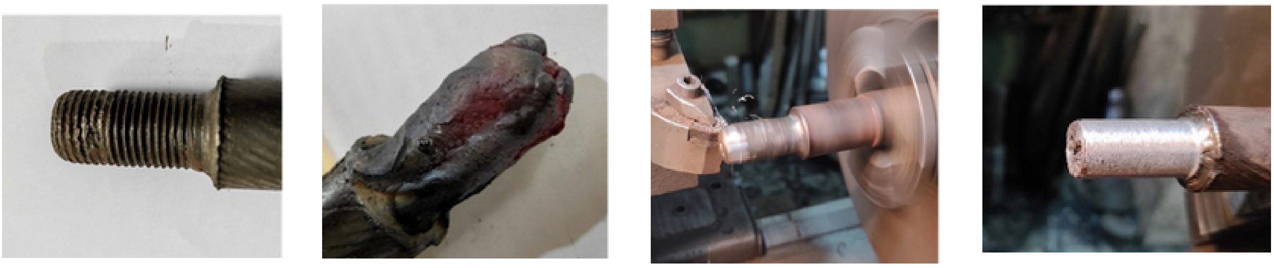
a) Deformed shaft
b) Application of build-up welding
c) Machining process
d) Restoring to its original condition

2.3.2. Purpose of Shaft Build-Up Welding

Since shafts are rotating machine components, they are prone to wear due to:

- High-speed operation
- Oscillations caused by the rotation of attached components
- Irregular lubrication
- Overheating

Worn shafts cannot maintain smooth and balanced rotation, leading to noisy operation and potential damage to the connected machine. This can ultimately result in irreparable failures.



a) b) c) d)

Figure 2.13: Steps for Repairing Threaded Sections on a Shaft

a) Worn and damaged threads
b) Application of build-up welding
c) Machining process
d) Restoring to its original condition

In some cases, replacing worn shafts may not be feasible. Recreating them manually on a lathe requires significant labor, leading to time loss and increased costs. Instead, only the worn sections of the shaft can be filled with weld metal, machined, and reused efficiently.

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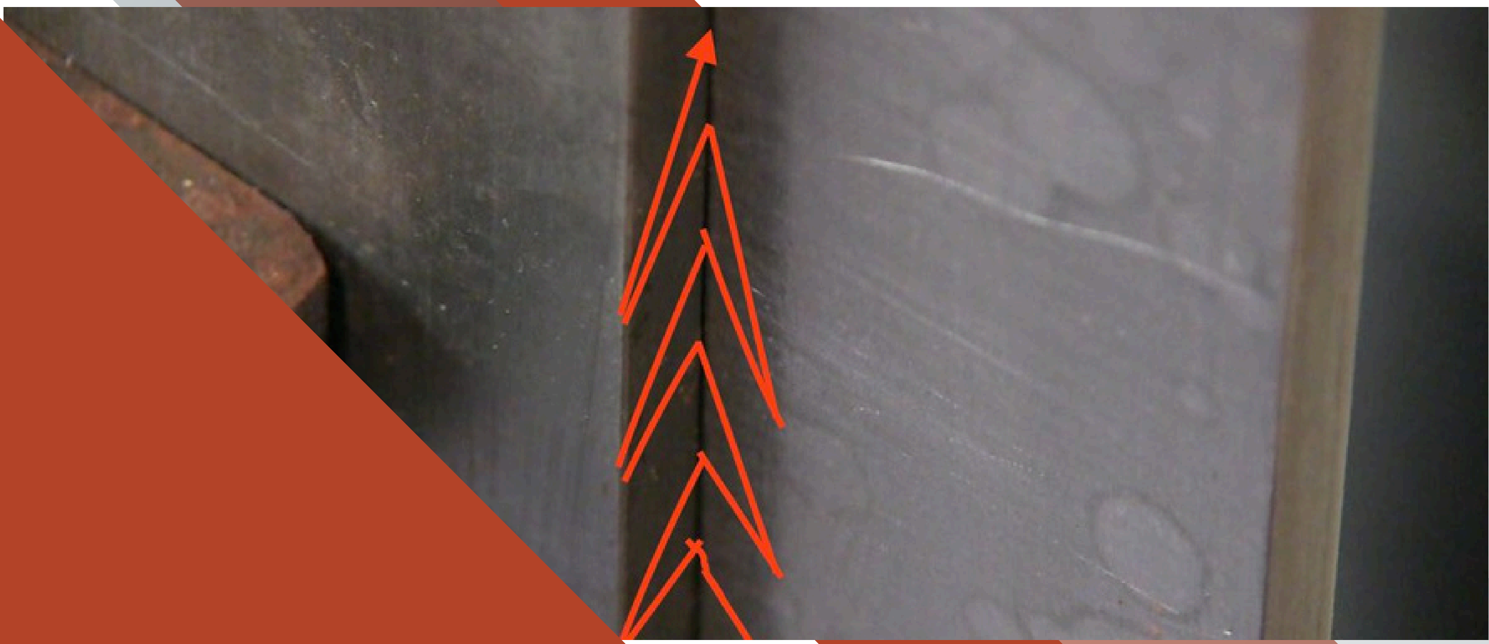
VERTICAL WELDING

3. LEARNING UNIT



3.1. VERTICAL WELDING POSITIONS

The horizontal position is the most comfortable and controlled position for shaping weld beads in positional welding. Since the workpiece is parallel to the ground, this type of welding is called horizontal welding.

However, for a trained welder, being able to weld in the horizontal position is not always sufficient, as workpieces encountered in production are not always positioned this way. Therefore, a welder must be capable of performing welds in various positions and understand the techniques required for each.

In general, welding positions are classified as follows and are denoted by letters according to the Turkish Standards Institution (TSE):

- Horizontal (Flat)
- Vertical (Top-to-bottom, Bottom-to-top)
- Side (Wall position)
- Overhead (Ceiling position)
- Inside and outside corner in the overhead position

The arc created by the welding current causes the heat-affected zone of the workpiece surface to melt. As the electrode melts, the core metal of the electrode combines with the molten mass in the heat-affected zone of the workpiece.

The core metal of the electrode plays a crucial role in this fusion, forming the weld metal. The majority of the weld metal is composed of the electrode's core metal.

Thus:

- Thin electrodes are used for joining thin materials.
- Thicker electrodes with a larger core metal diameter are used for joining thicker materials.

This ensures that the necessary weld metal is provided to fill the gap between the parts.

In top-to-bottom and bottom-to-top welding, metal flow occurs due to the weight of the molten weld metal. The amount and behavior of metal flow vary depending on the welding method, electrode movement, and welding angles.

3.2. TOP-TO-BOTTOM BUTT JOINT WELDING

The top-to-bottom butt joint welding method is most commonly preferred for sheet metal welding applications.

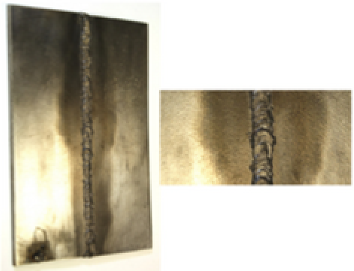


Figure 3.1: Sheet Metal Piece Welded from Top to Bottom

3.2.1. Performing Top-to-Bottom Vertical Butt Joint Welding

In vertical welding, also known as downward butt joint welding, the workpiece is positioned at a 90-degree angle to the horizontal plane.

The most significant difference between horizontal welding and other welding positions is the type of electrodes used.

- In horizontal welding, any type of electrode can be used.
- In vertical welding and other positional welds, the suitability of the electrode must be checked beforehand.

The electrode coating material should have low fluidity and solidify quickly.

- If the coating material does not have these properties, it will flow away during welding and fail to provide proper shielding.

To prevent excessive fluidity of the weld metal, high temperatures must be avoided.

- Therefore, the welding current should be kept as low as possible.

Figure 3.2: Vertical Welding with Electric Arc

3.2.2. Application Areas

- Typically used for workpieces that are intended to be welded with a single pass.
- Since this method produces a weaker weld bead, it is not recommended for joints requiring high strength and durability.

3.3. BOTTOM-TO-TOP BUTT JOINT WELDING

3.3.1. Performing Bottom-to-Top Vertical Butt Joint Welding

In this welding method, the workpieces to be welded are joined edge to edge.

- Welding starts from the bottom and progresses upward as the electrode moves in an upward direction.
- Compared to top-to-bottom welding, this position provides greater penetration and strength.

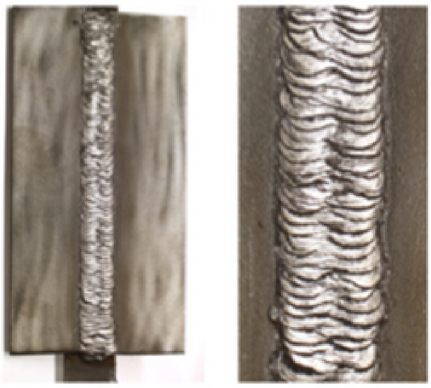


Figure 3.3: Bottom-to-Top Welding Application

3.3.2. Application Areas

- Bottom-to-top vertical welds generally involve high heat input, leading to significant localized heating.
- For this reason, except for very short welds, this method is not recommended for materials thinner than 4 mm.

3.4. BOTTOM-TO-TOP V-GROOVE WELDING

In bottom-to-top vertical welding, the welding process begins at the bottom of the joint, and the arc moves upward.

3.4.1. Performing Bottom-to-Top V-Groove Welding

- This method is generally used for thicker materials, which requires groove preparation.
- If a V-groove is cut into the workpiece before welding, and the weld progresses from bottom to top, it is called bottom-to-top V-groove welding.

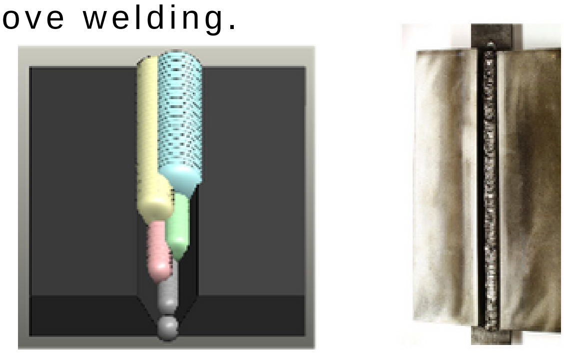


Figure 3.3: Bottom-to-Top Welding Application

3.4.2. Application Areas

- Bottom-to-top welds generate high heat input, causing significant localized heating. Therefore, except for very short passes, this method is not recommended for materials thinner than 4 mm.
- Bottom-to-top V-groove welding is suitable for materials with a thickness between 10 mm and 20 mm.
- For materials thicker than 20 mm, X- and K-groove preparations are required for double-sided welding.

3.5. BOTTOM-TO-TOP FILLET WELDING

In bottom-to-top welding, the process begins at the bottom of the joint and progresses upward.

- This technique is commonly used in vertical fillet welds, referred to as bottom-to-top vertical fillet welding.

3.5.1. Performing Bottom-to-Top Fillet Welding

- Fillet welds are among the most commonly used weld joint types in fabrication and manufacturing.
- Bottom-to-top fillet welding can be performed on one or both sides, depending on the required strength.
- Unlike butt joints, fillet welds do not require groove preparation, but extra care is needed when forming the weld bead.
- Gravity causes the molten weld metal to sag, so proper heat control is essential to ensure a uniform and strong weld.

Figure 3.4: Completed Bottom-to-Top Fillet Weld
a) First pass. b) Second pass c) Third pass

a) **b)** **c)**

3.5.2. Application Areas

- Bottom-to-top fillet welding is mostly applied to thicker materials. It has a wide range of applications in construction industry projects.
- Welded manufacturing (or design) holds a significant place in today's production methods. It is not only important that welding is done well, but also that it is used appropriately and calculated, with parts shaped according to the requirements of the welding process.
- The safest weld connection, especially under dynamic loading conditions, is the fillet weld. Therefore, excessive safety should not be expected in fillet welds. Particularly in thin sheet metal structures, continuous fillet weldsshould be avoided as much as possible.
- The weld cross-section and thickness should not be excessive. In fillet welds, the production costs increase with the thickness of the weld.
- If the weld volume is small, the existing stresses, warping, and the need for later straightening are also minimized.

3.6. BOTTOM-TO-TOP FILLET WELDING

In bottom-to-top fillet welding, multiple passes can be made on the weld joint.

3.6.1. Performing Bottom-to-Top Fillet Welding

In this welding method, the second pass is not made in one step to cover the root pass, as is done in bottom-to-top welding. This is because wider beads are not created in top-down welding.

Figure 3.5 : Top-Down Fillet Welds

3.6.2. Application Areas

- It is not recommended to use in welds where safety is a priority.
- It is recommended for welds where aesthetic welds are desired and strength is secondary.
- It is primarily applied to parts that are 8 mm thick or thinner.
- For parts thicker than 8 mm, basic electrodes are recommended.

3.7. TOP-DOWN OUTER CORNER WELDING

3.7.1. Performing Top-Down Outer Corner Welding

In this welding method, the parts have different outer corner positions. These are classified into three types: open, semi-open, and closed. The welding speed for closed outer corner welding is higher compared to the other two.

3.7.2. Application Areas

- It is mainly applied to parts 8 mm thick or thinner.
- For parts thicker than 8 mm, basic electrodes are recommended.
- It is used in the industry to weld the outer parts of angular pieces in vertical positions.

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CORNICE AND CEILING WELDS

4. LEARNING UNIT

4.1. CORNICE AND CEILING WELDING POSITIONS

During welding, the ideal position of the workpiece should prevent the molten weld pool from flowing due to gravity, ensuring it remains stable in place.

- The horizontal welding position offers the best conditions for the welder, as it allows for better control over the weld pool.
- In this position, higher welding current values are used, enabling a faster welding process.
- To perform all welds in the horizontal position, the workpiece must be easily rotatable or maneuverable.

However, in many manufacturing processes, workpieces cannot be positioned conveniently.
Thus, most industrial welding applications are carried out in three main positions:

1. Horizontal
2. Vertical
3. Overhead (Ceiling position)

In mass-production factories, skilled welders try to perform as many welds as possible in the horizontal position.
However, in construction sites, such as steel structures, tanks, and piping systems, this is impractical.
In such cases:

- Special electrodes suited to the working position are used.
- Welding parameters and working conditions are carefully adjusted to ensure a proper weld bead.

4.2. SIDE (CORNICE/WALL) BUTT JOINT WELDING

This welding position is also called the side, cornice, or wall position.

- The workpieces are positioned vertically, but the weld bead is laid parallel to the horizontal axis.
- The workpieces are joined edge to edge (butt joint).
- The welder moves from left to right or right to left while welding.

Figure 4.1: Side Butt Joint Welding

4.2.1. Performing Side Butt Joint Welding

In all welding positions except the horizontal position, the molten weld pool tends to flow outward from the joint due to gravity. This challenge is overcome by using appropriate welding techniques, such as:

- Controlling welding speed and electrode angle.
- Using electrodes with suitable coatings, which contain additives that help prevent the weld metal from flowing out of the joint.

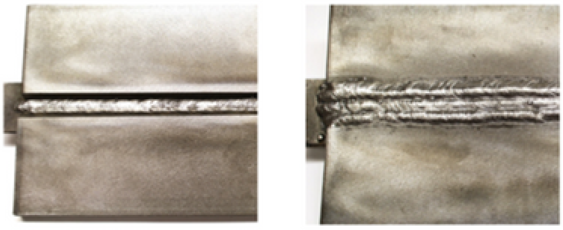


Figure 4.2: Side Butt Joint Welding Application

The welder should aim to reduce heat input during welding to decrease fluidity and improve control over the molten weld pool.

- The angle between the electrode axis and the welding surface should be adjusted to maintain the optimal position of the weld pool.
- While 350-amp current values can be used easily in horizontal welding, in other positions, the welding currentmust be kept lower to prevent excessive metal flow and ensure better weld quality.

Figure 4.3: Welded Joints in Different Positions

Key Considerations for Side Butt Joint Welding

- Except for the starting point and welding direction, the process follows the standard right-to-left welding characteristics.
- When hard-to-reach areas are encountered, one of the two welding directions (left-to-right or right-to-left) is selected based on feasibility.

4.3. SIDE V-GROOVE WELDING

Side V-groove welding is a welding method performed in the side (wall) position after V-groove preparation has been applied to the workpieces.

Figure 4.5: Side V-Groove Welding

4.3.1. Performing Side V-Groove Welding

- In cornice (wall) welding, materials thicker than 10 mm require groove preparation before welding.
- For materials between 10-20 mm thick, a single-sided V-groove is applied.
- For materials over 20 mm thick, a double-sided X- or K-groove is used.
- The groove angles should be:
  - 50° for the upper piece
  - 20° for the lower piece
- Single-sided V-groove welds are also called half-V welds.

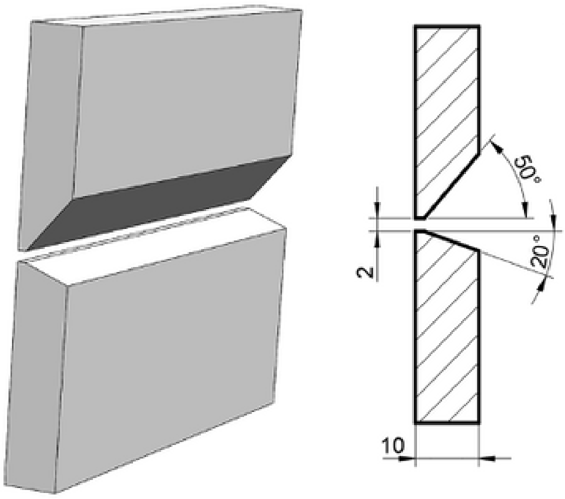


Figure 4.5: Side Butt Joint V-Groove Angles

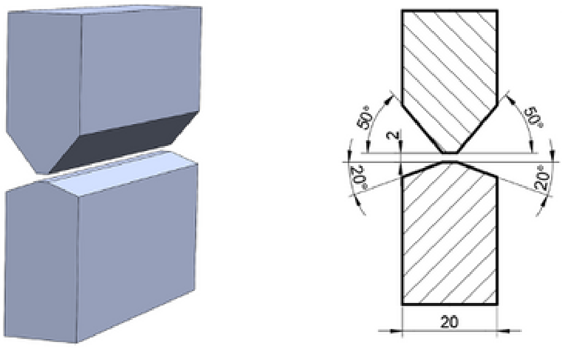
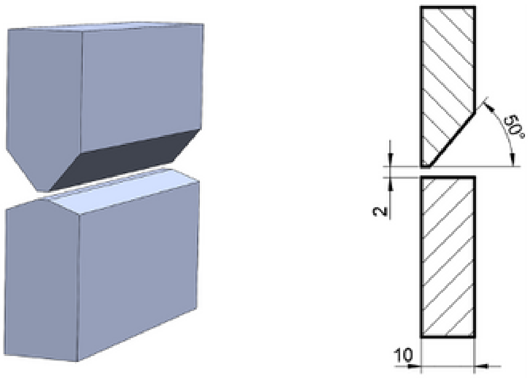


Figure 4.5: Side Butt Joint X-Groove Angles

In the cornice (wall) position, the effect of gravity causes the weld pool to flow outward, highlighting the importance of the weld groove. The half-V weld groove is the most commonly used groove in side welding.



FFigure 4.6: Single-Sided Lateral Butt Joint V Weld Groove (Half-V) Angles

To minimize the flow caused by gravity in the cornice position, the use of a backing is preferred.

4.3.2. Applications of Lateral V Welding

- Generally used for parts thicker than 10 mm
- Steel boiler manufacturing
- Steel roof assembly
- Shipbuilding industry
- Pipeline installation
- Steel construction joints

4.4. LATERAL FILLET WELDING

This is the fillet welding method applied to parts in a lateral position.

4.4.1. Execution of Lateral Fillet Welding

In this welding position, parts are tack-welded at a 90-degree angle (T or L shape) and are rotated 45 degrees, centering the joining corners.

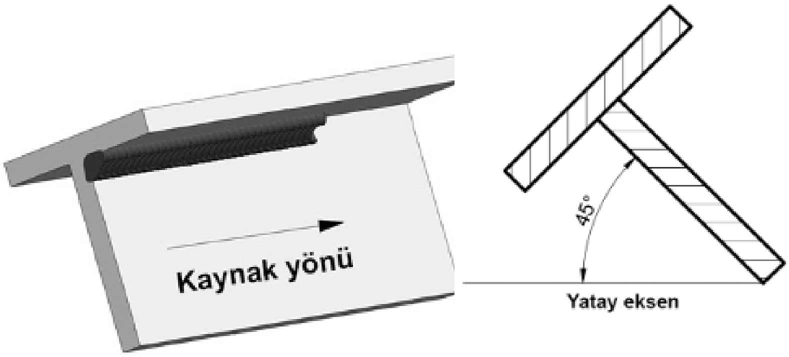


Figure 4.7: Lateral Fillet Weld

If the angle between the part and the horizontal axis is 80-90 degrees, it is classified as overhead fillet welding; for lower angles, it is considered cornice fillet welding.

4.4.2. Applications of Lateral Fillet Welding

Lateral fillet welding is one of the commonly used positional welding methods in large construction projects and machinery manufacturing. A single-pass weld is applied to parts up to 10 mm thick, while thicker parts may require multiple weld passes depending on the construction requirements.

4.5. OVERHEAD BUTT WELDING

Overhead butt welding is also known as overhead position welding. This method is generally applied to thick and large parts that cannot be rotated.

4.5.1. Execution of Overhead Butt Welding

During welding, the weld pool must be continuously monitored to prevent slag drippings. If continuous overhead welding is required, selecting thinner welding cables is recommended.

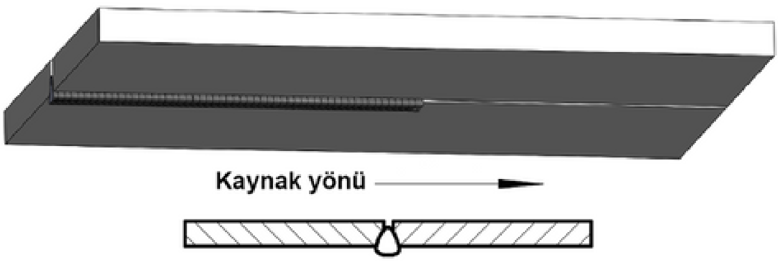


Figure 4.8: Direction of Overhead Butt Welding

Due to the physically demanding nature of the overhead welding position, it is essential to reduce the weight of the welding cables. For this reason, a cable cross-section of 35 mm^2 is sufficient for overhead welding. This reduces the load on the welder's arm, allowing for longer welding sessions without excessive fatigue.

Figure 4.9: Overhead Butt Welding

4.5.2. Applications of Overhead Butt Welding

- Steel roof assembly
- Steel bridge construction
- Shipbuilding industry
- Steel construction works

4.6. OVERHEAD V WELDING

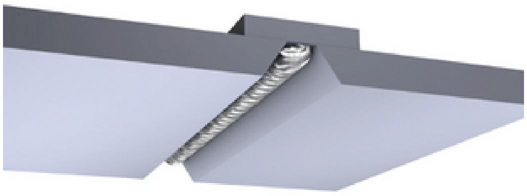


Figure 4.10: Overhead V Welding

Overhead V welding is applied with the weld positioned above the welder's head.

4.6.1. Execution of Overhead V Welding

This welding method is used for materials thicker than 10 mm by preparing a total groove angle of 60 degrees (30 degrees on each piece). Unlike side welding, the weld beads should be placed side by side rather than forming a cap-like structure. A narrower weld bead increases the strength of the joint.

4.6.2. Applications of Overhead V Welding

- Large, immovable, and non-rotatable construction projects and thick materials (Image 4.11)
- Steel roof assembly
- Steel bridge construction
- Shipbuilding industry
- Steel construction works

Figure 4.11: Applications of Overhead V Welding

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CELLULOSIC AND BASIC ELECTRODE WELDING

5. LEARNING UNIT

5.1. BUTT JOINT WELDING WITH CELLULOSIC ELECTRODE
5.2. BUTT JOINT WELDING WITH BASIC ELECTRODE

5.1. BUTT JOINT WELDING WITH CELLULOSIC ELECTRODE

Electrode manufacturing companies have developed electrodes to meet all types of industrial electrode needs.

The variety of electrodes has increased in line with industry demands. One of the best examples of electrodes designed to meet different needs is the cellulosic electrode.

5.1.1. The Role and Importance of Cellulosic Electrodes in Industry

Approximately 30% of the coating formula of cellulosic electrodes consists of cellulose and other organic substances. When these burn within the arc, they generate CO and CO_2 shielding gases.

The arc of cellulosic electrodes is strong, and their penetration is greater compared to other electrodes.

For the complete combustion of organic substances, moisture is required. Therefore, the coating of cellulosic electrodes contains up to 5% moisture.

This moisture requirement provides an advantage in storage, as the electrode does not need to be baked in an oven.

Figure 5.1: Butt Joint with Cellulosic Electrode

Due to the strong arc of cellulosic electrodes, welding can be easily performed in all positions, including vertical-down welding.

This ensures the formation of a deep-penetration, strong weld seam.

For this reason, cellulosic electrodes are commonly used in the following areas:

- Natural gas and oil pipelines
- Water and wastewater pipes
- Storage tanks and boiler manufacturing
- Shipbuilding industry
- Steel bridge construction
- Steel structures requiring deep penetration welding

Figure 5.2: Example Cellulosic Elecktrodes in Industry

5.1.2. Differences Between Rutile and Cellulosic Electrodes

Properties of Rutile-Coated Electrodes

- Contains up to 50% titanium oxide.
- Easy to use.
- Produces a highly stable arc.
- Contains a moderate amount of oxygen (weld seam profiles are smooth).
- Slag is easy to remove.
- Not suitable for cold welding of parts thicker than 20 mm (due to its high hydrogen and oxygen content, it has low impact resistance and a high risk of cracking).
- Not suitable for high-strength steels.
- Typically used with DC current (negative - polarity) and AC current.

Properties of Cellulosic-Coated Electrodes

- Contains cellulose.
- Due to the presence of hydrogen in the arc atmosphere, its penetration is 70% higher than other electrodes.
- Weld seam profile is convex.
- Particularly suitable for vertical-down and overhead welding.
- Has a stable arc, produces very little slag, and is easy to clean.
- Generally used with DC current (positive + polarity).
- Preferred in welds requiring X-ray inspection.

5.1.3. Procedure for Butt Joint Welding with Cellulosic Electrodes

Before starting welding with a cellulosic electrode, proper preparations must be made. These preparations include:

- Wearing protective clothing since cellulosic electrodes produce excessive spatter and smoke during welding.
- Using an exhaust system if welding in enclosed spaces.

- Preparing the workpieces by opening the appropriate groove angles based on their thickness and setting the welding machine's amperage according to the electrode diameter (as indicated on the electrode packaging).
- Tacking the workpieces in the correct position before welding.
- Electrode angle and movement should follow the same techniques as used for rutile electrodes. Since less slag is formed, the molten pool is easier to control, allowing welding in any position.

The amperage setting and current type in cellulosic electrode welding vary according to electrode diameter:

- Cellulosic electrodes are generally used with DC current and positive (+) polarity.
- Welding parameters should be adjusted based on the electrode diameter and current values.

5.2. Butt Joint Welding with Basic Electrodes

Basic electrodes, which have a low-hydrogen coating, are used to produce weld seams with excellent strength and ductility.

Figure 5.3: Welding Application with Basic Electrode

- **5.2.1. Properties of Basic Electrodes**
- The electrode coating consists of calcium compounds.
- Safely used for high-strength steels and thick-section parts.
- Can be used in cold environments.
- Resistant to hot and cold cracking.
- Has low penetration, and the weld bead profile is convex.
- Due to its thick coating, droplet transfer occurs in medium-sized drops.

5.2.2. The Role and Importance of Basic Electrodes in Industry

The weld metal has high resistance to cracking.
Basic electrodes can be used in all welding positions and have excellent gap-filling capability.
Additionally, basic electrodes are highly effective in welding machine parts operating below 0°C, where other electrode types often fail.
In modern technology, one of the biggest challenges is brittle fracture, and basic electrodes are used to produce the most resistant weld seams against this issue.

Common Applications of Basic Electrodes:

- Shipbuilding industry
- Boilers and pressure vessels
- Heavy machinery and equipment industry
- Welding of unknown composition carbon and low-alloy steels
- Welding of steels containing high levels of carbon, sulfur, phosphorus, and nitrogen
- Joining steels with different carbon contents
- Welding of cast iron and steels
- Welding of components subjected to dynamic loads
- Welding of thick-section parts to reduce the risk of cracking
- Welding of machinery, equipment, and structures operating below 0°C

5.2.3. Electrode Drying Before Welding

Basic electrodes have a high moisture absorption tendency due to their coating composition, so they must be stored carefully.
Electrodes that have absorbed moisture should be dried at 250°C for at least 30 minutes before welding.
Otherwise, the moisture in the coating will cause porosity in the weld and lead to hydrogen embrittlement.
Storage and Drying of Basic and Alloy Electrodes
For electrodes that are properly stored and used shortly after being removed from their packaging, drying is not necessary.
Recommended Drying Parameters:
For general applications:

- If unalloyed electrodes are exposed to air for more than 4 hours, they should be dried at 250-400°C for 2-3 hours.
- If alloyed electrodes are exposed to air for more than 2 hours, they should be dried at 250-400°C for 2-3 hours.

For critical applications:

- If unalloyed electrodes are exposed to air for more than 2 hours.
- If low-alloy electrodes are exposed to air for more than 1 hour.
- If high-strength electrodes are exposed to air for more than 30 minutes, they should be dried at 360-420°C for 2-3 hours.

Important considerations:

- The maximum temperature should not be exceeded, but the time required for the drying unit to reach this temperature should be considered.
- If the drying unit is cold and fully loaded with electrodes, it may take up to 8 hours to reach the required temperature.
- The number of electrodes inside the drying unit is crucial for drying efficiency.
- The distribution of electrodes inside the unit significantly affects the outcome.
- The electrode at the center of the bundle will reach the target temperature later than the overall unit temperature.

5.2.4. Procedure for Butt Joint Welding with Basic Electrodes

- Basic electrodes are generally used with DC current and positive (+) polarity.
- Welding parameters should be adjusted according to the electrode diameter and current values.
- Basic electrodes must be dried at 250-300°C for 2-3 hours before welding.
- The thick coating of basic electrodes allows operation at high current intensities. However, high currents may cause the electrode to overheat quickly, so the welding process should be completed without interruptions.
- The electrode angle should be between 80-90 degrees.
- The arc length should be kept short; the gap between the electrode and the workpiece should be half the core wire diameter.
- The welding speed should be lower than that of rutile electrodes; otherwise, the slag will not sufficiently cover the molten metal, leading to poor weld quality. The slag coverage of the weld pool is directly related to the welding speed (Figure 5.4).

a) Slow b) Fast

Figure 5.4: Slag Coverage of the Weld Pool Depending on Welding Speed

- Striking the arc requires special care, especially when welding over a previously welded seam with an existing weld crater. In such cases, the arc should never be started directly on the crater. Otherwise, the previous weld crater will develop porosity.
- Therefore, the electrode should be ignited on an unwelded section and then moved backward to continue welding from the crater.
- The electrode should be struck by rubbing it against the workpiece, not by tapping.
- At the end of the electrode, a proper weld crater must be formed. When approximately 40-50 mm of electrode length remains, the welder should move back 15-20 mm along the weld seam to create a strong finish. This process should not be done too quickly, ensuring the weld pool remains liquid.
- The electrode should be held motionless for a few seconds and then removed from the workpiece to form a proper crater.
- Slag removal is more difficult in basic electrodes, and the welding speed affects this process.
- Tacking the workpieces together is preferably done using a rutile electrode.
- The electrode tip should be oriented toward the center of the crater in the horizontal position. Swinging movements should be minimized, but if necessary, slight oscillations within 2-3 times the core wire diameter can be applied.

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CAST IRON WELDING

6. LEARNING UNIT

6.1. CAST IRON WELDING

Cast irons are iron-carbon alloys containing between 2.1% and 6.67% carbon.

They may also contain phosphorus, sulfur, silicon, and manganese as additional elements.

Due to their high carbon content, cast irons exhibit:

- High wear resistance
- High compressive strength
- Low melting temperature
- Good castability

However, the high carbon content of cast iron causes rapid heating in the weld area during welding and rapid cooling after welding.

This results in internal stresses in the material.

During rapid cooling, carbon remains in the Fe_3C (cementite) structure, making the affected area harder and more brittle.

The difference in carbon distribution between the base metal and the weld area leads to additional stresses.

As a result, the risk of cracking and fractures in or near the weld zone increases significantly.

6.2. WELDING OF CRACKED CAST IRON

In modern industry, cast iron is widely used, and cracks and fractures can occur in these materials.

The purposes of cast iron welding include:

- Repairing defects that occur during casting
- Manufacturing complex parts as a single unit
- Repairing broken or worn-out parts

Except for white cast iron, all types of cast iron can be welded, but their weldability is lower compared to steels.

However, with the appropriate welding techniques, a strong bond can be achieved.

Reasons for welding cast iron:

- Low cost
- Ease of use
- Simple equipment requirements
- Does not require extensive technological knowledge

Figure 5.4: Slag Coverage of the Weld Pool Depending on Welding Speed

- content of cast iron causes rapid heating in the weld area during welding and rapid cooling after welding.
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- During rapid cooling, carbon remains in the Fe_3C (cementite) structure, making the affected area harder and more brittle.
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6.2.1. Casting Electrodes Used in Cast Iron Welding

- In the welding of cold and annealed cast iron (up to a maximum of 300°C), besides high-carbon cast iron electrodes, electrodes with a pure nickel core wire are also used (Figure 6.1).
- Purposes of Using Casting Electrodes with a Pure Nickel Core Wire:
- Used in the welding of grey cast iron, white malleable cast iron, and ductile cast iron, as well as their welding with steel.
- Especially used for joining and repair welding of broken or worn-out cast iron parts.

Figure 6.1: Casting Electrode and Information Label
a) Casting Electrode b) Electrode Information Label

- Provides excellent results in repairing casting defects through welding.
- Even at low current, it covers the base metal well and reduces the mixing ratio with the base material.
  - This allows welding without annealing, especially for thick-section parts, and minimizes the risk of cracking.
- Weld seams should be shorter than 30 mm to reduce welding stresses.
- If the weld is hammered before cooling, welding stresses can be reduced.

Since cast iron contains a high amount of carbon, it becomes brittle and hard, so it should not be hammered while cold.

Purposes of Using Monel (Nickel-Copper) Core Casting Electrodes:

- Used in cold and semi-hot (300°C) welding of grey cast iron, malleable cast iron, and ductile (spheroidal) cast iron.
- Used for welding grey cast iron to steel.
- Used for joining and repair welding of broken or worn-out cast iron parts.
- Used for repairing casting or machining defects through welding.
- No hardness issues in the transition zone, resulting in a crack-free and porosity-free weld seam.
- If the weld seam is lightly hammered before cooling, welding stresses are reduced.

Purposes of Using Nickel-Iron Core Casting Electrodes:

- Provides smooth melting and fusion.
- Has a quiet and stable arc.
- Suitable for position welding.
- Used in cold and hot welding of parts subjected to dynamic forces.
- Since the thermal expansion of the weld metal is low, it exhibits minimal shrinkage after welding.
- Has higher strength compared to pure nickel electrodes.
  - Therefore, it is highly suitable for welding ductile cast iron, malleable cast iron, grey cast iron, and their welding with steel, copper, and nickel materials.
- Easy arc initiation and re-striking with a stable arc.
- Ensures a smooth weld seam.

Figure 6.2: Casting Electrode and Information Label

6.2.2. Reverse Polarity in Cast Iron Welding

- When the electrode holder is connected to the negative (-) pole in direct current (DC), most of the heat is generated on the workpiece.
- When the electrode holder is connected to the positive (+) pole, approximately 66% of the heat is concentrated on the electrode, reducing the thermal effect on the workpiece.

6.2.3. Drilling Holes at the Start and End Points of Cracks

- For cracks that start and end within the material, holes should be drilled at both ends of the crack.
- In cast iron welding, annealing is recommended to facilitate drilling and to prevent crack propagation during welding.
- To eliminate the temperature difference between the weld seam and the base metal, the base metal should be kept at welding temperature.
- This is especially critical for large-volume parts.
- Thus, preheating the base metal before welding is necessary.

Preheating Requirements:

- A large heating torch should be used whenever possible to ensure better heat distribution.
- The workpiece should be placed on a firebrick to minimize heat loss to the surroundings.
- A support should be used to prevent warping and deformation of the workpiece.
- If the workpiece is heated in a furnace, the furnace should be preheated to the target temperature before placing the workpiece inside.

Figure 6.3: Preheating Processes

Preparation of Joint Areas

The following steps should be taken when preparing joint areas:

- Identifying the exact start and end points of the crack is crucial. If the weld is completed before reaching the actual end of the crack, the crack will continue to spread after welding.
- If the crack extends to the edge of the part, a strong tack weld should be applied at the edge before any other process.
- The exact endpoint of the crack must be determined. For this purpose, penetrant liquid, commonly used in non-destructive testing (NDT) methods, should be applied to the crack and left to settle (iodine solution can also be used for this).
  - Iodine evaporates from the surface but stains the crack down to its finest point.
- The last visible point of the crack should be identified using a magnifying glass and marked with a dot.
- A 3-4 mm hole should be drilled at the marked point to prevent the crack from spreading during and after welding. Otherwise, the crack will continue to propagate.
- If the crack reaches the outer edge of the part, the exposed end should be secured with a strong tack weld before any other process.
- If the tack weld breaks during welding, the remaining tack weld material should be removed using a chisel or grinding wheel, and a new strong tack weld should be applied.
- Welding should never continue while the edge is open. Otherwise, deformation of the part will be inevitable.
- For cracks that start and end within the part, 3-4 mm holes should be drilled at both ends of the crack.
- If the part is large and the crack is longer than 50 cm, and one end of the weld does not thermally affect the other end, short weld passes should be made first from one end, then from the other.
  - However, before starting the third pass, the first pass should be allowed to cool to the touch.
  - Additionally, as the two sides approach the center of the weld, welding should pause at both ends, and welding should continue from only one side.

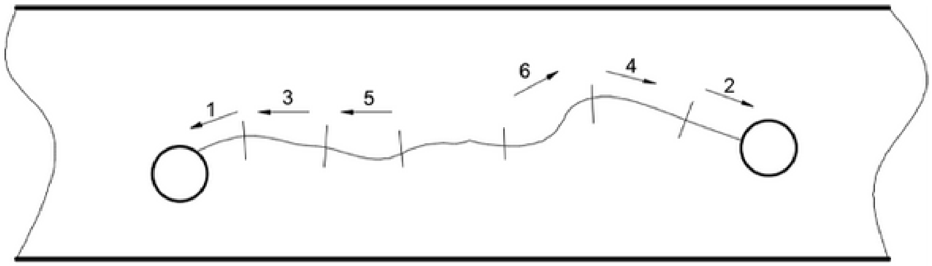

Figure 6.4: Preheating Processes

- High phosphorus and sulfur content increases the brittleness and cracking tendency of grey cast iron.
  - Oil- or grease-absorbed cast iron should be heated to 250°C for a few hours before welding.
  - In some cases, it should be exposed to high temperatures of the electric arc to remove oil or grease.
  - For this, a rutile electrode should first be used to apply a filler layer to the welding area, which is then cleaned.
- The casting skin, which becomes oxidized during cooling and prevents proper adhesion of the electrode metal to the base metal, should be ground before welding.
  - The grinding should be done on both sides of the weld area, with a width of at least 10 mm and a depth of 1 mm.
- Sharp edges must be removed with a file.
  - Otherwise, thin, sharp parts may burn during welding and mix into the weld seam as oxides.
- For cracks longer than 50 cm, short weld passes should be made starting from the ends.
  - The third pass should only be applied after the first pass has cooled to the touch (Figure 6.5).
- As weld passes approach the center of the crack, welding should be paused before continuing with the final pass.

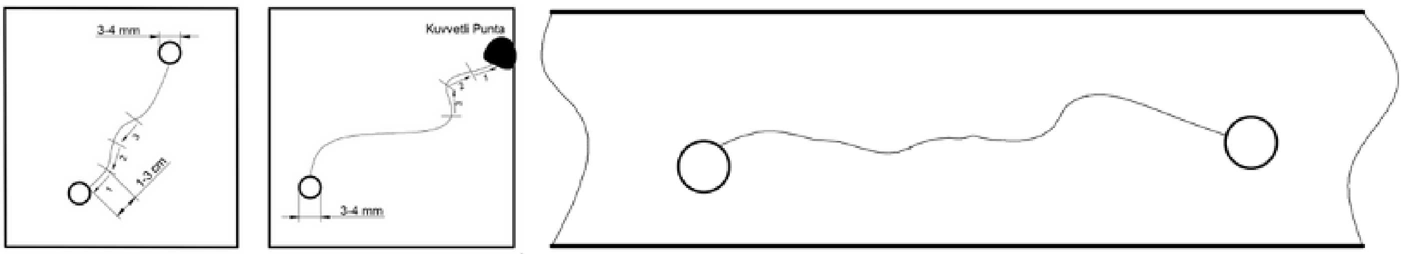

Figure 6.5: Pass Sequences in Cracked Castings
a) Passes in a crack within the part
b) Passes in a crack extending to the edge of the part
c) Pass sequence for cracks longer than 50 cm

6.2.4. Importance of Groove Preparation for Welding Thick-Sectioned Cracked Cast Iron

- The weld groove should be prepared according to the thickness of the section.
- If the groove is not adequately opened, two major problems may arise:
- Increased risk of the crack opening further during welding.
- Insufficient strength in the welded section, leading to a new crack that may soon become irreparable.
- Steps for Groove Preparation in Cracked Cast Iron Parts:
- The sides of the opened weld groove should be ground to a minimum width of 10 mm and a depth of 1 mm to remove oxide layers.
- The weld groove should only be opened after drilling holes at the crack endpoints.
- The weld groove shape should be designed according to the thickness of the section:
- It should have a U or double U shape depending on the thickness.
- A 2 mm gap should be left at the bottom of the groove.

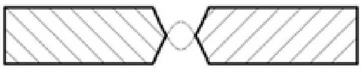


Figure 6.6: a) Weld Groove Cross-Section b) Weld Groove

Figure 6.7: Peening of the Weld

- Once the part has cooled to a temperature that can be touched by hand, a 1-3 cm weld should be applied.
  - Welding should never start from the end but always from the inside, progressing toward the end of the crack.
- Before starting the next 1-3 cm weld, the end of the previous weld pass must be cleaned using a grinding wheel or chisel.
- In multi-pass welding, the first pass should be completed faster than the following passes.

6.2.5. Welding Procedure for Cracked Cast Iron

When welding cast iron, it is essential to remember that carbon clusters within cast iron can absorb oils and other fluids.

- If these fluids are not removed before welding, they can cause porosity in the weld.

Important Considerations Before Welding:

- The welding area must be cleaned of all foreign substances (oil, grease, rust).
- The type of cast iron must be identified.
- The electrode must be selected according to the casting material.

Welding of Cast Iron

- The entire workpiece should be heated to approximately 200-300°C to prevent hardening in the transition zone and reduce shrinkage stresses.
- Nickel or nickel-based alloys should be used as filler material.
- An entire electrode can be burned in one go, but the weld seam must be hammered immediately after welding.
- If the workpiece is heated above 600°C, welding should be done with filler metal that matches the base metal composition.

Since cast iron welding requires high precision and experience, proper techniques are essential.

- Different types of cast iron—such as grey cast iron, ductile iron, and malleable cast iron—require specific welding procedures.
- Some cast iron parts may undergo structural changes due to external factors, such as operating conditions.
  - Example: Cast iron valves exposed to high-pressure steam for long periods.
  - These materials become extremely brittle, and gas penetration into microvoids reduces strength, making welding nearly impossible.
- Prolonged exposure to direct fire or high temperatures can cause carbon and silicon to oxidize, making the material difficult to melt.

Post-Welding Cooling Process

- After welding, the entire workpiece should be heated to a temperature close to the welding temperature.
- The part should be slowly cooled by placing it in asbestos material or a still-air environment to prevent rapid cooling and cracking.

6.2.6. Application of Welding Method and Post-Welding Processes

- Use the thinnest possible electrode (Ø2.5 or 3.25 mm) and apply low current intensity while keeping the arc short.
- Never exceed the maximum recommended amperage setting.
- Weld seam lengths should be limited to 4-5 times the electrode diameter.
- Use direct current (DC) welding.
- Periodically pause to prevent excessive heat concentration in one area.
- Each weld should be hammered immediately after welding.
  - The hammering process should start from the hottest part of the weld and move backward.
- Controlled stops should be made to ensure the part's temperature does not exceed 70°C.
- Short weld beads should be applied to reduce welding stresses.
- After welding, the entire workpiece should be heated close to the welding temperature and slowly cooled in asbestos or a still-air environment.

6.3. WELDING OF BROKEN CAST IRON

- Heat input in cast iron welding should be kept as low as possible.
- Higher heat input increases the likelihood of breakage in the welded area or heat-affected zone (HAZ).
- Rapid heating and cooling make cast iron more brittle.

6.3.1. Importance of Groove Preparation for Welding Thick-Sectioned Broken Cast Iron

If the weld groove is not opened sufficiently, two major issues may arise:

1. Increased risk of crack propagation during welding.
2. Insufficient strength, which may later result in an irreparable crack during operation.

Steps for Groove Preparation in Broken Cast Iron Parts:

- The weld groove should be opened according to the thickness of the section.
    - The groove should be in V or X shape with an angle of 80-90°, depending on thickness.
    - A 2 mm root gap should be left at the bottom.

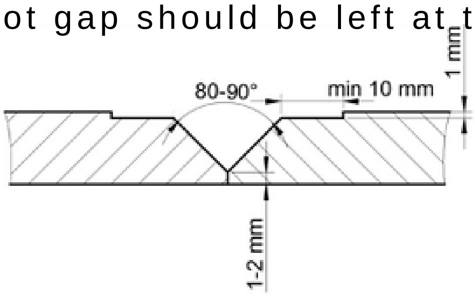

Figure 6.8: Advanced Weld Groove Design

- Sharp edges on both sides of the groove should be rounded.
- Each broken part should be prepared with the groove mentioned above and then tack welded at appropriate intervals (Figure 6.9).

6.3.2. Welding Process for Broken Cast Iron

Before welding, the following factors must be considered:

- Identify the type of cast iron being welded.
- Select the appropriate electrode based on the casting material.
- Ensure all parts are cleaned of foreign substances (oil, grease, rust, etc.).

6.3.3. Application of Welding Method and Post-Welding Procedures

- In multi-pass welding, the first pass should be applied faster than subsequent passes.
- The arc length should be kept short, approximately equal to the electrode core diameter.
- Weld beads should be limited to 1-3 cm at a time and immediately hammered and brushed after each pass.

Figure 6.9: Weld Groove Preparation

- Use the thinnest possible electrode (Ø2.5 mm or 3.25 mm) and apply low current intensity while keeping the arc short.
- Never exceed the maximum recommended amperage setting.
- Weld bead lengths should be limited to 4-5 times the electrode diameter.
- Use direct current (DC) welding.
- Pause intermittently to prevent excessive local heat concentration.
- Each weld bead must be immediately hammered after welding.
    - The hammering process should start from the hottest part of the weld and move backward.
- Welding should be stopped periodically to keep the workpiece temperature below 70°C.
- Short weld passes should be applied to reduce welding stresses.
- The weld seam should be hammered before it cools to minimize internal stresses.
- After welding, the entire workpiece should be heated to a suitable temperature and slowly cooled.

Figure 6.10: Welded Broken Cast Iron

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WELDING OF NON-FERROUS METALS

7. LEARNING UNIT

7.1. COPPER WELDING
7.2. BRASS WELDING
7.3. WELDING OF ALUMINUM AND ITS ALLOYS

7.1. COPPER WELDING

Among non-ferrous metals, copper (Cu), aluminum (Al), and brass alloys are the most commonly used materials.

- Copper has a melting point of 1083°C and is the second-best thermal and electrical conductor after silver (Ag).
- Its high sensitivity to oxygen causes a thin oxide layer to form on its surface.
- Due to this oxide layer, copper has high corrosion resistance.
- Over time, copper forms a green-colored oxide layer on its surface, which can be harmful to human health.
    - Therefore, copper utensils used in the food industry and kitchens are coated with tin.

Types of Copper

There are two types of copper commonly available in the market:

1. Pure Copper (99.9% Cu)
2. Electrolytic Copper, obtained by subjecting pure copper to an electrolysis process

Additionally, copper alloys with different properties and applications are formed by adding elements such as:

- Tin (Sn)
- Zinc (Zn)
- Nickel (Ni)
- Silicon (Si)
- Aluminum (Al)
- Phosphorus (P)

Importance of Copper Welding in Industry

- Many copper and copper alloy products are designed for various electrical, mechanical, and architectural applications.
- Although not all copper alloys are equally easy to weld, all copper and copper alloys can be welded.

The increasing use of TIG and MIG welding methods has limited the use of shielded metal arc welding (SMAW) with covered electrodes for copper.

- However, SMAW is still preferred due to its simplicity, affordability, portability, and widespread availability.

Shielded metal arc welding (SMAW) for copper is primarily used for:

- Joining and repair welding of components
- Parts with thicknesses less than 25 mm
- Applications that are not exposed to severe chemical corrosion or heavy loads

Figure 7.1: Copper Welding

7.1.1. Importance of Reverse Polarity in Copper Welding

When welding copper and its alloys with covered electrodes, it is generally done using Direct Current Reverse Polarity (DCRP).

- This ensures that two-thirds of the heat is concentrated near the positive (+) pole.
- In this case, the arc temperature exceeds 3500°C.
- The remaining one-third of the heat is concentrated near the negative (-) pole, where the workpiece is connected.

Since an electrode connected to the positive (+) pole melts faster than one connected to the negative (-) pole, the required heat to melt copper is achieved more quickly.

For thick-coated electrodes, higher heat input is required for proper combustion, making operation with the positive (+) pole more effective.

7.1.2. Preheating Process

Copper has high thermal conductivity, which causes heat to dissipate into the surrounding material during welding, making the welding process more difficult.

- This issue can be resolved by preheating the material before welding.
- Generally, preheating is applied to parts thicker than 2 mm at approximately 200-300°C using an oxy-acetylene flame.
- For parts thicker than 6.5 mm, the preheating temperature can go up to 500°C.

7.1.3. Heat Collecting Backing Plates The unique properties of copper significantly impact its weldability.

- Although copper has a lower melting point (1083°C) compared to steel (1535°C), it is more challenging to weld.
- This is because copper has five times higher thermal conductivity than steel, requiring more heat input during welding.
- Additionally, the heat applied during welding spreads to the surrounding material, causing heat loss.

To minimize heat dissipation, the following methods are used:

- Preheating the material
- Using heat-collecting backing plates made of copper or steel

Figure 7.1: Copper Welding

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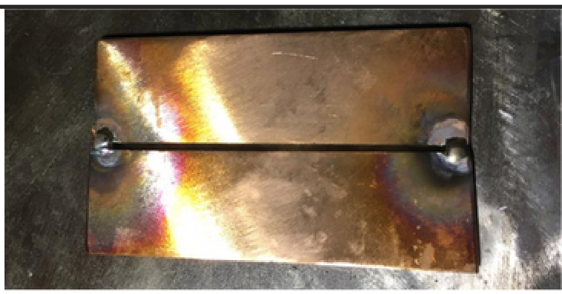

Figure 7.2: Backing Plate Used in Copper Welding

One of the major challenges in copper welding is its high thermal expansion.

- Due to this characteristic, the heat applied during welding causes visible deformation in the part.
- When the heat is removed, copper contracts at the same rate, making welding more difficult.
- This expansion and subsequent contraction can lead to cracking in welded joints.

Compared to steel and its alloys, copper welding requires:

- A wider groove angle and root gap
- More tack welds
- Higher preheating between passes

Additionally:

- The largest possible electrode diameter should be selected based on the thickness of the material.
- Whenever possible, welding should be done in the horizontal position.

7.1.4. Copper Welding Process

In copper welding, groove design and angles generally do not differ significantly from those used for steel.

Pre-Weld Preparation

- For parts up to 3.5 mm thick, butt welding without a root gap is possible.
- For thicker sections, a single V-groove (60-90°) or a double V-groove (70-90°) should be used.
- The root gap should not exceed 3.5 mm.

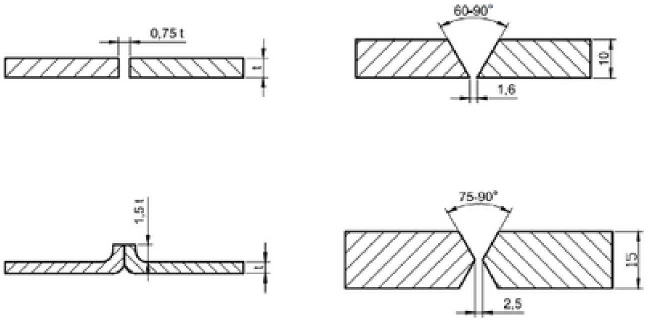

Figure 7.3: Weld Groove and Dimensions Used in Copper Welding

Oil, dirt, and oxides on the surface of the parts to be welded must be thoroughly cleaned using a wire brush and sanding stone before welding and then dried.

Figure 7.4: Cleaned Copper Surface

Electrodes Used in Copper Welding

The copper and its alloys available in the market have different chemical compositions.

- To ensure high-quality welding, the electrodes used must be compatible with these chemical compositions.
- Due to this, various types of electrodes with different chemical compositions are available.
- Electrodes are classified according to the American Welding Society (AWS) standard A 5.6.

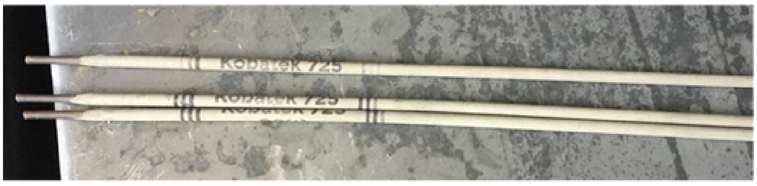

Figure 7.5: Copper Electrode

- Pure copper electrodes are used for welding pure copper, as well as for repair welding of coatings on cast iron and steel.
- Silicon bronze electrodes are used for welding brass, copper, and some iron-based alloys.
- Phosphor bronze electrodes are used for welding brass and phosphor bronze.
- Copper-nickel alloy electrodes are used for welding copper-nickel alloys and for applying copper-nickel coatings on steel.
- Aluminum bronze electrodes are used for welding aluminum bronze, as well as for joining copper alloys with other types of alloys.

Arc Length, Electrode Movements, and Amperage Adjustment

In shielded metal arc welding (SMAW) of copper, the arc length (the distance between the electrode and the workpiece) should be kept short, generally around 3 mm.

- The electrode should be held at an angle of 60-80 degrees to the workpiece.

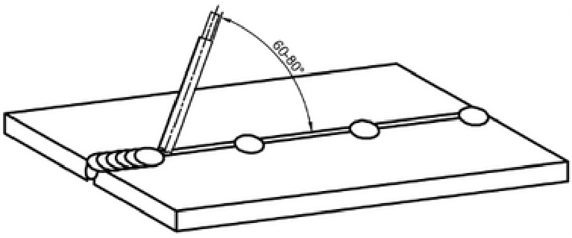

Figure 7.5: Electrode Angle in Copper Welding

- The electrode should be given a slight oscillation movement, but this movement should not exceed twice the electrode diameter.
- Welding should be performed in the horizontal position whenever possible.
- The current setting on the welding machine should be 50 amps per millimeter of electrode diameter.

Formula for Calculating Current Intensity:

I=50×dI=50×d

Where:

I = Current intensity (amperes)

50 = Constant coefficient

d = Electrode diameter (mm)

7.1.5. Application of the Welding Method and Post-Weld Procedures

1. **P**re-Weld Preparation
   - The edges of the workpieces should be thoroughly cleaned of oil, dirt, and moisture.
   - The appropriate root gap should be left, and the weld groove should be prepared.
2. Workpiece Positioning
   - Based on the root gap, flat or specially shaped backing plates should be clamped to the workpieces using a vise.
3. Preheating
   - For materials thicker than 2 mm, preheating between 200-300°C should be applied.
   - An electrode matching the chemical composition of the material and close to the thickness of the workpiece should be selected.
   - The electrode should be connected to the positive (+) pole.

4.Welding Process
- The current should be adjusted based on the electrode diameter.
- The arc length should be kept short.
- The electrode should be held at a 60-80° angle to the workpiece.
- A small oscillation movement should be used while welding.
- Slow cooling should be ensured after welding.

5.Post-Weld Cleaning
- Slag should be removed from the welded joint.
- Rapid cooling should be avoided to prevent shrinkage and cracking of the weld metal.

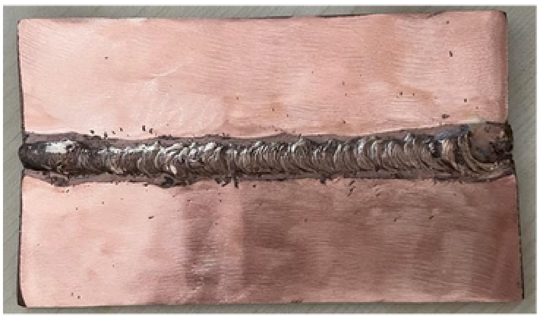

Figure 7.5: Copper Joint Welding

7.2. BRASS WELDING

Brass is an alloy of copper (Cu) and zinc (Zn). Its melting temperature varies depending on the zinc content, approximately 900°C.

Brass Alloy and Its Industrial Applications

Brasses are generally categorized into three groups based on their zinc content and alloying elements. If the zinc content is below 20%, it is called low-zinc (red) brass, while if it exceeds 20%, it is referred to as high-zinc (Muntz metal) brass. In addition to copper and zinc, elements such as tin (Sn), manganese (Mn), aluminum (Al), iron (Fe), and phosphorus (P) can be included in the composition, forming low-alloyed brasses.

Their resistance to machining, cold forming, and external effects are among their most important properties. High fatigue strength, good mechanical properties, and affordability make them suitable for use in the defense industry, shipbuilding, light bulb sockets, musical instrument components, and screw manufacturing.

The Importance of Brass Welding in Industry

Brass has a broad range of copper-zinc alloys, which can further expand with the addition of lead, aluminum, tin, phosphorus, silicon, and manganese. This results in a variety of different welding behaviors.

Since lead-containing manufacturing brasses tend to form porous structures and become brittle at high temperatures, they are preferably joined using soldering instead of welding. Additionally, due to the formation of a brittle aluminum layer during welding, the MIG or TIG welding methods are preferred.
When the correct electrode selection is made based on the zinc content and alloying elements, high-quality welds can be achieved using shielded metal arc welding (SMAW). Furthermore, this method is applicable where high tensile and fatigue resistance are required.

7.2.1. Importance of Reverse Polarity in Brass Welding

An electrode suitable for the brass alloy is selected and connected to the positive (+) terminal.

7.2.2. Preheating

Before welding, brass parts are preheated to 200-300°C. Since silicon-containing brasses are brittle, preheating is not applied to them. The interpass temperature should not exceed 93°C.

7.2.3. Importance of Ventilation Against Zinc Evaporation

Since the primary metal in brass is copper, brass welding exhibits characteristics similar to copper welding. However, the presence of zinc makes welding more challenging. The welding temperature (900°C) is higher than zinc's melting point (420°C), and as the welding process progresses, zinc begins to evaporate (at 905°C), altering the alloy's chemical composition.
If proper ventilation is not ensured, the welder may be exposed to harmful zinc oxide fumes. Additionally, zinc oxide fumes obscure vision, hinder the flow of molten metal, and prevent the proper wetting of the welding surface. Excessive evaporation leads to significant zinc loss, which affects the physical and mechanical properties of the base metal. To achieve the best results and minimize zinc evaporation, welding should be performed in a horizontal position, using the largest possible electrode diameter and applying fast weld passes.

7.2.4. Brass Welding Process

Before welding, surface cleaning must be performed.
Cleaning of Brass Components Before Welding
As in copper welding, any grease, dirt, and oxides on the surface of brass materials must be thoroughly cleaned using a wire brush and grinding stone. If these contaminants are not removed, they reduce weld strength and complicate the welding process.

Figure 7.6: Copper Joint Welding

Electrodes Used in Brass Welding

The electrodes used in brass welding are selected based on the zinc content and the desired properties of the weld seam.

- If the zinc content is below 20%, phosphor bronze [(E Cu Sn-A) and (E Cu Sn-C)] or silicon bronze (E Cu Si) electrodes are used.
- If the zinc content exceeds 20%, phosphor bronze and silicon bronze electrodes, as well as aluminum bronze (E Cu AlA2) electrodes, can be used.

Figure 7.7: Brass Electrode

Aluminum bronze electrodes are used in cases where high tensile strength, fatigue resistance, and good corrosion resistance are required. Medium-quality welds can be achieved with silicon bronze and aluminum bronze electrodes.

Weld Groove Shapes and Dimensions in Brass Welding

- For brass materials up to 4 mm in thickness, butt welding is applied.
- For thicker materials, a 60-degree single or double-sided V-groove is created.
- Welding is generally performed in a horizontal position.
- Compared to steel materials, a wider gap is left between the two materials.

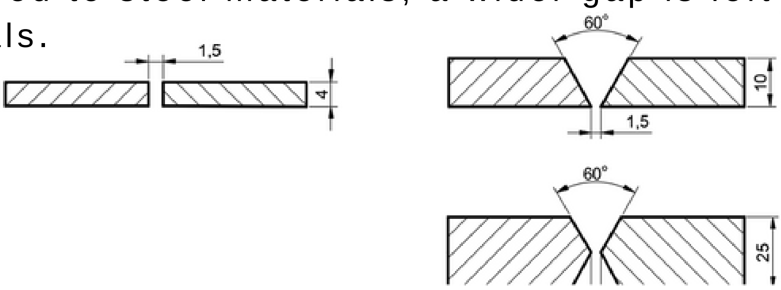

Figure 7.8: Weld Groove Shapes and Dimensions Used in Brass Welding

Electrode Arc Length, Movements, and Amperage Setting

- In the welding of brass materials, the arc length should be kept short. To prevent zinc vaporization, the weld pool should be kept as small as possible. Excessive oscillation movement of the electrode should be avoided. The horizontal angle between the electrode and the material should be between 75-85 degrees.

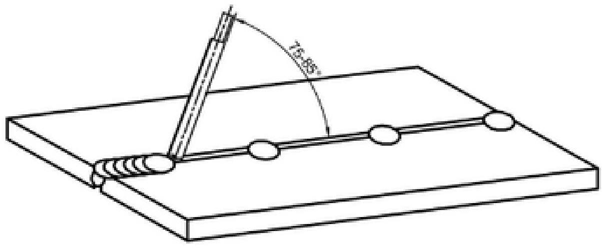

Figure 7.9: Angle to be Given to the Electrode in Brass Welding

The amperage setting is calculated using the following formula, as in copper welding:
d: Electrode diameter
I: Amperage setting
$I = 50 \times d$

7.2.5. Application of the Welding Method and Post-Welding Procedures

• The oil and dirt on the edges of the materials to be welded are cleaned. For materials thicker than 4mm, a 60-degree single or double-sided V groove is opened, and a wider gap is left between the materials compared to steel materials.

Figure 7.10: Weld Groove Shapes and Dimensions Used in Brass Welding

The electrode is held at angles of 75-85 degrees to the materials and welded in a horizontal position with a short arc length and minimal oscillation movement.
• Zinc vaporization may occur during welding, which is harmful to human health. Therefore, the welding environment must be very well ventilated.
• The welded piece is cooled slowly, and the welding slag is broken and cleaned.

Figure 7.11: Brass Joint Welding

7.3. WELDING OF ALUMINUM AND ITS ALLOYS

After steel, the most consumed metallic material is aluminum (Al) and its alloys. It is a silver-colored metal with a melting point of 660°C. Pure aluminum is soft and has one-third the weight of steel. Due to its sensitivity to oxygen, it forms a strong and thin oxide layer (Al_2O_3) on its surface, which makes it highly resistant to oxidation and protects it from external factors.

Aluminum is produced from bauxite, the most abundant ore. Depending on the elements contained, bauxite is classified into four groups: white bauxite, red bauxite, siliceous red bauxite, and brown bauxite. In general, aluminum alloys are divided into two groups: heat-treatable alloys and non-heat-treatable alloys.

The Role and Importance of Aluminum Welding in Industry

Due to its lightweight, good thermal and electrical conductivity, and corrosion resistance, aluminum is widely used in the food industry, chemical industry, automotive and shipbuilding industry, machinery and equipment manufacturing, as well as architectural applications and construction.

Today, approximately 50% of aluminum alloy joints in various industries are made using welding. Shielded metal arc welding (SMAW) for aluminum is not commonly used as it generally does not meet the desired conditions.

7.3.1. The Importance of Reverse Polarity in Aluminum and Alloy Welding

In welding with direct current (DC) power sources, the electrode is connected to the positive (+) terminal.

7.3.2. Drying Electrodes Before Welding

According to the American Welding Society (AWS) A 5.3 standard, two types of electrodes are used in the electric arc welding of aluminum: E1100 and E4043. Alloy 1100 is commercially pure (99%) aluminum, while alloy 4043 contains 95% aluminum and 5% silicon and is suitable for most general-purpose applications.

Figure 7.12: Aluminum Electrode

The weld metal has strength. When corrosion resistance is required, an electrode with properties similar to the material being welded should be selected. Electrodes should be stored in dry environments. Moist electrodes cause porosity in the weld seam. Therefore, electrodes that are not completely dry should be baked in an oven at 175-200°C for about one hour to dry them properly.

7.3.3. Cleaning Aluminum and Its Alloys' Surfaces with Mechanical and Chemical Solutions

The parts to be welded usually arrive at the welder's station after being cut and shaped. These processes cause the formation of oil layers, dust, and burrs on the material surface.

The hydrogen, oxygen, and porosity found in oils and greases create foam, reducing welding quality. Therefore, oils on the surface of the material are removed chemically, while chemically formed dust and burrs are cleaned mechanically. The welding joint area should be cleaned with a stainless steel wire brush, and to completely remove the oxide layer from the surface, the area must be scraped (see Figure 7.13).

Figure 7.13: Aluminum part with a cleaned surface

7.3.4. The Process of Welding Aluminum and Its Alloys

The shielded electrode electric arc welding method can be used for welding all types of aluminum and non-heat-treatable alloys. Aluminum has a strong tendency to absorb oxygen, especially at high temperatures. Although the oxide layer that forms on the surface is beneficial, it causes significant problems during the welding process. This is because the melting point of the oxide layer (2100°C) is much higher than that of aluminum. During welding, excessive heat is required to melt the oxide, causing the base metal to melt suddenly and collapse. To address this issue, the oxide layer on the surface of the aluminum must be removed before welding.

The high tensile stresses of aluminum alloys and the lack of proper fixation of the pieces to be joined can lead to the formation of hot cracks in the weld metal. These cracks can be minimized by preheating, modifying the joint design, and selecting a more suitable electrode.

Aluminum materials are generally not tack-welded unless necessary, and a single-pass weld bead is preferred. This is because aluminum oxidizes quickly when exposed to heat, requiring repeated cleaning when tack welding or performing multiple weld passes. Instead, aluminum materials are secured using weights and various fastening elements. After tack welding and bead application, a crater forms at the tip of the electrode, covering its end and preventing arc formation. Therefore, the crater at the tip of the electrode must be opened with a side chisel.

Figure 7.14: Backing used in aluminum welding.

The Importance of Weld Seam Cleaning in Aluminum Welding

Thick aluminum materials need to be welded with multiple passes. Therefore, slag must be thoroughly cleaned after each pass.

Figure 7.15: Weld Seam Cleaning in Aluminum Welding
a) Slag not cleaned b) Slag cleaned

Otherwise, slag residues will form and may cause cracks. The slag formed must be thoroughly cleaned after each weld seam using a pointed welding chisel or a wire brush. Additionally, the weld surface should be scraped to remove the oxide layer formed during welding. These processes are essential for the strength of the weld.

Weld Groove Preparation for Aluminum Materials

- For materials up to 4.5-5 mm in thickness, a square butt weld is applied. If the edges are cut precisely and squarely, no additional preparation is required.
- For thicker materials, a single or double-sided V-groove is prepared at an angle of 60-90 degrees.
- Depending on the thickness, the root face is set between 1.5-6 mm, and the root gap is between 0.8-1.5 mm.

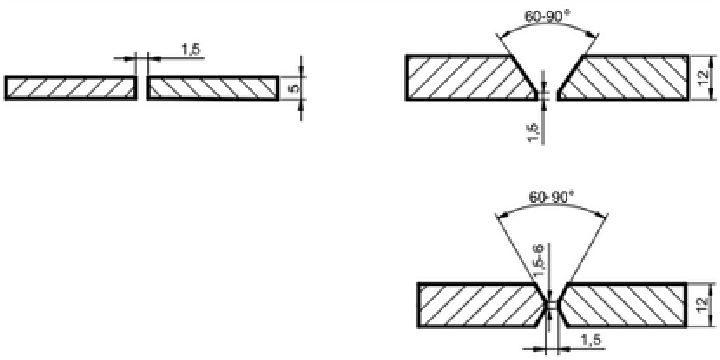

Figure 7.16: Weld Groove Shapes and Dimensions Used in Aluminum Welding

Preheating in Aluminum Welding

- Generally, preheating is not applied to materials with a thickness of up to 5 mm.
- For aluminum materials thicker than 5 mm, preheating around 200°C is applied.
- This process can be carried out using an oxy-acetylene flame.

7.3.5. Application of the Welding Method and Post-Welding Procedures

The weld grooves of the parts to be welded are prepared, and surface cleaning is performed before welding

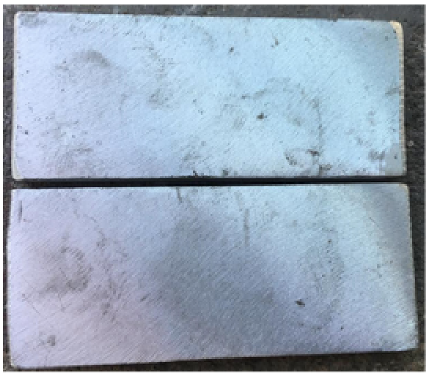

Figure 7.17: Aluminum part with surface cleaning

After the cleaning process, welding should be performed without delay.

• To prevent internal stresses and distortions, the parts are tack-welded or fixed with weights. After tack welding, the same initial cleaning process is repeated.

• Since both the aluminum electrode and the base metal melt and solidify quickly, electrode sticking can be an issue. Therefore, the electrode is ignited by making a brushing motion on the surface of the base metal.

• The electrode should be held at 90 degrees initially and then at 60 degrees in the direction of the weld seam as welding progresses.

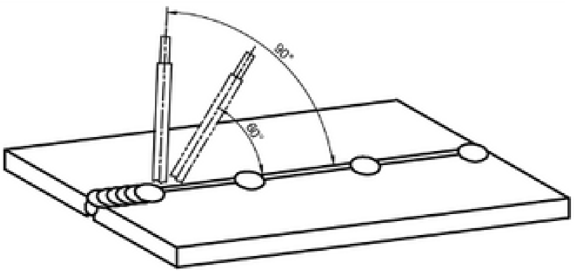

Figure 7.18: Holding the electrode at a 90-degree angle initially and at a 60-degree angle as welding progresses.

The electrode should not be tilted too much as it causes porosity and spattering.

- Care should be taken to control the electrode so that the slag floats on the weld pool.
- The electrode should not be moved excessively from side to side.
- The arc length should be short (3-5 mm) to prevent excessive melting.
- If possible, a single-pass weld should be preferred. Multiple passes are generally avoided due to potential difficulties in cleaning the flux coating from the weld surface.
- If multiple passes are required, the same cleaning process should be applied after each pass.
- The slag should be cleaned at the end of the welding process.

Figure 7.19: Aluminum Joint Welding

At the end of the welding process, the slag formed on the weld is mechanically cleaned using a wire brush and a pointed chipping hammer.

- Additionally, the weld seam is cleaned by applying steam or scrubbing with hot water.
- The presence of slag residues between passes or on the surface is checked by applying a 5% silver nitrate solution to the weld area. If slag remains, it foams and reveals itself.

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WELDING METHOD FOR ALLOYED STEELS

8. LEARNING UNIT

8.1. WELDING OF ALLOY STEELS

Although carbon steels are economical to produce, they do not meet all requirements. In particular, due to their low wear resistance and toughness properties, alloying is performed to enhance or modify the desired properties of the steel.

8.2. WELDING OF STAINLESS STEELS

Steels that contain 12% or more chromium are called stainless steels. A very thin but impermeable chromium oxide (Cr_2O_3) layer forms on the surface of these steels, preventing rust from penetrating inward.

If only nickel is present as an alloying element in steel, it makes the steel resistant to corrosion. However, the synergistic structure formed by using nickel together with chromium provides much higher corrosion resistance. Molybdenum is another element that enhances corrosion resistance, but it is expensive.

The different types of stainless steel structures are as follows:

- Austenitic stainless steels
- Ferritic stainless steels
- Martensitic stainless steels
- Duplex stainless steels
- Precipitation-hardened stainless steels

Arc Welding of Austenitic Stainless Steels

The welding of chromium-nickel stainless steels involves joining them with other steels or rolling product stainless steels. If stainless steel parts require repairs, welding is again used. In the welding of austenitic stainless steels, covered electrode arc welding, as well as TIG and MIG welding methods, are commonly used.

Covered electrode arc welding is frequently applied in the welding of austenitic stainless steels, where electrodes with similar compositions are preferred. During the process, proper welding sequence is followed to minimize welding stresses. For thick sections, preheating between 100-150°C and hammering the weld bead after each pass are methods used to reduce welding stresses. To prevent carbide precipitation and subsequent intergranular corrosion, the welded area should be rapidly cooled. This method is applied only to steels containing more than 0.06% carbon. In the case of repairing casting defects in stainless steel castings, a solution heat treatment and rapid cooling should be performed after welding. Any heat treatment applied to the casting must also be applied after the repair.

Austenitic chromium-nickel stainless steels are susceptible to hot cracking, especially when using covered electrode arc welding. The precautions and considerations to avoid this include:

- Selecting the smallest possible electrode diameter
- Applying the lowest current intensity
- Avoiding zigzag movements of the electrode and making thin weld passes
- Cooling the workpiece to room temperature between passes in multi-pass welding
- Ensuring that the crater at the end of the weld is properly filled
- If cracks are detected, grinding them away before proceeding with welding

For these steels, welding materials with a high manganese content are used. Experiments have shown that austenitic welds containing 7-10% manganese provide better resistance to hot cracking at high temperatures.

Arc Welding of Ferritic Stainless Steels

Ferritic stainless steels are best welded using TIG, MIG, and plasma welding methods, as they incorporate a shielding gas. Therefore, ferritic stainless steels are not welded using conventional arc welding.

Arc Welding of Martensitic Stainless Steels

Various types of electrodes are used for manual welding of these steels. The composition of these electrodes may match that of the base metal, but sometimes the proportions of elements like carbon, manganese, and chromium are adjusted to account for potential depletion in the molten metal.

For high-carbon steels (C > 0.50%), the carbon content is modified to reduce brittleness after solidification. The composition of the molten metal is also adjusted to ensure a high austenite content, which provides significant ductility. This type of filler metal is suitable for high-carbon and precipitation-hardened steels but may negatively affect wear resistance in abrasive environments.

Typically, basic-coated electrodes (+ electrode) are used, and a very short arc is maintained. In difficult positions (such as vertical or overhead welding), lower current intensity is applied. The recommended current intensity varies depending on the specific welding conditions.

The joint preparation for high-alloy steels is similar to that of regular steels. For thicknesses up to 3 mm, welding can be done in a single pass, but in such cases, a backing plate should be used. In multi-pass welding, proper fusion of the root pass and the surface finish of subsequent passes must be ensured. Slag should be thoroughly cleaned between passes using a stainless steel brush and chisel, ensuring that the temperature of the joint does not fall below the preheat temperature.

Current Types, Electrode Movements, Arc Length, and Amperage **Settings in Stainless Steel Welding**

A short arc length and low current intensity should be used in welding stainless steels. For covered electrode welding, either DC with a positive (+) electrode or AC/DC electrodes is commonly used. Rutile electrodes are preferred for welding thin stainless steel sheets in flat positions. However, when material thickness exceeds 2 mm, basic electrodes should be used.

With technological advancements, new electrode products continue to be introduced. Before starting the welding process, the information on the electrode package should be reviewed to ensure it matches the workpiece and welding position.

Stainless steel electrodes generate more fumes compared to other electrodes, so special precautions should be taken for health and safety.

After welding stainless steel, the high heat causes oxidation around the weld, resulting in discoloration or darkening. To remove this discoloration, special pastes are used. Since these pastes contain strong chemicals, direct skin contact should be avoided, and necessary precautions should be taken before using them.

Figure 8.1: Oxidation of Stainless Steel Weld Metal

Electrode Selection for Stainless Steel Welding

The type of stainless steel to be welded is determined from the information label of the part. Then, the appropriate electrode is selected based on the information label of the electrode.
If the information matches, welding can proceed. The determination of matching information is done in light of the following details:
Carbon and alloyed steels have low electrical conductivity resistance. In stainless steels, this value is 4 to 7 times higher. Therefore, stainless steel electrodes heat up more quickly, are produced shorter, and are loaded with a current intensity that is 25% lower compared to normal electrodes.

8.2.1. Process Steps in Stainless Steel Welding

- The area to be welded must first be free from paint, varnish, and other foreign substances. Moisture, sulfur, and other chemical substances negatively affect the quality of the weld.
- For high-quality welding, the best quality stainless steel material and electrodes should be used.
- The welding groove should be properly and appropriately opened.
- A grinding tool or stainless steel wire brush should be used for cleaning welding slag and spatter.
- Electrodes must be well protected from moisture. Unused electrodes should be stored in special racks or drying ovens.
- The welding groove should be dried with a torch or dry air to remove moisture.
- For 300 series stainless steels, preheating and post-weld heat treatment are not required.
- To keep the heat input low, small-diameter electrodes should be used.
- Electrodes compatible with the base alloy or one grade higher in the same group should be used.
- If proper precautions are not taken during cooling in 300 series stainless steel welding, cracks may occur in the weld.
- In horizontal and flat welding, the electrode should be held at an angle of 150 degrees in the welding direction, and a short arc length should be maintained.
- In vertical welding, the electrode should be held perpendicular to the plate and moved over the first pass with slight oscillations.
- Overhead welding should be performed with a short arc and without excessive electrode movement.

- The best wear resistance is achieved with low amperage and direct current flat welding.
- Very low amperage can cause an unstable arc, electrode sticking, slag formation, and difficult cleaning, leading to losses in wear resistance.
- Very high amperage or a long arc length can distort the welding sequence and cause cracking.
- If the slag is difficult to clean, the possible reasons could be:
  - The welding groove is dirty or narrow.
  - The welding passes are not uniform.
  - The electrode has absorbed moisture.
  - The weld has not fully cooled.
- Cracking in stainless steel welding can occur due to:
  - Crater formation in the passes.
  - Leaving a long arc length at the start and end of the weld.
  - Overheating the part.
  - Rapid welding passes.
  - Incorrect welding groove preparation.
  - Using the wrong electrode type.
- Since stainless steel is smooth and clean, deep penetration is not required. Ensuring complete fusion in the final passes is sufficient.

8.2.2. Application of Stainless Steel Welding and Post-Weld Procedures

- The area to be welded is first cleaned of paint, varnish, and other foreign substances.
- The highest quality stainless steel material and electrodes are used for a high-quality weld.
- The weld groove spacing is adjusted.
- A grinding tool or stainless steel wire brush is used to clean welding spatter and slag.
- Electrodes are removed from the drying oven.
- Preheating and post-weld heat treatment are performed.
- In horizontal and flat welding, the electrode is held at an angle of 150 degrees in the welding direction, and a short arc length is maintained.
- The electrode is moved across the plate with slight oscillations.
- Slag is cleaned after welding

8.3. WELDING OF TOOL STEELS

Application Areas of Tool Steels

Tool steels are generally used in the production of various work tools such as drills, deep drawing dies, punches, and all types of cutting blades. Therefore, they are primarily utilized in the processing and shaping of fundamental materials, especially metals.

Welding is performed on tool steels found in all professional workshops for two main reasons:

- Repair and maintenance of worn-out parts
- Joining of broken tools

In cases where welding is necessary, proper welding preparations should be carried out before proceeding with the process.

8.3.1. The Welding Process of Tool Steel

The welding of tool steels is not significantly different from other welding methods. The most crucial aspect is selecting the appropriate electrode for the steel.

When welding the hard tip tools of machinery, electrodes should be chosen according to their hardness level. These electrodes include:

- Austenitic electrodes with carbon and nickel for areas exposed to minimal wear.
- High-manganese electrodes for areas exposed to moderate wear.
- High-hardness electrodes for areas exposed to extreme wear.

Repairing Worn Parts

When filling the worn parts of tool steels used in the cutting teeth of construction machinery or excavator buckets, each pass should be laid perpendicular (90 degrees) to the previous one.

To prevent cracking, a softer electrode should be preferred between the base metal and the top layers. Preheating should be applied before starting the welding process. During welding, the heat from the previous pass will act as preheating for the next pass.

Figure 8.2: Welding of Worn Parts

Electrodes Used in the Welding of Tool Steels

There are various types of electrodes available on the market. Electrodes should be selected based on the properties of the tool steel by referring to the information provided on the electrode packaging.

Preheating in the Welding of Tool Steels

In the welding of tool steels, preheating is applied within a range of 100 to 400 °C, depending on the type of steel material.

8.3.2. Application of Tool Steel Welding and Post-Welding Processes

- The welded part should be cleaned of oxide, oil, and dirt.
- An electrode suitable for tool steel should be selected.
- Thin parts should be tack-welded with a gap.
- Preheating should be applied.
- A short arc length and short welds should be used without excessive electrode movement.

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WELDING OF LARGE DIAMETER PIPES

9. LEARNING UNIT

9.1. LARGE DIAMETER PIPES

Throughout history, humans have employed various methods to transport water to places of use, constructing channels and aqueducts.

As technology has advanced, needs have increased, factories have been built, cities have grown, and the variety and quantity of fluids to be transported have expanded.

9.1.1. The Role and Importance of Large Diameter Pipes in Industry

Pipes are materials used to transport liquids, gases, and small granular solids (such as minerals and food) from one place to another.

In factories, cities, and even between countries and continents, pipes are used to transport water, sewage, petroleum, natural gas, and other fluid substances. Additionally, they are utilized in the construction of tunnels, buildings, roofs, bridge platforms, and other structures.

Figure 9.1: The Use of Large Diameter Pipes in Industry

Pipes are manufactured from different materials depending on where they are used and the characteristics of the fluid passing through them.

The types of pipes based on the materials they are made of are as follows:

- Steel pipes (Welded and seamless steel pipes, Figure 9.2)
- PVC pipes
- Concrete pipes
- Cast iron pipes
- Pipes made from copper and its alloys
- Pipes made from aluminum and its alloys

Figure 9.2: One of the Application Areas of Pipes

9.1.2. Large-Diameter Pipes Used in Gas and Liquid Transmission

Round-section pipes are generally used for transmitting gases and liquids. Pipes are manufactured from different materials depending on the type of liquid or gas they carry and are usually named after their application areas. These names include:

- Boiler pipes
- Water pipes
- Natural gas pipes
- Oil pipelines
- PE-coated pipes
- PPRC installation pipes
- Underfloor heating pipes
- SRM pipes

Figure 9.3: Oil Pipeline Installation

9.1.3. Large Diameter Pipes in Steel Construction

Round, square, and rectangular section pipes are used in the construction of residences, office buildings, roofs, bridges, steel furniture, automotive, architectural decoration, etc. These pipes are referred to by the following names:

- Special pipes
- Industrial pipes
- Square and rectangular profiles

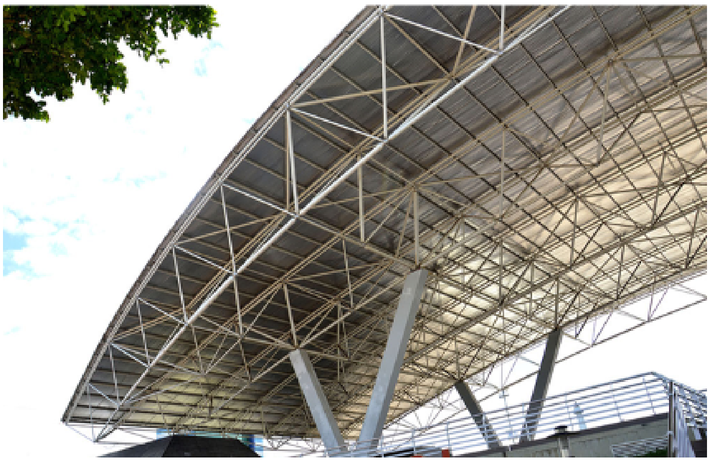

Figure 9.4: Steel structure

9.2. BUTT WELDING OF LARGE-DIAMETER PIPES

Pipes used in liquid and gas transmission lines are joined by butt welding.

9.2.1. Fitting Parts in Butt Welding of Large-Diameter Pipes

Cut and cleaned pipes need to be fitted together before welding. Otherwise, welding defects may occur. Tools used for edge preparation and cleaning can be utilized for the fitting process.

9.2.2. Beveling for Large-Diameter Pipes

The beveling of pipes should be done according to their diameters and wall thicknesses. Different cutting processes are applied for beveling.

Cutting

Pipes should be cut according to the required measurements and position at the assembly site. Common cutting methods include:

- Oxy-gas cutting
- Cutting with electrodes
- Plasma cutting
- Cutting with an angle grinder
- Cutting with a band saw
- Cutting with a hydraulic saw

Image 9.5: Fitting and deburring

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- Cutting with a band saw
- Cutting with a hydraulic saw

Image 9.6: Cutting with an angle grinder

Cleaning

During the cutting process, burrs form inside the pipes. To prevent future blockages, burrs and foreign substances (oil, rust, paint) must be thoroughly cleaned. To remove these, chisels, files, handheld and stationary grinders, wire brushes, sandpaper, and chemical substances are used. No foreign residue should remain to ensure the weld's strength.

Intersection and Beveling for Welding

Pipes are not always laid by welding them end-to-end (linearly). Pipe installations may include angular turns in different directions, intersections of pipes coming from different directions, and the joining of pipes with different diameters.

In such cases, intersection cutting is required, and for pipes with a wall thickness greater than 5 mm, beveling for welding must be performed. Special beveling techniques are used in these situations, with bevel angles ranging between 50° and 90°.

Figure 9.7: Intersection Cutting

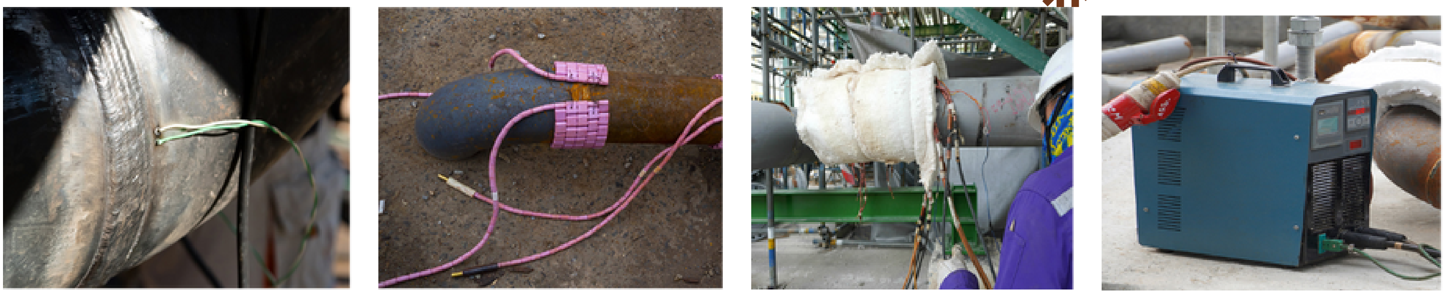
9.2.3. The Process of Butt Welding Large-Diameter Pipes

In some pipe welding applications, the material properties and large dimensions of the pipe require special preparations. Annealing and clamping devices are used for these preparations.

Annealing

The parts require preheating and slow cooling after welding. In some cases, annealing continues during the welding process. Additionally, heat treatment can be applied after welding to relieve stress.

Annealing is applied to alloy and carbon steel pipes with a wall thickness greater than 13 mm. These applications can be carried out using propane heaters, electrical resistance, and induction current devices.



a) b) c) d)

Figure 9.8: Induction Heat Treatment Steps

a) Connection of contact thermometer
b) Wrapping of the heater
c) Insulation of the heater
d) Setting the value from the control panel

Clamping Apparatus

Before starting welding, the pipes to be welded must be tack-welded. Since large-diameter pipes are cylindrical, aligning them is difficult. During tack welding, these pipes should be temporarily held together using special clamps, V-beds, and clamping apparatus. Tack welds inside the welding groove should be applied in a way that prevents crater cracks. During the pipe joint welding process, these tack welds may need to be ground and removed.

Figure 9.9: Apparatus Used for Pipe End Preparation

Considerations in Butt (Butt Joint) Welding

- If necessary, an appropriate welding bevel should be made on the pipes to be welded.
- Pipes must be cut accurately and to the correct dimensions (Figure 9.12).
- Before welding, the edges of the weld bevel must be cleaned of rust, oxide, oil, paint, and other foreign substances at least 20 mm wide from both the inside and outside.

- Care must be taken to ensure that there is no misalignment in the axis of the pipes being joined.
- Misalignments caused by ovality or thickness differences in the pipes should be prevented.
- Properly fitted parts should be tack welded in clamping devices, and a gauge should be used during tack welding.
- The welding position should be selected carefully. If possible, the part should be rotated horizontally while welding; however, this is not always feasible. In such cases, the pipe should be welded using all positions.

9.2.4. Application of Large Diameter Pipe Butt Welding and Post-Welding Operations

- After cutting, cleaning, fitting, and preparing the weld bevel, the parts are tack welded in a V-bed with proper spacing.
- A template is used between the two parts during tack welding.
- A root pass is applied to the tack-welded parts in the horizontal position. The root pass can be performed using TIG welding.
- After slag removal from the welded parts, additional passes are made, and the weld area is cleaned.

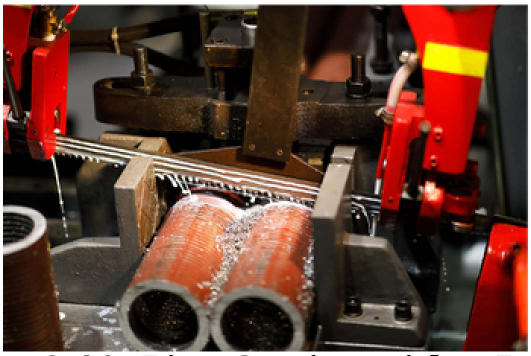
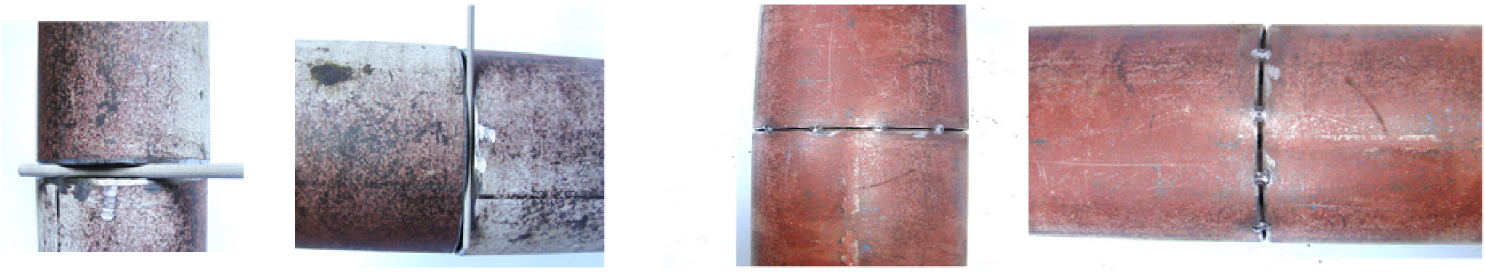


Figure 9.10: Pipe Cutting with a Band Saw



a) b) c) d)

Figure 9.11: The Sequence of Operations to be Followed in Pipe Welding

a) Tack welding spacing on the horizontal axis
b) Tack welding spacing on the vertical axis
c) Tack welding on the horizontal axis
d) Tack welding on the vertical axis

9.3. FLANGE WELDING OF LARGE DIAMETER PIPES

- Pipes are used to transport fluids from one place to another. In some cases, pipes need to be connected to pumps, boilers, or each other in a detachable manner.
- Since welds create permanent joints, flanges are welded to sections of pipes that need to be removable. These flanges are then bolted together. When maintenance or replacement is required in piping systems, the flanges are unbolted, separated, and necessary work is carried out (Figure 9.12).

Figure 9.12: Pipe assembly joined with a flange

9.3.1. Alignment of Parts in Flange Welding

Flanges play a crucial role in the transportation of liquids, gases, and solid materials. Flanged connections are particularly used in areas requiring high durability.

9.3.2. Bevel Preparation in Flanged Joints

Large-diameter pipes are generally prepared with a V-groove for welding. The beveling process is performed either manually or using automated machines.

9.3.3. Execution of Flange Welding

- The appropriate flange type is selected based on the connection conditions and the materials used (Figure 9.15).
  - Blind flanges
  - Threaded flanges
  - Stub-end flanges
  - Backing ring flanges
  - Slip-on flanges
  - Steel flanges
- Flanges are tack welded to the pipes after ensuring that the bolt holes align.
- The gasket thickness required to ensure a leak-proof seal is considered in length calculations.
- Precautions are taken against distortions caused by heat during welding.

9.3.4. Application of Flange Welding and Post-Welding Processes

- If necessary, a bevel is prepared on the pipe and flange, and they are aligned.
- The pipe and flange are tack-welded at equal intervals at a 90-degree angle or at the desired angle (Figure 9.13).
- If required, preheating is applied.
- An inside corner weld is performed depending on the welding position.
- Some flanges are welded externally, while others are welded internally (Figures 9.14 and 9.15).

Figure 9.13: Tack Welding of the Flange

Figure 9.14: External Welding of the Flange

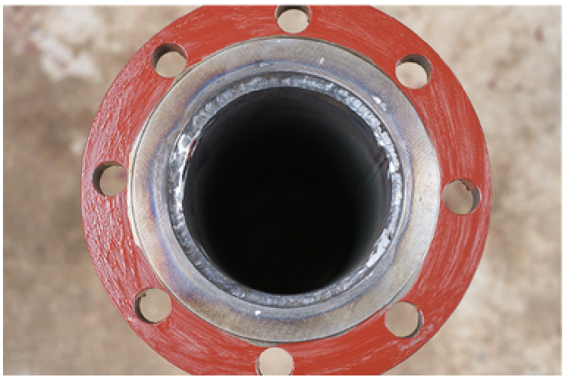


Figure 9.15: Tack Welding of the Flange

9.3.4. Application of Flange Welding and Post-Welding Processes

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Figure 9.13: Tack Welding of the Flange

Figure 9.14: External Welding of the Flange

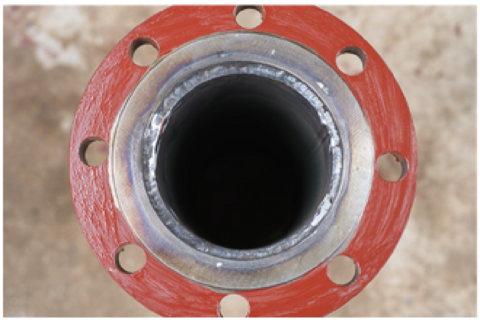

Figure 9.15: Tack Welding of the Flange

- If necessary, heat treatment is applied after the welding process.
- After welding, a sealing and pressure test is conducted.

9.4. WELDING OF LARGE DIAMETER PIPES - T WELDING

It is performed by joining two or more pipes in different ways.

9.4.1. Cross-sections of Pipes to be T-Jointed

The intersections that occur at the junction points of two or more pipes being joined are called cross-sections.

To mark the cross-section on pipes, either templates are prepared using cross-section methods or practical methods are used to draw directly onto the pipes.

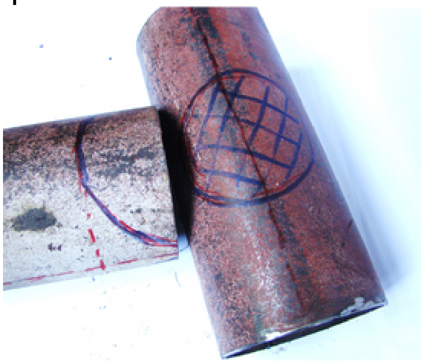

Figure 9.16: Pipes with Cross-Sections Cut and Beveled, Forming a Segmented Elbow

9.4.3. Beveling for T Joints

- Cross-section development is the most commonly used T welding preparation.

9.4.4. Considerations in Cross-Section T Joint Welding

- The correct drawing method should be chosen when adjusting pipes by cross-section opening.
- Marking should be done accurately.
- After cutting and fitting, burrs inside the pipe must be cleaned.
- During tack welding, the necessary rules for pipe joining should be followed, and equal spacing should be left around the tack-welded area.

9.4.5. Implementation of T Welding and Post-Welding Processes

- Cardboard templates are wrapped around the pipes to draw the cross-section, or marking is done directly on the pipes.

Figure 9.17: Cross-Section Marking

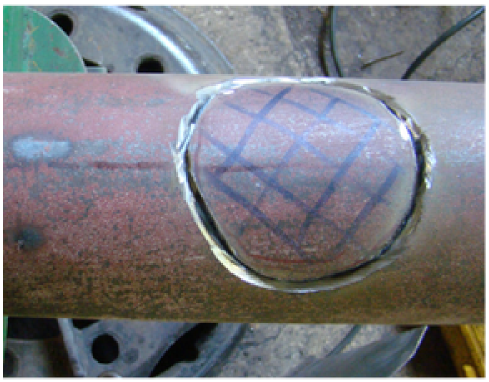

Figure 9.18: Cutting of the Cross-Section with a Chip Removal Machine

After cleaning the burrs and preparing the welding edges, the pipes are aligned and tack-welded with equal spacing

Figure 9.19: Tack Welding of Pipes with Cut and Fitted Intersections

A root pass is performed, followed by the completion of the weld.

Figure 9.20: Welding of Pipes with Beveled (T) Joint

If necessary, a heat treatment is applied after welding.
The weld seam is inspected for leakage and pressure tested.

9.5. WELDING OF LARGE DIAMETER PIPES IN L JOINTS

When laying pipelines, it may be necessary to change direction. The connection elements used at corners for direction changes are called elbows. Elbows are named according to their angles (e.g., 90-degree elbow, 120-degree elbow, etc.).
There are also pre-manufactured elbows available, which are produced as single or multi-piece components.

Figure 9.21: Locations Where L Elbows Are Used

9.5.1. Fitting Parts in L Welding

Used in the joining of narrow and wide-angle parts.

9.5.2. Beveling in L Joints

The smallest angle beveling process is applied to the edges of corner and elbow pipes.

9.5.3. Considerations in L Welding

• The cutting angle must be correctly calculated according to the angle of the elbow to be made.
• The correct cutting method should be chosen.
• Pipes must be fitted together and tacked.
• The root weld must not protrude inside the pipe, as over time, it may accumulate residue and cause blockages.

9.5.4. Application of L Welding and Post-Welding Processes

• Pipes are cut using a suitable cutting tool to create the appropriate intersections for their diameters and then fitted together (Figure 9.22).

Figure 9.22: Angled Cut L Elbow

The pipes are tack welded to each other at 90 degrees perpendicular or at the desired angle with equal spacing.

Figure 9.23: Tack Welding of L Elbow

If necessary, preheating is applied.
The welding seam is performed by adjusting the electrode angle and movement according to the welding position

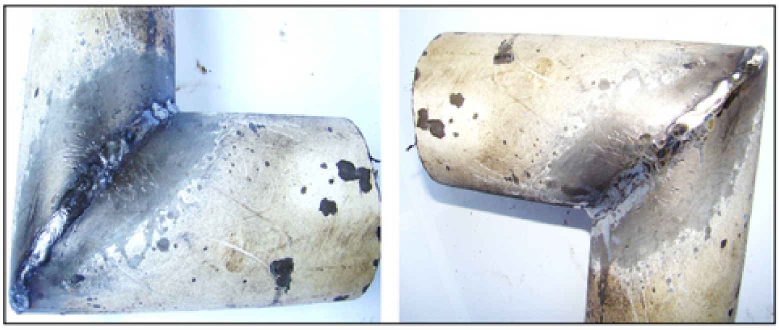

Figure 9.24: Welding of L Elbow

If necessary, heat treatment is applied.

- The sealing and pressure control of the weld seam is performed.

Welding Defects That Occur After the Application of Large Diameter Pipe L Welding

Various factors (environmental and welder errors) can cause defects during welding. These defects can prevent the pipes from performing their intended function in their application areas and may even lead to accidents. Therefore, precautions should be taken to prevent these defects. The main welding defects are as follows:

- Porosity
- Slag and foreign material residues
- Undercutting
- Cracks
- Welding start and end points

Inspection Methods Conducted After the Application of Large Diameter Pipe L Welding

Pipes must be inspected after welding. If there are leaks in the fluids passing through the pipes, various accidents may occur depending on the nature and pressure of the fluid.
For this reason, an appropriate inspection method is selected and applied based on the importance and specifications of the weld.
Inspection methods are divided into destructive and non-destructive testing. Materials subjected to destructive testing are not used but are produced for testing purposes.
Before operating welded pipes in a system, non-destructive testing is applied. If the test results are positive, the pipe systems are put into operation. Non-destructive testing methods include:

- Visual Inspection: External defects in the weld seam are detected through visual examination. Visual inspections are performed before, during, and after welding.
- X-ray (Radiographic) Inspection: This method involves taking an X-ray image of the welded area to inspect it.

Figure 9.25: Examination of X-ray Film

Ultrasonic Inspection: A welding inspection method using high-frequency sound waves.
It is primarily used to detect internal defects.

Figure 9.26: Ultrasonic Inspection Device

• Dye Penetrant Inspection: A testing method using special dyes to reveal surface defects such as pits, cracks, and voids.

Figure 9.27: Inspection with Dye

Hardness Test Inspection: A method used to measure whether the weld seam has the desired hardness. It is performed using one of the hardness measurement methods.

Figure 9.28: Hardness Measurement Test Device

Magnetic Inspection: Used to detect defects in welds with magnetic properties using magnetic particles.
Pressure Testing: A method used to check for leaks and measure the strength of weld seams in pipes using pressurized liquids or air.

Figure 9.26: Ultrasonic Inspection Device