Pipe Welding

PIPE WELDING

LAKE WASHINGTON INSTITUTE OF TECHNOLOGY WELDING DEPARTMENT

OpenWA
Olympia, WA

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INTRODUCTION AND COURSE OUTCOMES

Welding around a pipe is critical to industries such as hydroelectric, nuclear, boilers, construction, manufacturing, oil and gas. It's the lifeline of infrastructure worldwide. Gas tungsten arc welding (GTAW) and shielded metal arc welding (SMAW) are the most common welding processes used to create and maintain this lifeline.

Course Description

This course includes both theory and lab work. It is a continuation of the principles, procedures, and operation of equipment to properly and safely weld various diameters of pipe in various positions, using Shielded Metal Arc Welding (SMAW) and Gas Tungsten Arc Welding (GTAW).

Course Outcomes

Upon successful completion of this course students will be able to:

- Describe the principles and terms used in pipe and tube welding
- Use math to make equipment adjustments/calibrations and to complete fabrication projects
- Select and safely set up SMAW and GTAW pipe welding equipment
- Store, transport, and handle all types of SMAW and GTAW equipment properly and safely
- Prepare metal for shielded metal arc pipe welding procedures using proper joint design, equipment, and joint preparation techniques
- Use technical resources to access information regarding welding and fabrication processes
- Follow industry standard safe practices, including the using and wearing of all safety equipment needed to weld or be in a welding environment
- Complete a resume, cover letter, job application, and job search as necessary
- Select the proper metals and consumable materials, including electrodes, wire, filler metal, and/or shielding gases, for various welding tasks by using metallurgy principles
- Prepare metal for welding or cutting procedures using proper equipment and joint preparation techniques for ferrous and non-ferrous metals
- Use welding machines, shop equipment, and hand tools to safely perform welding and/or fabrication procedures

- Select, assemble, and adjust welding machines for various processes to produce welds that meet AWS standards
- Demonstrate the ability to start an arc, run a bead, and assess a weld puddle
- Use proper welding techniques to produce welds on lap joints, corner joints, T-joints, and/or butt joints in a variety of positions, including 1F, 2F, 3F, and 4F and/or 1G, 2G, 3G, and 6G
- Use math to make equipment adjustments and/or calibrations and to complete fabrication projects
- Use visual inspection methods and/or destructive testing to identify defects and/or discontinuities
- Follow ANSI Z49 safety standards, including recommended practices for personal protective equipment and hazardous material laws/processes

LICENSES AND PERMISSIONS

For Further Information

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ABOUT THIS BOOK

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PART I
ABOUT PIPES

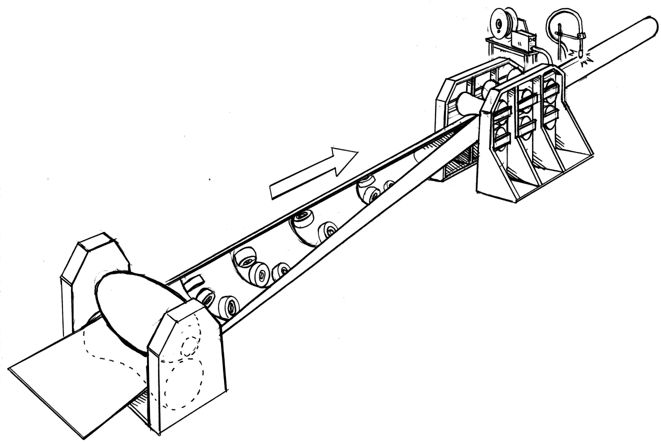
1.

WELDED AND SEAMLESS WROUGHT STEEL PIPE

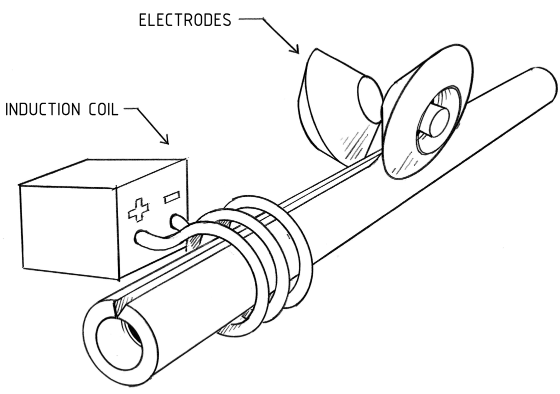
Pipe for most applications is made from low-carbon steel. Pipes are selected based on the working pressures involved and the materials to be transported. For example, steam lines in a nuclear power plant must be strong enough to withstand high pressures and high temperatures. They must also resist corrosion.There are two types of pipe – welded wrought steel pipe and seamless wrought steel pipe.

Welded Wrought Steel Pipe

Welded wrought steel pipe is pipe that is made by rolling a flat sheet into a cylindrical shape and welding the length of the seam. The seam is commonly welded with *submerged arc welding* (SAW) or *electric resistance welding* (ERW).



Assembly Machine for Rolled Pipe



Close-up of Rolled Pipe Assembly

ERW is ideal for welding long seams in pipe because it is exceptionally fast, economical, and requires no filler metal. Current is induced into the pipe as it passes through a ring of induction coils (work coils) near the electrode discs. The electrodes complete the welding circuit. The heat generated at the electrodes melts the seam, and high pressure forces the edges together to produce a strong, defect-free seam weld.

Welded pipe is less expensive to produce than seamless pipe. It is commonly used in foundation piles for buildings, bridges, and piers; in structural columns; in wall castings; and in steel poles for street-lights and electrical transmission lines. Large-diameter welded pipe can be used to transport fluids, but it is not as uniformly round as seamless pipe, which can make installation and fitting difficult. Seamless pipe is used to meet the stringent quality requirements for piping corrosive environments and high-pressure applications.

Seamless Wrought Steel Pipe

Seamless wrought steel pipe is pipe made using an extrusion process. Seamless pipe is also called *cold drawn seamless* (CDS) pipe. The process involves heating a solid round billet of steel in a rotary hearth. Rollers spin the heated billet as a piercing mandrel pushes through it to form the pipe. Once the billet has been pierced, it is processed to the specific diameter and wall thickness.

Seamless pipe is most commonly used for high-pressure applications and in environments involving extreme temperatures, such as those involving oil and gas processing, power plants, heat exchangers, boiler tubes, and steam pipes.

2.

PIPE SIZE

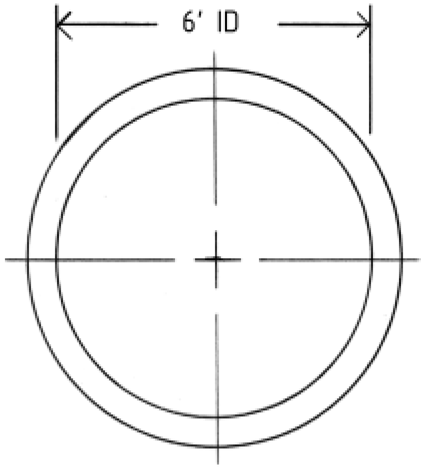
ANSI (American National Standards Institute)/ASME (American Society of Mechanical Engineers) B36.10M is the standard for both welded and seamless wrought steel pipe dimensions and weight for high or low temperature and pressure.

The standard uses two numbers to size pipe: nominal pipe size and schedule numbers. *Nominal pipe size* (NPS) is a North American set of standard sizes for pipe that refers to pipe diameter. *Schedule numbers* refer to wall thickness of the pipe.

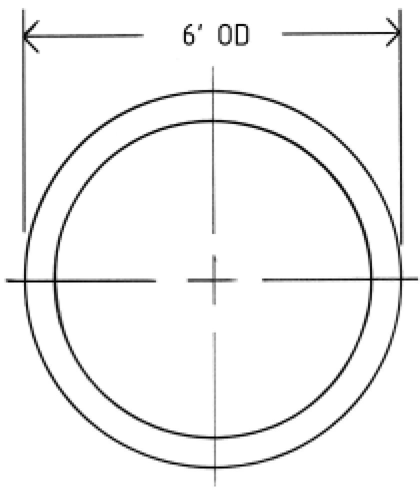
Nominal Pipe Size

Pipe sizes are documented by a number of standards, such as ANSI/ASME B36.10M, API 5L, and ASTM A53/A53M in North America as well as ISO 65 internationally. The European equivalent of NPS is *diameter nominal* (DN).

For pipe sizes 1/8” though 12”, the NPS is approximately equal to the inside diameter (ID) in inches. For pipe sizes 14” and above, the NPS is equal to the outside diameter.



Inner Diameter



Outer Diameter

Schedule Numbers

Thin-wall pipe has a wall thickness of up to 5/16”. Pipe thicker than 5/16” is considered thick-wall pipe. For example, 6” schedule 40 pipe is considered to be thin-wall pipe because it has a wall thickness of 0.280”, while 6” schedule 80 pipe is considered to be thick-wall pipe because it has a wall thickness of 0.432”.

In the 1920s, the American National Standards Association (now ANSI) standardized the dimensions for wrought steel and wrought iron pipe based on the *iron pipe size* (IPS) system in use at that time. The association defined three designations for wall thickness: *standard weight* (STD), *extra-strong* (XS), and *double extra-strong* (XXS). Only three designations were required to represent wall thickness because there was only a small selection of wall thickness available.

In later years, a series of additional designations, known as *schedule numbers*, were added to the standard to better reflect the range of wall thicknesses used in industry. The original three designations are still used today, however extra-strong and double extra-strong are commonly referred to as *extra-heavy* (XH) and *double extra-heavy* (XXH). Extra-strong may also be represented as double E.H. or XX.

3.

PIPE VS. TUBE

Pipe differs from tubing in that pipes are used for transporting materials, while tubing is used for structural applications. Therefore, the *inside diameter* (ID) is the critical dimension for pipe because the ID is used to calculate capacity. On the other hand, the *outside diameter* (OD) is the critical dimension for tubing because OD is used to calculate tolerances.

Pipe

Pipes transport fluids under low pressure, such as with cross-country pipelines, and fluids under high pressure, such as in refineries and power plants.

The nominal dimensions for pipe 12" and below are based on ID. Engineers and designers use ID to calculate pipe size based on the amount of fluid to be transported, along with other factors. Therefore, a 6" pipe has an internal diameter of approximately 6 inches.

Tube

Tubing is used for structural applications, boiler tubes, utility poles, bridges, overhead crosswalks. Therefore, the nominal dimensions for tubing are based on outside diameter (OD) because the OD is used to measure outside tolerances: stresses that are on the outside pushing in, instead of on the inside pushing out.

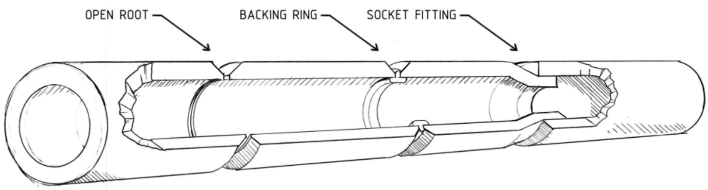
4.

PIPE CONNECTIONS

Welding is the most common method of joining pipe. Pipe joints are typically butt-welded or made with socket fittings. Socket fittings are typically used on small diameter pipe and tubing with less than 2" OD. The socket fitting forms a lap joint that is welded with a fillet weld.

The most commonly used joint design for joining pipe is the open root single-V groove joint. If the joint is to be welded with an open root, a root face (land) is typically ground on each bevel. The size of the root face varies with the wall thickness of the pipe and the welding process used.

A backing ring, or chill ring, can be used depending on the application. If a backing ring is used, no root face is required. This is commonly referred to as a feather edge.



Attachment Types

Joint Design

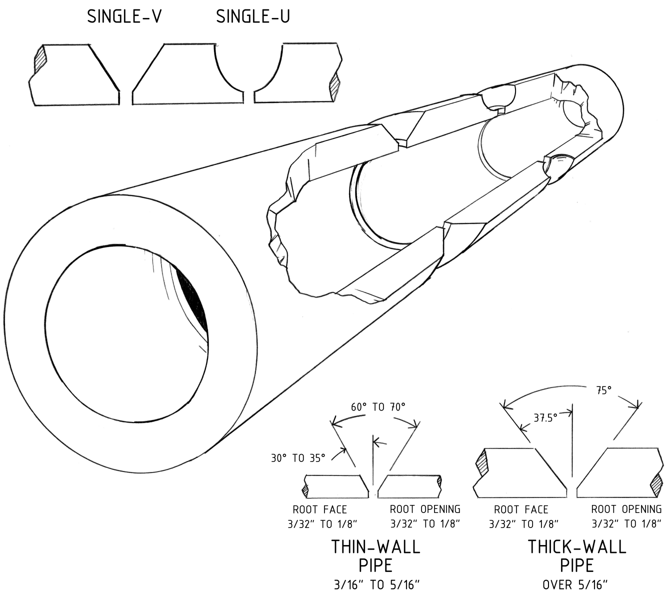
Joint preparation involves several factors, including pipe diameter, wall thickness, the type of pipe to be welded, and the welding process used. Pipe up to 3/16” wall thickness can be welded without any joint preparation. Most pipes over 3/16” wall thickness require some joint preparation.

A wide groove angle may not be the best choice for thin-wall pipe because it would require more passes to fill the joint than a narrower groove angle. Each pass would add heat to the weld zone, which may result in overheating. This can create problems with distortion due to excessive heat buildup in the weld zone. Narrower groove angles require fewer passes, which result in less overall heat build-up.

The type of pipe must be considered as well. For example, carbon steel pipe requires a single-V groove joint design, typically with a root face unless a backing ring is used. However, stainless steel pipe does not require a root face. Instead, each bevel is prepared with a feather edge, also called a knife edge. Aluminum pipe typically calls for a single-U groove joint preparation.

The welding process also influences joint design. For example, SMAW and GTAW require large groove angles so the arc can reach into the root of the joint to ensure complete penetration. GMAW and FCAW require smaller groove angles because wire electrodes are narrow, which give them better access to the root area.

Pipe with a wall thickness between 3/16" and 5/16" requires a groove angle in the range of 60º to 70º with a root face of 3/32" to 1/8". Thicker pipe requires a 75º groove angle, with a root face between 3/32" and 1/8" and a root opening between 3/32" and 1/8".

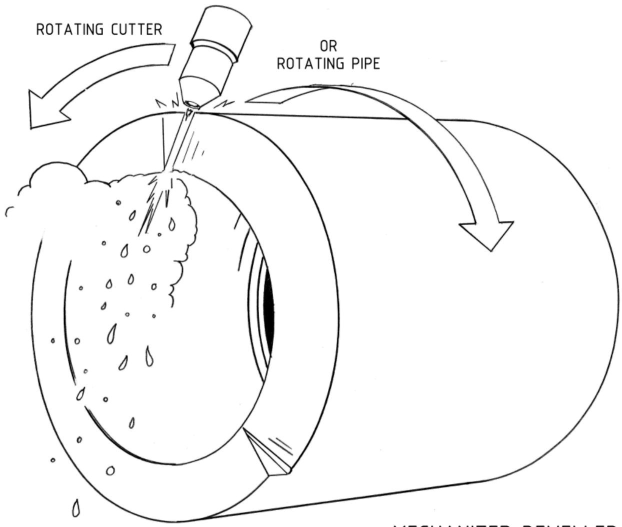


Groove Types and Measurements

Joint Preparation

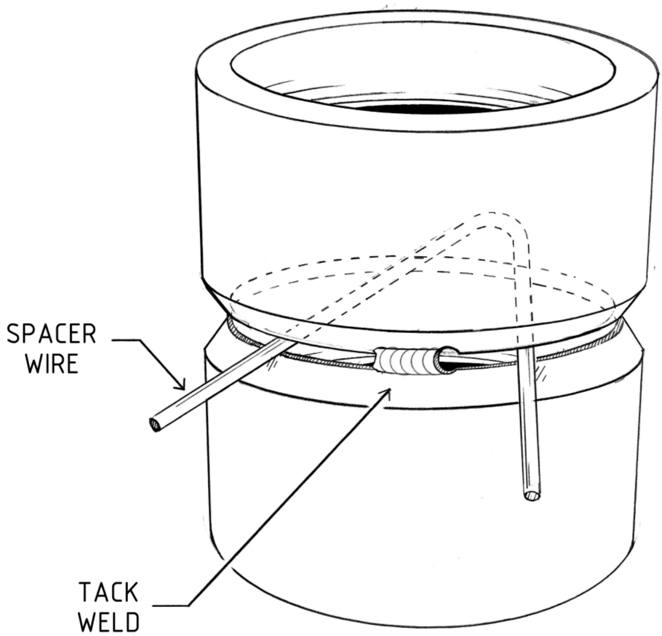
To prepare a pipe joint, each section of pipe must be beveled to the proper angle. The best way to produce a smooth, even bevel is to use a mechanized beveller with an OFC or PAC cutting torch. If necessary, bevels can be cut manually. However, manual preparation is time-consuming and less accurate than mechanized beveling.

Typically, the groove angle, the size of the root face, and the root opening are detailed in the WPS. If a backing ring is specified, no root face is required. A file should be used to deburr the inside edge of each section of pipe, and a wire brush should be used to clean the groove surfaces. When necessary, an appropriate cleaning solvent should be used to remove any oil, grease, or other contaminants.



MECHANIZED BEVELLER

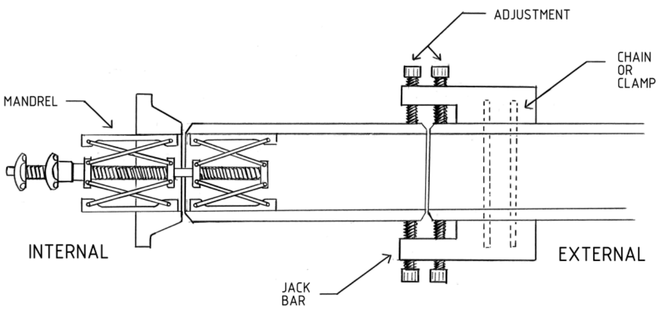
Joint Alignment and Fit-up



Spacer Wire Placement

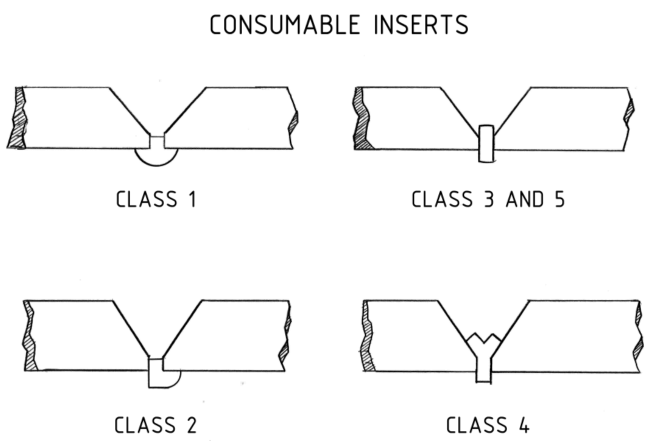
Joint fit-up must be as consistent as possible around the circumference of the pipe to ensure a quality weld. Typically, pipe line-up clamps are used to hold pipe sections and keep them aligned during tacking and welding of the root pass. On large-diameter pipe, it may be necessary to leave the line-up clamp in place until most of the root bead is deposited in order to prevent cracking caused by the weight of the pipe. Pipe line-up clamps are available for pipes ranging from 1" to over 9" in diameter.

There are two types of line-up clamps-those that attach to the inside of the pipe and those that attach to the outside of the pipe.



Different Clamp Types

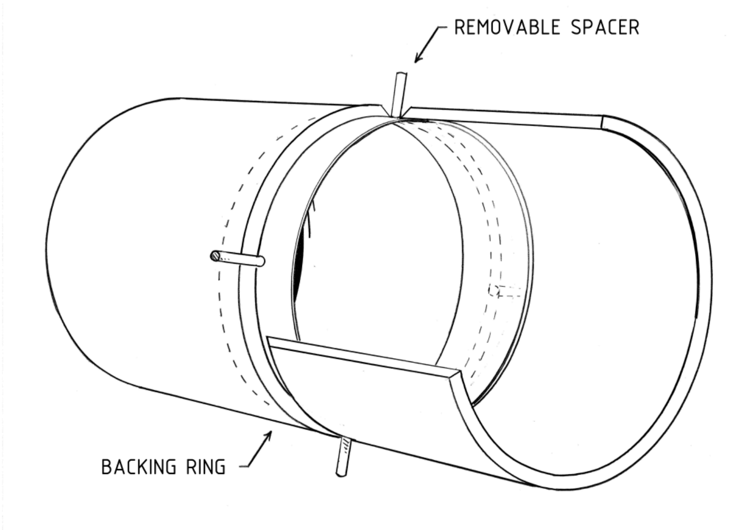
Consumable inserts can also be used as spacers to ensure a properly spaced root opening. Consumable inserts become part of the root bead. Five classes of inserts are available.



Backing Rings/Chill Rings

Backing rings, or chill rings, are commonly used in pipe welding. Backing rings prevent excessive burn-through and keep spatter and slag from falling into the pipe. They also eliminate the need for backing gas on base metals prone to sensitization, such as stainless steel or titanium. Backing rings have spacers to ensure a consistent root opening for tack-up.

Some backing rings are equipped with spacers that are designed to be broken away once the tack welds are deposited. Other rings have spacers consisting of consumable inserts that become part of the root bead. However, backing rings may not be appropriate for some applications because they can provide a source of turbulence and resistance to the flow of material through the pipe.



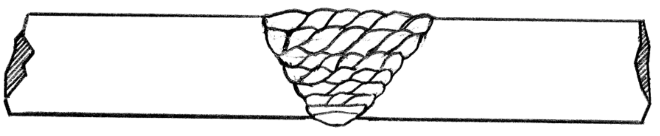
Backing Ring Placement

PART II
WELDING PASSES

5.

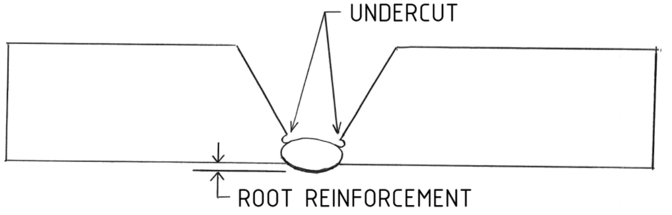
WELDING PASSES

The three types of weld passes used to weld all groove welds are the root pass, intermediate pass(es), and cover pass(es).



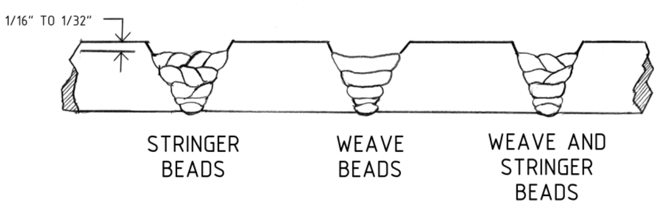
Side View of a Finished Multi-Pass Weld

- The root pass is typically deposited as a single weld bead.



Side View of a Root Pass

- Intermediate passes are deposited as a single weave bead or two more stringer beads. The last intermediate pass should fill the joint to within 1/16" to 1/32" below the surface of the pipe.



Side view of Intermediate Passes

- The cover pass is deposited as a series of stringer beads or as a single weave bead. The choice of stringer beads or as single weave beads for intermediate and cover layers is based on joint position, direction of travel, and the welding process used.

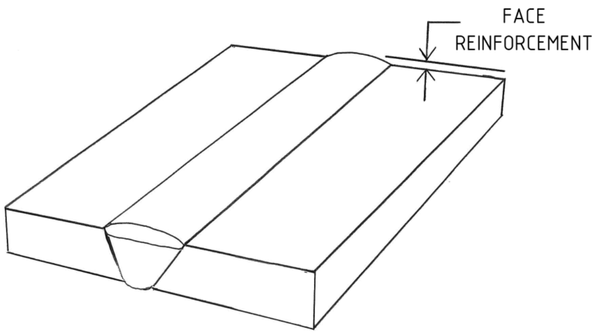


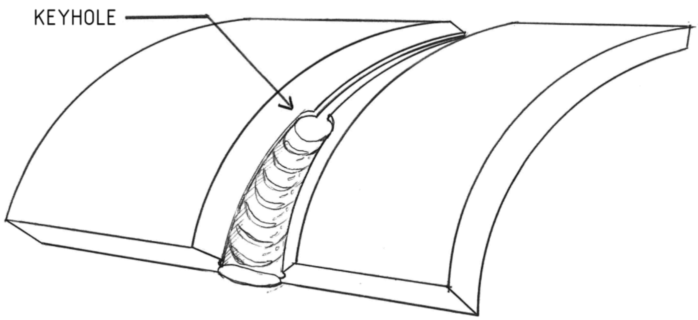
Diagram of Cover Pass

A suitable inter-pass temperature should be maintained throughout the welding operation. This allows the pipe to cool more slowly and helps to prevent the build-up of residual stresses in the joint, especially on thick-wall pipe with high alloy content. Therefore, if the welding is stopped and the pipe is allowed to cool completely, it should be preheated with an oxy-fuel gas torch or with an electric induction heating blanket before resuming the welding operation.

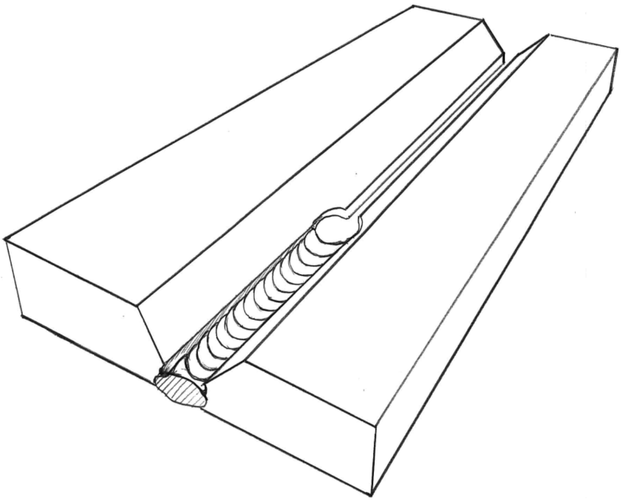
Typically, a qualified *welding procedure specification* (WPS) accompanies the welding job. The WPS includes joint preparation; welding processes to be used; electrode type and size; welding parameters and bead placement; preheat, inter-pass, and post heating requirements; and any other necessary details. The WPS is based on the applicable pipe welding code (API 1104, ASME Section IX, or AWS).

Generally, the narrower the weld bead, the higher its impact strength.

Keyholes



The *keyhole* is a tear-shaped area of burn-through at the leading edge of the weld pool.



Wider View of Keyhole

It is a critical feature of open root welding because it ensures complete penetration to the root side of the joint. The keyhole should be about a third larger than the outside diameter of the electrode so the electrode can fit through it. A keyhole that is too large will produce excessive burn through and excessive root reinforcement. A keyhole that is too small will result in incomplete penetration.

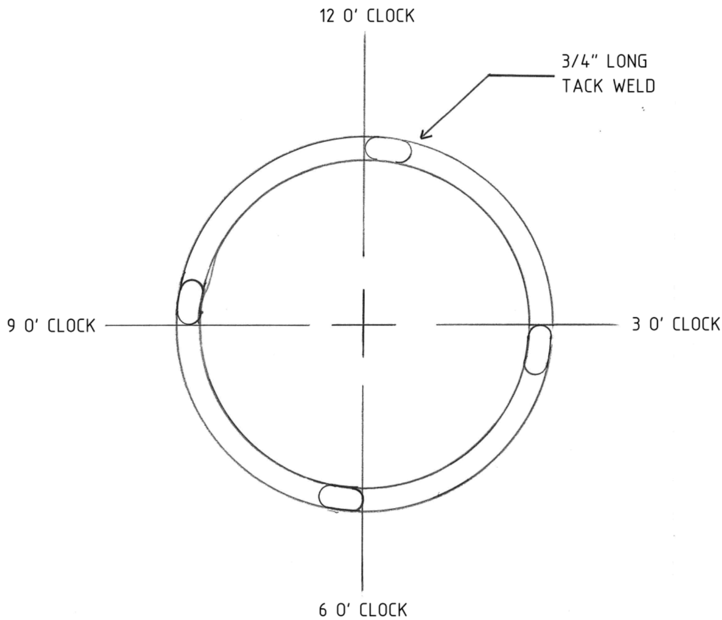
Smooth Tie-Ins

When the weld pool has to tie into the end of another bead, slow the travel speed slightly. Make sure the weld pool fills the crater at the end of the other weld, and that it blends into the other bead to ensure a smooth tie-in. Then break the arc.

6.

TACK WELDS

Tack welds keep pipe joints aligned during welding. They also maintain a consistently spaced root opening on open root joints. Typically, four evenly spaced tack welds are made around the pipe at approximately the 12, 3, 6, and 9 o'clock positions or the 11, 2, 5, and 8 o'clock positions, depending on welder preference.



Tack Weld Locations

Each tack weld should be about ¾" long and should penetrate to the root of the joint.

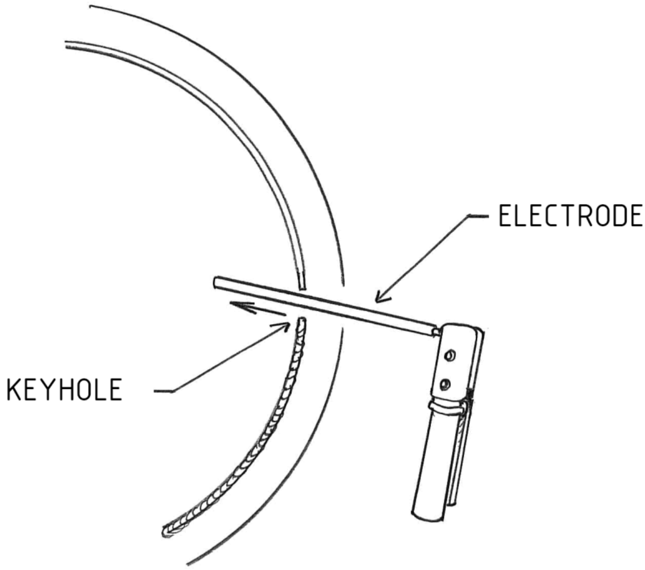
The larger the pipe, the longer the tack welds required. As a general rule, tack welds on large-diameter pipe should be about 5-10% of the pipe diameter. After tack-up, the joint should be inspected to be sure the root opening is consistent and any misalignment (hi-lo) falls within acceptable limits.

Depositing Tack Welds

- Strike the arc in the root of the joint about ½” in front of the starting position for the tack weld.
- Pull the electrode back to establish a long arc length.
    - A long arc length helps to stabilize the arc. It also allows time for shielding gas formers in the flux coating to break down and form a gas shield to protect the molten metal.
- Hold a long arc and move the electrode back to the starting position with a slow steady motion to preheat the base metal.
- Push the electrode into the joint until the arc length is about 1/16” above the root face.
- Hold the electrode in position until the keyhole forms.
- Once the keyhole forms, increase the arc length to about one electrode diameter.
- Use a steady travel to deposit the tack.

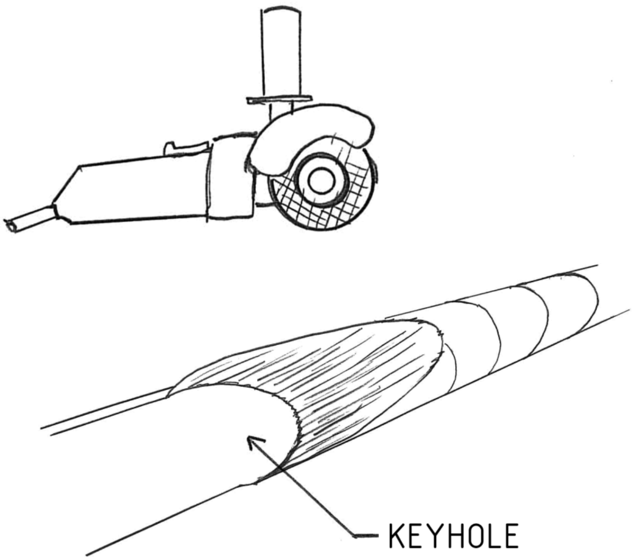
Note: It may be necessary to use a slight whipping motion to control the weld pool and keyhole size.

Extinguishing the Arc



A common technique for extinguishing the arc after depositing a tack weld with SMAW is to push the electrode through the keyhole with a quick thrust and then withdraw it when the arc is extinguished. This technique ensures that the keyhole retains the correct size. It also aids in obtaining complete penetration when restarting the root bead and when making tie-ins. A tie-in is a point where a weld bead fuses into a tack weld or into another weld bead.

Cleaning and Feathering Tack Welds



It is important that all slag is removed from tack welds and they are brushed thoroughly with a wire brush to prevent slag inclusions in the first intermediate weld bead (hot pass).

Tack welds can be feathered using a hand grinder on both sides of the tack to ensure good tie-ins. The minimum thickness of the feathered edge of a tack weld should be no less than 1/16".

Over-grinding tacks may weaken them and cause them to break, allowing the root opening to close up.

Avoid scarring the groove faces or root face when feathering tacks. Feathering tack welds can weaken them and cause them to break under the stress of welding, especially on large diameter pipe. Therefore, it is good practice to feather only the tack at the starting position and the adjacent tack in the direction of welding.

The remaining tacks should then be feathered as welding progresses around the pipe.

7.

ROOT PASSES

A *root pass* is a weld pass made to produce a root bead. The root pass should penetrate completely into the root of the joint. The technique for welding the root bead varies slightly with welding position.Some undercutting is common along the toes of the face side of the weld. This undercutting is eliminated by the first intermediate pass (hot pass). However, undercutting along the root side of the weld (internal undercut) is not acceptable. It must be corrected, or the weld will be rejected.

Starting Techniques

There are two techniques for starting a root bead. One technique is to start in the root of the joint and “burn through” the tack welds. The other technique is to start on a tack weld and tie into successive tacks as welding progresses around the pipe.

The problem with burning through tacks, especially on large-diameter pipe, is that the root can close up as the root bead cools and contracts. Considering that tack welds on large-diameter pipe can be as long as 3” or more, burning through tacks also presents issues with productivity.

Stopping and Starting Root Beads

Depending on the diameter of the pipe, it may be necessary to stop several times to change electrodes while depositing the root bead. To extinguish the arc on the root pass, push the electrode through the keyhole. This maintains the proper keyhole size. Clean the weld thoroughly by chipping slag and brushing the weld with a wire brush, then feather the crater.

To restart the weld, strike the arc on the root bead about ½” behind the feathered edge. Move toward the feathered crater with a long arc. Shorten the arc to one electrode diameter at the crater, and hold it in position until the keyhole forms. Then continue welding.

Finishing Root Passes

Once the root bead is deposited, the slag is chipped and the bead is brushed with a wire brush, a hand grinder is used to grind the bead lightly to remove high spots and visible slag before depositing the first intermediate pass (hot pass) with an E7018 electrode.

Other Best Practices

Aside from the normal stops and restarts associated with changing electrodes, it is best to complete the root bead around the entire circumference of the pipe before stopping for an extended period. Root beads deposited with downhill travel are typically concave through the vertical portion of the weld. An additional bead is deposited on the vertical portion of the root bead to produce an even surface.

It is important to maintain a consistent weld pool and a keyhole about 5/32" to 3/16" for the entire root pass to ensure an even weld bead and complete penetration. Therefore, the welder must watch the weld pool and adjust travel speed and electrode angles as well as use different electrode manipulation techniques to maintain the weld pool and keyhole.

If there is poor or bad fit up, the welder must adjust travel speed and electrode angles to compensate. If the root opening is narrow, the travel speed should be reduced to ensure complete penetration. If the root opening is too wide, the travel speed should be increased to prevent excessive penetration. If weld quality is critical, the welder should bring poor joint fit-up to the attention of the supervisor before welding.

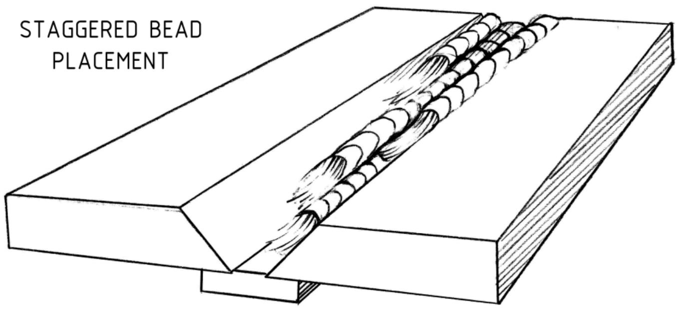
8.

INTERMEDIATE PASSES

An *intermediate weld pass* (or *hot pass*) is a single progression of welding subsequent to the root pass and before the cover pass. In pipe welding, the first intermediate weld pass fills any undercut caused by the root pass. It also burns out particles of slag that may remain in the groove. The hot pass should fuse into the root bead and into the sides of the joint.Depending on welding position and direction of travel, intermediate passes may be deposited as weave beads, stringer beads, or a combination of both.

Stopping and Restarting Intermediate Passes

Intermediate weld beads should be staggered so no two adjacent beads start or stop in the same place. This ensures a stronger weld and minimizes areas of weakness where the weld may fail.



To break the arc, welders should use a quick movement of the wrist away from the direction of travel. At minimum, the last 2” section of the weld bead and an area about 1” in front of the crater should be cleaned to prevent slag inclusions.

To restart with an E6010 electrode, strike the arc on the previous bead about ½” in front of the crater and establish a long arc. Move slowly toward the crater, and shorten the arc while tracing around the crater to re-establish the weld pool. The crater should be filled completely before resuming normal travel.

To restart with a low-hydrogen electrode, strike the arc in front of the crater, and travel back to trace the crater, but do not use a long arc. Maintaining a short arc length helps to prevent porosity. It also minimizes sagging in the 2G and 6G positions.

Other Best Practices

Intermediate weld passes are typically deposited with the largest diameter electrodes possible to fill the weld joint efficiently. Each intermediate weld pass should fuse completely into the previous weld pass. The number of intermediate passes (fill passes) making up the intermediate layers required depends on the wall thickness, the groove angle, the size of the electrode, and the welding process used.

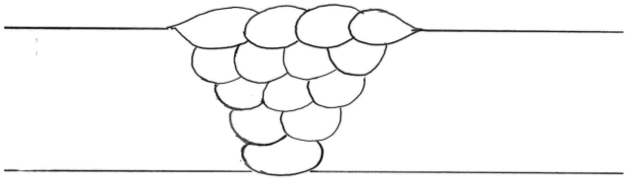
Slag produced by SMAW or FCAW must be completely removed after each pass to prevent slag inclusions, and the weld should be brushed with a wire brush.

The last intermediate layer should fill the joint to within 1/16" to 1/32" of the surface of the pipe.

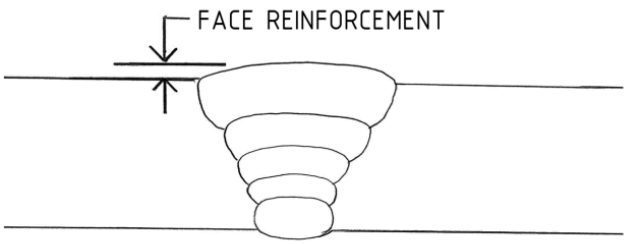
9.

COVER PASSES

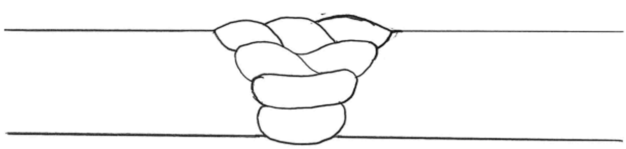
A *cover pass* is a weld pass or passes resulting in the exposed layer of a multi-pass weld on the side from which welding was done. The cover pass provides face reinforcement and gives the weld a neat appearance. Depending on the welding position and the direction of travel, the cover pass may be deposited as a weave bead or as a series of stringer beads.



STRINGER BEADS



WEAVE BEADS



WEAVE AND STRINGER BEADS

Best Practices

If the welding process produces slag, do not weave.

Face reinforcement should be within the limits specified by the applicable code.

The cover pass should fuse into the sides of the joint by 1/16” to 3/32” with a smooth transition into the base metal.

PART III
WELDING POSITIONS

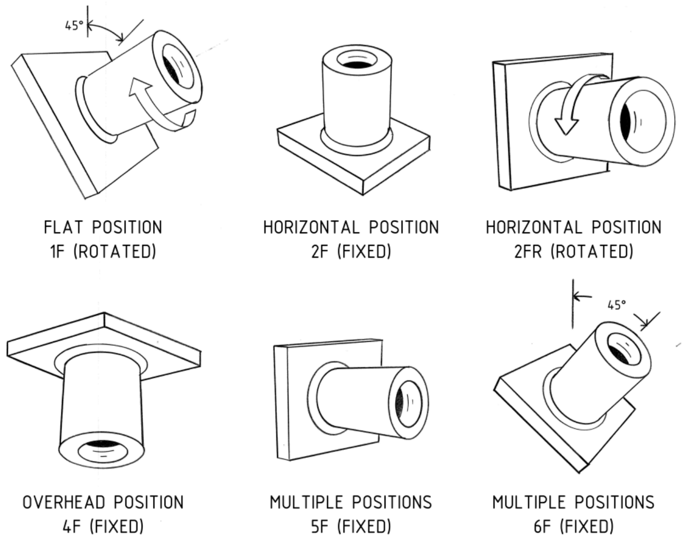
10.

PIPE WELDING POSITIONS

Each welding position has a number designation, and each weld type has a letter designation: “F” for fillet weld or “G” for groove weld. These alphanumeric designations are used on drawings, prints, and *welding procedure specifications* (WPSs) to specify welding positions. They are also used to designate welding test positions for welding procedure qualification and welding qualification.

Fillet Weld Positions

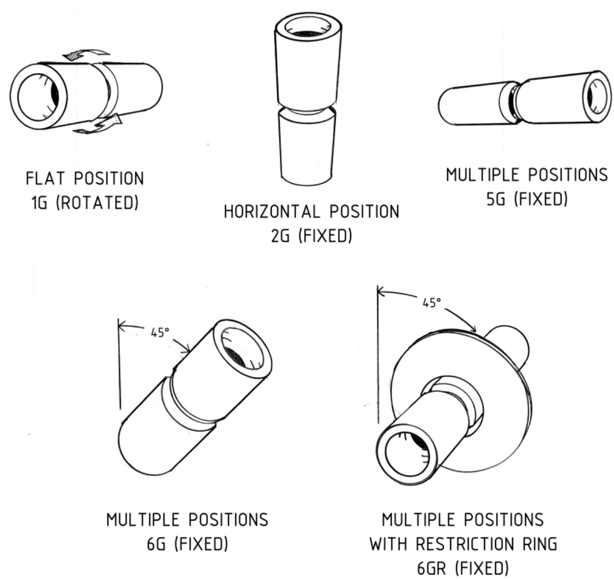
Fillet welds are typically used to weld pipe to plate or to weld socket joints. Fillet welds have six designations:



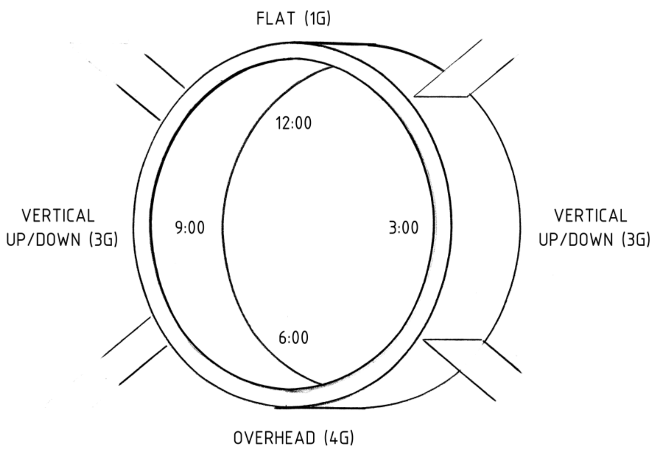
- **1F** (flat position, rotated): the assembly is positioned at approximately 45º and rotated.
- **2F** (horizontal, fixed): the pipe axis is vertical, and the joint is in the horizontal fixed position.
- **2FR** (horizontal, rotated): the pipe axis is horizontal, and the assembly is rotated as welding progresses.
- **4F** (overhead, fixed): the pipe axis is vertical, and the joint is in the overhead position.
- **5F** (multiple, fixed): the pipe axis is horizontal, and welding is done in the overhead, vertical, and flat positions.

- **6F** (multiple, fixed): the pipe axis is approximately 45º and welding is done in the overhead, horizontal, and flat positions.

Groove Weld Positions



Groove welding is most commonly used for joining pipe. Welding power source settings and electrode manipulation vary with the welding position. The standard pipe positions for groove welding are 1G, 2G, 5G, and 6G. There is also a 6GR position that is used strictly for welder qualification purposes. It is similar to the 6G position but also involves a restriction ring that makes the weld more challenging by restricting access to the joint.



Roll Welding

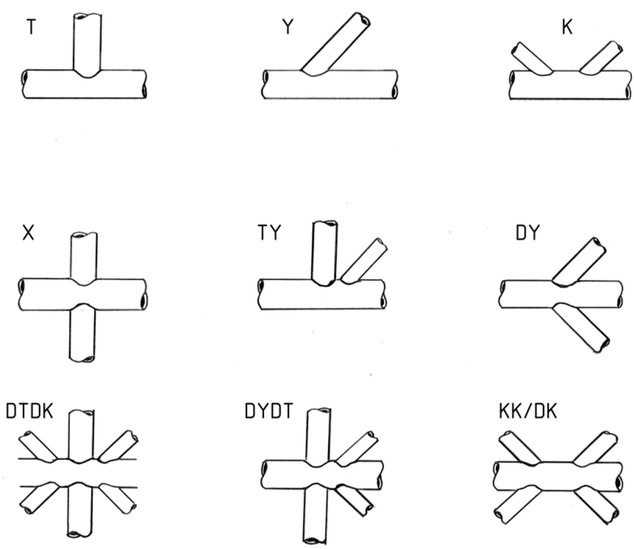
Roll welding refers to welding performed in the 1G position. The pipe itself is rotated so all welding is performed at or near the top of the pipe in the flat position. Roll welding is commonly performed with GMAW or FCAW. In applications where pipe can be rotated, roll welding reduces welding time and improves overall weld quality because it eliminates the need to weld out of position.

Position Welding

Position welding refers to welding performed in the flat, vertical, and overhead positions. The pipe itself is fixed in place and not rotated.

Position welding is more challenging than roll welding because position welding requires the welder to adjust electrode angles and apply different welding techniques while welding around pipe.

Other Weld Positions



Other welding joints include Y, T and K connections. These joints are typically fillet welds but can also be groove welds. These joints are commonly used to create offshoots from the main pipeline.

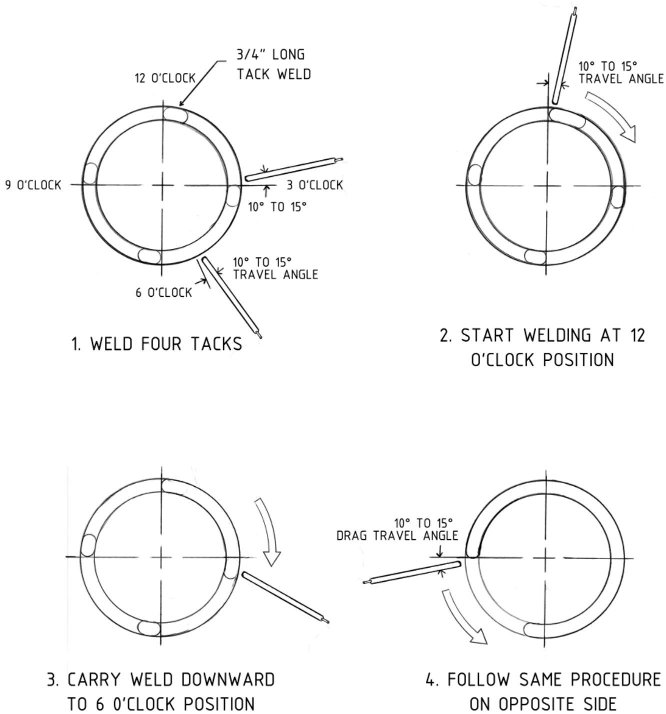
11.

DIRECTION OF WELDING

The direction of welding affects heat input. Whether 5G and 6G position welds are deposited with downhill or uphill travel depends on the wall thickness of the pipe and on the type of base metal.

Downhill Welding

Thin-wall mild steel pipe, such as the type used for cross-country pipelines, is typically welded with downhill travel. The weld starts at the top of the pipe and progresses to the bottom of the pipe.

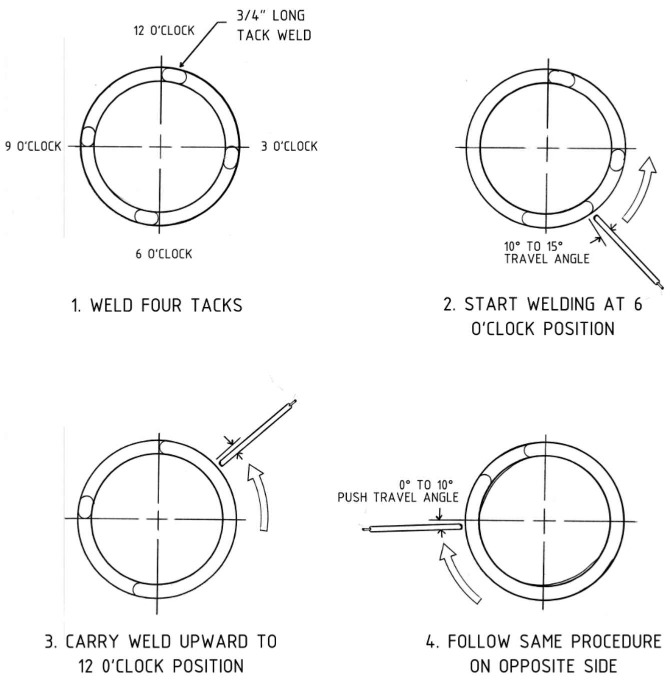


Downhill welding allows for faster travel speeds and lower heat input, which results in higher production rates and minimal problems with distortion and other welding-related problems. Thin-wall pipe also retains heat longer, which means it cools at a slower rate. This results in higher ductility in the weld zone.

Weld pool control can be a problem with downhill welding because gravity causes the molten weld pool to flow in the direction of travel. If the weld pool grows too large, slag can become trapped under the molten metal and cause slag inclusions and incomplete fusion. The welder must watch the weld pool carefully and adjust travel speed to keep the electrode on the leading edge.

Uphill Welding

Thick-wall pipe or pipe made from alloy steel is typically welded with uphill travel. The weld starts at the bottom of the pipe and progresses to the top of the pipe.

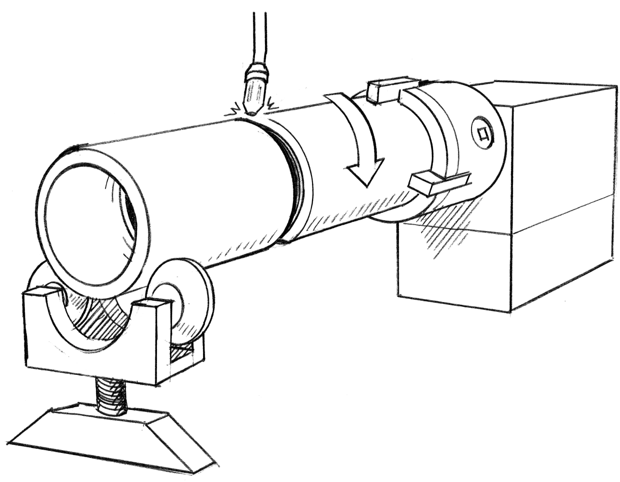


Uphill welding involves higher heat input, slower travel speeds, and thicker weld beads compared to downhill welding. This helps to compensate for the rapid heat loss associated with thick-wall pipe and allows the weld zone to cool at a slower rate. Slower cooling helps to avoid brittleness.

12.

ORBITAL WELDING

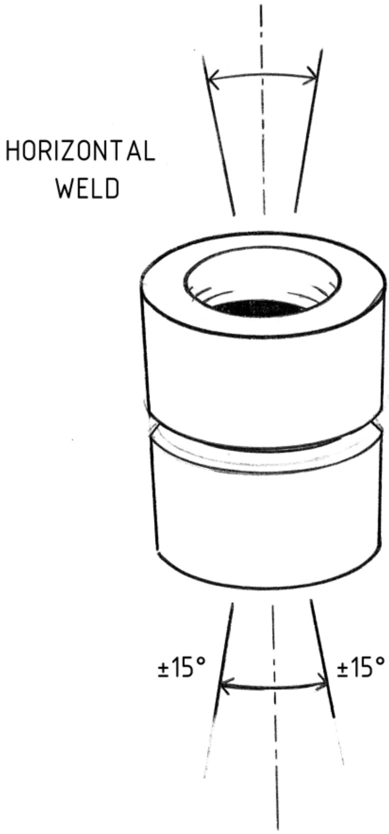
Orbital welding involves mechanically rotating a welding arc 360° around a pipe or tube joint to produce a continuous weld. The first orbital systems were developed over 50 years ago to replace fittings on fluid lines in aircraft with welded joints.



On thin-wall tube, a simple right angle saw cut is sufficient edge preparation, and welding can often be performed without filler metal. For thick-wall material, a U-groove joint is the preferred joint preparation. Orbital systems can also be set up for use with GMAW and FCAW.

13.

2G POSITION (HORIZONTAL)



For the 2G position, the pipe is vertical +/- 15º, and the joint is horizontal. The pipe is fixed (not rotated). The work angle is 90º with a 5º to 10º drag travel angle.

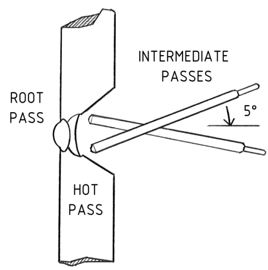
Root Pass

The root bead is deposited with the work angle about 5º below horizontal (85º from the bottom pipe), with a 10º to 15º drag travel angle using a steady drag. Start the bead on a feathered tack weld, and tie into tacks as welding progresses around the pipe. If the root opening is wide in some places, use a slight weave to bridge the gap. The finished bead should be brushed to remove any silicon deposits.

- Strike the arc on the tack weld about ½" in front of the feathered edge to preheat the front edge of the tack.
- Hold a long arc and move to the leading edge of the tack.
- As the weld pool forms, shorten the arc to about 1/16" or 1/32" above the root face and hold it in place until the keyhole forms.
- Use the whip-and-pause technique to deposit the root bead.
- Whip one electrode diameter forward to remove heat from the weld pool, and then return the arc to the leading edge of the weld pool and pause to deposit filler metal.
- If the weld pool begins to sag, lower the work angle 5º to 10º to direct heat toward the top edge of the joint.

Intermediate & Cover Passes

The electrode angles and welding technique are similar for depositing intermediate and cover passes with GMAW-P or FCAW-G.



The first intermediate bead is deposited with the electrode centered on the bottom toe of the root pass. The work angle is about 5º above horizontal (85º from the top pipe) with a 10º to 15º drag travel angle using a steady drag. The second intermediate bead is deposited with the electrode centered on the top toe.

The cover pass is deposited with the same electrode angles as the beads in the intermediate layer. The bottom and top cover beads should be about 1/16” to 1/8” wider than the original groove width with a smooth transition into the base metal. The work angle is 5º below horizontal (85º from the bottom pipe) with the same travel angle and a steady drag. The weld bead should overlap the first intermediate pass by one-half to two-thirds.

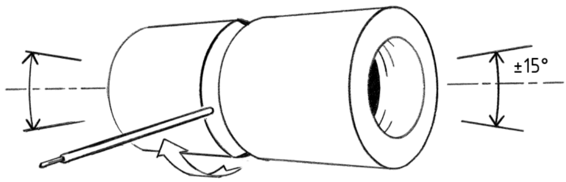
14.

5G FIXED POSITION (MULTIPLE)

In the 5G position, the pipe is horizontal +/-15º. The work angle is 90º with 5º to 10º travel angle. Maintain the same travel angle in all welding positions.

On 5G position welds with GMAW-P, the direction of travel can be uphill with push travel or downhill with drag travel. Regardless of the direction of travel, a Z-weave technique is used to deposit the intermediate and cover passes unless specified otherwise.

The 5G and 6G positions are the most challenging to weld because they involve multiple welding positions. Joints in the 5G and 6G position can also be welded uphill or downhill depending on wall thickness and the type of base metal. The welding procedure specification (WPS) will indicate the direction of travel.



Uphill Travel

- Strike the arc on the tack nearest the 6 o'clock position about ½" from the feathered edge.
- Use a long arc to preheat the front edge of the tack, and shorten the arc to form the keyhole.
- Deposit the root bead in the overhead position using push travel.
- It is important to maintain a consistent keyhole and weld pool.
    - If the keyhole starts to close up, decrease travel speed until the keyhole grows to the correct size.
    - If the keyhole grows too large, increase travel speed, and use the whip-and-pause technique to control heat input.
- As the welding position changes from overhead to vertical, the weld pool can be controlled using a whip-and-pause technique.

    - Using a wrist motion, the electrode is advanced in the direction of travel about one electrode diameter to allow the weld pool to cool slightly.
    - Then the arc is returned to the leading edge of the weld pool to deposit filler metal.
- Use the whip-and-pause technique for the remainder of the root pass.
- Watch the weld pool closely, and keep the electrode on the leading edge.
- Tie into the adjacent tack, and break the arc.
- Chip away the slag, and brush the weld thoroughly with a wire brush before depositing the next section of the root bead.

In 5G position with uphill travel, the cover pass is typically welded with E7018 electrodes using a Z-weave or crescent weave unless specified otherwise. When using weave beads, pause briefly at each toe to fill any undercut and to ensure complete fusion into the sides of the joint.

Downhill Travel

- Strike the arc on the tack nearest the 12 o'clock position about ½" from the feathered edge.
- Move the arc to the leading edge of the tack, and shorten it to form the keyhole.
- Use a steady drag to deposit the root bead.

- Keep the arc on the leading edge of the weld pool, and adjust travel speed as necessary to maintain a consistent keyhole and weld pool size.

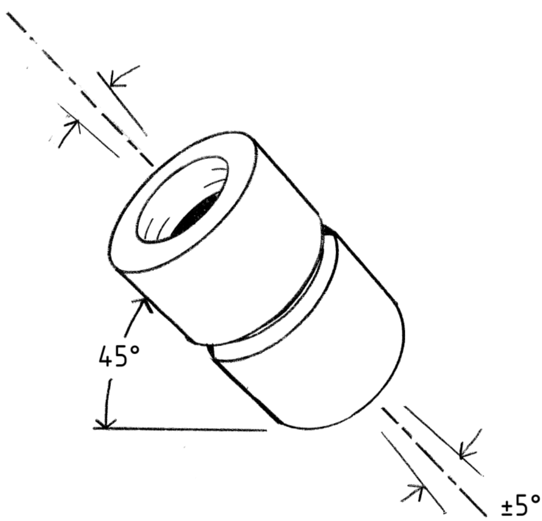
In 5G position with downhill travel, the cover pass is typically welded with E6010 or similar electrodes using a Z-weave technique.

Key Notes

- It is important to pause briefly at each toe to prevent undercut and to fuse into the sides of the joint.
- The electrode should be kept on the leading edge of the weld pool.
- Maintain the same electrode angles relative to the joint in the overhead, vertical, and flat positions.
- The weld should be cleaned by chipping away the slag and brushing it thoroughly with a wire brush.
- A properly deposited root bead should provide the appropriate amount of root reinforcement as specified by the applicable code.
- Incomplete root penetration is cause for the entire weld to be rejected.

15.

6G FIXED POSITION (MULTIPLE)



For the 6G position, the pipe is positioned at a 45º angle +/-5º and the work angles are the same as those used for the 2G position: 90º with a 5º to 10º drag travel angle.

On 6G position welds with GMAW-P, the direction of welding is downhill with drag travel. Stringer beads are used to deposit the intermediate and cover layers. The electrode angles and steady drag technique are the same as the 2G position.

On 6G position welds with FCAW-G, welding progression is always uphill with push travel. Stringer beads are typically used for wall-thicknesses up to and including schedule 80.

The 5G and 6G positions are the most challenging to weld because they involve multiple welding positions. Joints in the 5G and 6G position can also be welded uphill or downhill depending on wall thickness and the type of base metal. The welding procedure specification (WPS) will indicate the direction of travel.

Uphill Travel

- Start the arc on the tack weld closest to the 6 o'clock position.
- The keyhole is formed at the leading edge of the tack weld, and welding should progress up the joint in the overhead position.
- Switch to push travel angle as the welding position changes from overhead to vertical.
- The weld pool and keyhole size are controlled using a whip-and-pause motion.

- Tie into the next tack, and break the arc.
- If the weld pool starts to sag, lower the work angle 5º to 10º to reduce heat on the bottom toe.

Downhill Travel

- After forming the keyhole, use a steady drag to deposit the root bead.
- Adjust travel speed to keep the electrode on the leading edge of the weld pool as you progress along the joint.

Key Notes

- Maintain the same electrode angles relative to the joint in the overhead, vertical, and flat positions.
- The weld should be cleaned by chipping away the slag and brushing it thoroughly with a wire brush.
- A properly deposited root bead should provide the appropriate amount of root reinforcement as specified by the applicable code.
- Incomplete root penetration is cause for the entire weld to be rejected.

PART IV
WELDING METHODS

16.

WELDING PIPE WITH GMAW AND FCAW

When welding carbon steel pipe with GMAW or FCAW, the root bead is typically deposited with modified GMAW short circuiting transfer (GMAW-S) or traditional GMAW-S using 0.035" or 0.045" ER70S-6 electrode wire. The groove angle is in the range of 60° to 75° depending on wall thickness, with a 1/16" to 3/32" root face and a 3/32" to 1/8" root opening.

The intermediate and cover layers are deposited with pulsed spray transfer (GMAW-P) using 0.035" or 0.045" ER70S-6 or with gas shielded flux cored arc welding (FCAW-G) using 0.035" or 0.045" E71T-1 electrode wire. However, FCAW-G is typically used for in-house fabrication.

Overheating in the weld zone can be a problem because GMAW and FCAW are continuous wire processes. Therefore, it may be necessary to lower the current slightly on the cover layer to control the weld bead.

17.

MODIFIED GMAW-S

Traditional GMAW short circuiting transfer (GMAW-S) produces excessive spatter and is prone to fusion problems because the short circuits occur at erratic intervals and with varying intensity. This is especially true when GMAW-S is used with 100% CO2 shielding gas.

However, modified GMAW-S controls welding current independent of wire feed speed to produce stable short circuits, uniform droplet deposition, and a weld pool with small ripples. The result is a calm weld pool with uniform root penetration, consistent tie-in to groove faces, and significantly reduced spatter, even when 100% CO2 is used for shielding.

Modified GMAW-S was made possible by developments in inverter-based welding power source technology. It was developed primarily for depositing root passes in open root pipe and plate applications.

Modified GMAW-S is known by different trade names: the Lincoln Electric Company calls it Surface Tension Transfer (STT) while the Miller Electric Company calls it Regulated Metal Deposition (RMD).

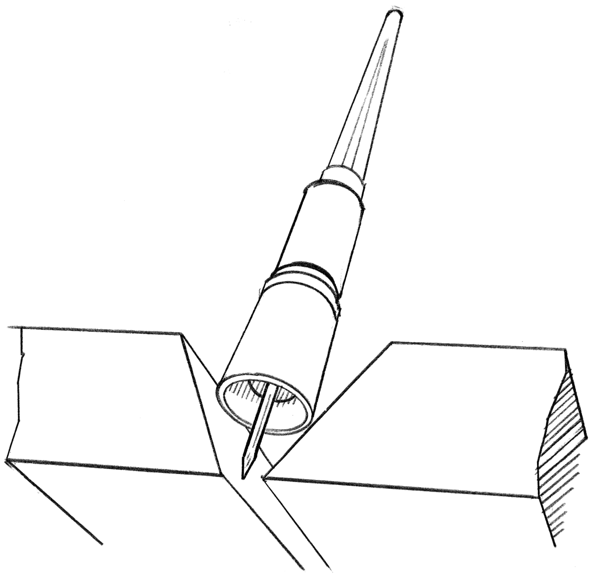
Some advantages of modified GMAW-S include the following:

- High tolerance for misalignment between pipe sections
- Consistent root reinforcement inside the pipe
- No need for backing gas to prevent sugaring on stainless steel pipe
- Reduced skill level required on the part of the welder
- X-ray quality welds at travel speeds three times faster than GTAW
- Suitability for a variety of metals, including carbon steels, stainless steels, and nickel alloys
- No need for hot passes due to higher deposition rates than GTAW and traditional GMAW-S.

18.

WELDING PIPE WITH GTAW

Gas tungsten arc welding (GTAW) is commonly used to weld the root bead in pipe joints where high quality welds are essential, such as in high-pressure piping systems for power plants and refineries. Typically, the first intermediate pass is also welded with GTAW because a GTAW weld bead is thin compared to a bead deposited with SMAW. The remainder of the joint is typically welded with SMAW using low-hydrogen electrodes, such as an E7018.



Depositing GTAW Root Pass

When using GTAW to deposit a root bead, the root face should be approximately 1/16" with a root opening of 1/16" to 3/32". The tungsten electrode should extend to the top edge of the root face with the nozzle resting on the groove faces of the joint. The work angle is 90º with a 15º to 20º push travel angle. The filler rod angled about 20º above the joint. The direction of welding is uphill.

- With the electrode in the joint, and the nozzle (cup) resting on the groove faces at or near the 6 o'clock position, start the arc and hold it in position until the weld pool and keyhole form.
- Push the torch forward with a consistent travel speed while oscillating the electrode about 15° to either side of center.
- Let the nozzle rest on the groove faces as you oscillate the electrode forward. This technique is called "walking the cup".
- Dip the filler rod into the leading edge of the weld pool with a steady rhythm to maintain a consistent weld bead.
- The electrode must be reground if it becomes contaminated by touching it to the pipe or to the filler rod.

When welding a root on high alloy steel, stainless steel, or titanium, an inert backing gas, or purge gas, such as argon should be used to prevent contamination, or sugaring, on the root side of the weld. GTAW may be specified to fill the entire joint on some base metals or where weld integrity is deemed critical, such as in some aerospace applications.

19.

GTAW ORBITAL WELDING

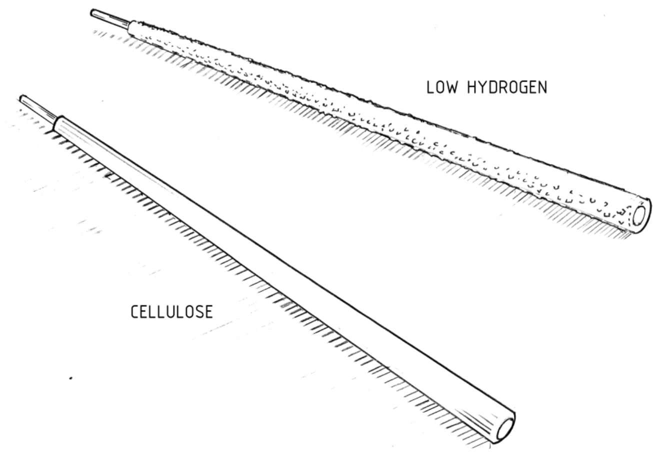
Orbital welding is most commonly used with GTAW for welding tube to tube and tube to tube fittings, pipe to pipe and pipe to pipe fittings, and tube to tube sheet. (*Tube sheet* is metal plate with regularly spaced holes designed to support and isolate the dense array of tubes in heat exchangers and boilers.) Orbital GTAW can be used on a variety of materials, including carbon steels, alloys steels, stainless steels, titanium, nickel, copper, and aluminium alloys. Orbital GTAW is typically specified where high internal weld quality is required, such as in semiconductor clean rooms, in the pharmaceutical and food processing industries, in the petrochemical industry, with power generation, and with aerospace applications.

Specialized, closed-chamber weld heads are available for orbital GTAW applications involving tubes with diameters ranging from 1.6mm to 170 mm (0.0625” to 6.7”) and wall thicknesses of up to 3.5mm (0.14”). Closed-chamber weld heads hold a joint in alignment and ensure complete shielding gas coverage of the weld area. Alternatively, open welding heads combined with special running gear around the circumference of the pipe can make it possible to use orbital GTAW on large-diameter pipe, such as those used as water intake pipes for hydroelectric power plants.

20.

WELDING PIPE WITH SMAW

Typically, the root pass is deposited with a deep penetrating electrode, such as an E6010 or E6011. Electrodes with higher tensile strength, such as an E7010 or E8010, can be used for the root pass if required. Intermediate and cover layers are deposited with low-hydrogen electrodes, such as an E7018, when travel is uphill. For downhill travel, and E6010 or another suitable electrode from the F3 group is used.



Electrode Types

Electrodes and operating ranges are typically specified in the welding procedure specification (WPS). Low-hydrogen electrodes, such as an E7018, have different performance characteristics than electrodes in the deep penetrating F3 group that must be considered when welding pipe. They cannot be used for downhill travel because they produce a heavy slag that can flow ahead of the weld pool and cause slag inclusions.

The arc length must be kept as short as possible to prevent the weld bead from sagging and to minimize the risk of developing pinhole porosity. Low-hydrogen electrodes must be stored in an electrode oven or in a portable electrode quiver to prevent the flux coating from absorbing moisture, which can introduce hydrogen gas into the molten weld metal.

PART V
NONDESTRUCTIVE EXAMINATION

21. NONDESTRUCTIVE EXAMINATION IN WELDING

Nondestructive examination (NDE) is the process of determining the suitability of a material or a component for its intended purpose using techniques not affecting its serviceability. Nondestructive examination is performed by a technician who is qualified to conduct specific NDE processes. A technician certified to Level II or III is a person qualified to interpret nondestructive examination results according to the controlling code or standard for the job.

Indications

Indications are categorized as relevant, non-relevant, or false. A relevant indication is an NDE indication caused by a discontinuity that requires evaluation. A non-relevant indication is an NDE indication caused by a discontinuity that does not require further evaluation. A false indication is an NDE indication interpreted to be caused by a discontinuity at a location where no discontinuity actually exists. False indications are non-relevant indications.

Relevant indications are caused by discontinuities. Relevant indications are categorized as continuous line, intermittent or broken line, small dots, or round. Indications may also be categorized as faint or gross, depending on their dimensions. Relevant indications must be evaluated against the requirements of the applicable fabrication code or standard.

All possibilities that the indication is non-relevant or false are first eliminated, after which the cause of the indication may be determined. It is then determined whether the indication is allowable per the applicable fabrication code or standard.

Methods

Common nondestructive examination methods are visual, liquid penetrant, magnetic particle, ultrasonic, radiographic, electromagnetic, and hydrostatic. Visual examination (VT) is the most extensively used method of NDE. It is typically used to determine surface condition, alignment of mating surfaces, conformance to a specific shape, or to locate leakage. VT may be used before, during, and after welding.

22.

INSPECTOR DUTIES

Before welding begins, the inspector checks drawings, WPSs, and performance qualifications; establishes hold points; develops a documentation plan; reviews material documentation; examines base metals; verifies fit-up and joint alignment; and reviews welding consumable requirements.

During welding, the inspector checks preheat and inter-pass temperatures, verifies conformance to the WPSs, examines the root pass, and examines weld layers. After welding, the inspector examines the surface quality of the finished weld and verifies dimensional accuracy.

23. VISUAL EXAMINATION (VT)

Visual examination (VT) is the most common form of nondestructive examination (NDE), and also the cheapest. Welders are the first visual testers on any welding they perform; inspecting your own work for visible flaws is an essential habit to build. VT can involve the use of tools such as gauges, flashlights, picks, tape measures, or magnifying glasses.

The inspector performing VT should check to see if all welds comply with drawing requirements for size, length, and location. All craters should be filled to the full cross section of the weld. Fillet welds are typically checked for size and surface contour with fillet weld gauges. Groove welds should be filled to the full cross section of the joint or as specified. Face and root reinforcement should not exceed the acceptance criteria of the applicable code or standard.

Types of Gauges Used for VT

A *Cam Type gauge* is a multi-use gauge that can be used to measure many different things. It is adjustable. Cam Type gauges must be precision machined and therefore can be expensive.

A *depth gauge* is another multi-use gauge that can be used for butt joints and fillet welds. It is typically precision machined from stainless steel. Depth gauges include many different gauge styles.

A *HI-LO gauge* is a single purpose welding gauge. It is also typically precision machined from stainless steel. The tiny wire on a HI-LO gauge is fragile and can break easily.

A *fillet weld gauge* is another single purpose gauge. It comes in very specific dimensions to check fillet sizes. Fillet weld gauges come in adjustable and non-adjustable styles.

24.

LIQUID PENETRANT EXAMINATION (PT)

Liquid penetrant examination (PT), also known as dye penetrant testing, is an nondestructive examination technique that uses dyes suspended in high-fluidity liquids to penetrate solid materials and indicate the presence of discontinuities. It is low cost and requires little training to use.

Liquid penetrant examination is used to detect defects open to the surface, particularly in nonferrous metals such as aluminum, which cannot be examined by magnetic particle testing. (However, it cannot be used on materials with excessively porous surfaces, such as sintered metals.) The surface of a part must be completely clean and dry before administering liquid penetrant examination. The surface of the weldment is coated with a thin film of the penetrant, which is left on the surface for a predetermined amount of time known as dwell time. After the penetrant has been wiped clean, developer is applied to the surface to accelerate bleedout and enhance indication contrast.

Why It Works

Liquid penetrant examination uses the force of capillary action, which draws the liquids into all surface defects. This can be observed if two pieces of glass slides are held tightly together in a container of water. Capillary action causes the liquid between the slides to rise to a level above that of the water in the container.

Procedure

Liquid penetrant examination consists of six steps, followed in a set sequence to ensure accuracy and reproducibility. The PT procedure requires a cleaner, a *penetrant* (a solution or suspension of dye), and a *developer* (a material that is applied to the test surface to accelerate bleed-out and enhance the contrast of indications).

1. Apply a cleaner to the surface to ensure that the surface is clean and free from dirt, oil, grease, or other materials that may adversely affect the test.
2. Dry the surface.
3. Coat the surface of the weldment with a thin film of the penetrant, which is allowed to remain on the surface for a predetermined amount of time, known as the *dwell time*.
4. After allowing time for the penetrant to flow into the

defects, remove excess penetrant from the surface. Only the penetrant in the defects remains.

5. Apply the developer to the weldment.
6. Visually examine the part to locate indications and defects.

Notes on the use of penetrants:

- *Dwell time* is the total time penetrant is in contact with the component surface, including application and drain times.
- Dwell time is directly related to the size and shape of anticipated discontinuities since discontinuity size determines the rate of penetration. For example, tight cracks require more than 30 min for penetration if an adequate indication is to be achieved, while gross discontinuities may be suitably penetrated in 3 min to 5 min.
- Penetrant application is done by immersion, spraying, or swabbing (brushing) on dry parts over the areas to be examined.
- The application is extremely messy. Care must be taken to minimize penetrant overspray onto other components and to control the runoff of excessive penetrant from the part being examined.

Notes on the use of developers:

- The specific developer used is selected according to the manufacturer's recommendation for the type of penetrant used.
- The developer acts as a blotting agent, accentuating the presence of penetrant in a discontinuity by causing the penetrant within a discontinuity to seep over a greater area so that the size of the indication in the developer is larger than the actual size of the discontinuity.
- The developer also serves as a color-contrast background for the dye.
- Application consists of coating the test surface with a material to accelerate bleed-out and enhance indication contrast.
- Developer should be applied in several very light layers rather than in one thick coating, as too thick a coating of developer could prevent the penetrant from being drawn to the surface.

25.

MAGNETIC PARTICLE EXAMINATION (MT)

Magnetic particle examination (MT) is a test in which colored iron particles are dusted across the welded surface and an electromagnet is placed so that the iron gathers in specific ways to reveal a discontinuity. The test is moderately expensive and requires training to conduct properly.

MT is used to detect surface or very near subsurface discontinuity indications in ferromagnetic metals. Crack types detected by MT include crater cracks, transverse cracks, longitudinal cracks, and toe cracks.

Procedure

When a magnetic field is established (by circular or longitudinal magnetization) in a piece of ferromagnetic material containing one or more discontinuities, magnetic poles are set up at the discontinuities. Colored magnetic particles are applied to the material (by the dry or wet magnetization method). Impurities or discontinuities in the magnetized material interrupt the lines of magnetic force, showing the size, shape, and location of defects, as the colored particles concentrate around the defects. The patterns are usually characteristic of the type of discontinuity detected.

Maximum sensitivity with MT is obtained from linear discontinuities either oriented perpendicular to or laying at a 45° angle to the lines of magnetic flux. For this reason, each area should be examined twice, with the lines of magnetic flux during the second examination approximately perpendicular to the lines of flux during the first examination.

For efficient coverage of welds when using the prod method, prods must be crisscrossed and spaced appropriately. This is to ensure coverage over the entire weld, so the inspector doesn't miss any discontinuities. Wet or dry colored iron particles are applied to the surface while the magnetizing current is switched on and the prods are in contact with the surface.

After examination, demagnetization is mandatory for parts in critical service, such as engines and aircraft, that have been strongly magnetized. Filings, grindings, and chips resulting from operational wear are attracted to magnetized parts and interfere with performance.

Key Terms

Circular magnetization is a concentric magnetic field produced by a straight conductor, such as a piece of wire, carrying an electrical current. Circular magnetization is produced by a contact head, central conductor, or prods.

Longitudinal magnetization is a magnetic field produced when the current-carrying conductor is coiled and the magnetic field is parallel to the axis of the coil. The magnetic field strength produced within a coil increases in proportion to the number of loops within the coil. Longitudinal magnetization is achieved by coil or yoke.

The *magnetic leakage field* is the magnetic field that leaves or enters the surface of a part at a discontinuity or change in section configuration of a magnetic circuit. When a part with discontinuities is magnetized, a magnetic leakage field is produced at the discontinuities. Colored iron particles congregate at leakage fields and indicate the approximate shape of a discontinuity.

26.

ULTRASONIC TESTING (UT)

Ultrasonic testing (UT) is non-destructive testing that uses sound waves.

- Expensive
- Lots of training required
- More than one type of UT array

Ultrasonic examination is a true volumetric test method because it can identify the location of discontinuities within a material. UT is very sensitive and is capable of locating very fine surface and subsurface cracks as well as other internal discontinuities and defects.

High-frequency vibrations or waves are used to locate and measure defects in both ferrous and nonferrous materials. A high-frequency sound beam is directed into a part on a predictable path. The sound beam is reflected back when it encounters an interruption in the continuity of a material. The reflected beam is detected and analyzed to define the presence and location of the discontinuity.

Electronic Components

Electronic components required for UT include:

- An electronic signal generator to provide bursts of alternating voltage
- A sending transducer (crystal) to emit a beam of ultrasonic waves when the AC voltage is applied
- A receiving transducer to convert the sound waves to AC voltage (the receiving transducer and the sending transducer may be combined)
- An electronic device to amplify and demodulate or otherwise change the signal from the receiving transducer
- An electronic timer to control the operation
- A CRT display to characterize or record the output from the test piece. The CRT display uses A-scan presentation.

Waves

A *longitudinal wave* (straight beam) is a compression wave that represents wave motion in which the particle oscillation is the same direction as wave propagation.

A *shear wave* (angle beam) is a transverse wave that represents wave motion in which the particle oscillation is perpendicular to the direction of wave propagation.

UT of Root Passes

UT of the root pass is carried out from both sides of the weld, whenever possible, using a suitable angled probe and prescribed scanning patterns. UT of the root pass detects incomplete penetration or incomplete fusion. Scanning lines are marked at half skip distance back from the original root face on either side of the weld. A guide is then placed so that when the heel of the selected angle probe is butted against the guide, the probe index is on the scanning line.

Other UT

Ultrasonic examination of the fusion face and the weld body requires examining the entire weld volume. The probe is positioned to produce full skip distance to the nearest edge of the weld reinforcement. The probe index is located at a distance from the weld centerline equal to full skip distance plus one-half the full weld reinforcement width. The base metal is marked with two lines, parallel to the weld centerline, on both sides of the weld. The lines are at half skip and full skip distances and mark the boundaries of the scanning pattern.

27.

RADIOGRAPHIC TESTING (RT)

X-rays! Gama-rays!

- Similar concept to getting an x-ray at the doctors or dentist
- Moderately expensive
- Requires lots of training

The test material absorbs radiation, but less absorption takes place where there is a void, leading to darker areas on the processed radiograph.

Radiographs

A *radiograph* is a permanent, visible image on a recording medium produced by penetrating radiation passing through a material being tested. Image distortion occurs when the plane of the part and the plane of the film are not parallel. To minimize image distortion, the radiation beam must be directed in a direction perpendicular to the plane of the film. If distortion of the film image is unavoidable, the radiographer must take into consideration that all parts of the image are distorted; otherwise, the radiograph may be incorrectly interpreted.

Radioisotopes

Radioisotopes have different ranges of energy, making them suitable for different thicknesses of metals.

Gamma rays are produced from portable sources and are used extensively for field-testing of welds. The gamma ray source is made as small as possible in the shape of a cylinder whose diameter and length are approximately equal. The cylindrical shape permits the use of any surface of the source as the focal spot since all surfaces, as viewed from the test specimen, are equal in area. The wavelength of the gamma rays (energy level) is determined by the nature of the source. Gamma rays have different ranges of energy and different thickness limitations for materials examined.

X-Rays

The penetrability of X rays from the X-ray machine into the part depends on the voltage applied across the elements of the X-ray tube. Maximum voltages are established based on the thickness of the metal to be tested. The wavelengths of X radiation are determined by the voltage applied between the elements of an X-ray tube. Higher voltages produce X rays of shorter wavelengths and increased intensities, resulting in deeper penetration capability. The penetrating ability of X rays depends on the X-ray absorption properties of the particular metal.

Image Quality Indicator

An *image quality indicator (IQI)* is a device or combination of devices whose demonstrated image determines radiographic quality and sensitivity. The image or images demonstrated by an IQI provide visual data, quantitative data, or both to determine the radiographic quality. An IQI is not intended for use in judging size of, or acceptable limits for, discontinuities. An IQI is also called a penetrometer, or penny. Each IQI is identified by an identification number that gives the maximum thickness of material for which the IQI is normally used. Each IQI, or penetrometer, shows a lead number that identifies the thickness of the IQI in thousandths of an inch. Additionally, an IQI has three holes drilled through it, each to a specified diameter.

Shim stock may be used to compensate for the additional thickness of a weld compared with the base metal. Shim stock is sometimes used in RT of welds because the area of interest (the weld) is thicker than the part thickness. Shims are selected so that the thickness of the shim(s) equals the thickness added to the specimen by the weld in the area of interest. Shim stock is placed underneath the IQI, between it and the part. In this way, the image of the IQI is projected through a thickness of material equal to the thickness in the area of interest. The shim stock length and width are greater than those of the IQI.

Single-Wall RT

Single-wall RT for plate, pipe, or tubing welds is relatively simple to achieve because the critical areas of the weld are clearly defined in terms of their length, width, and thickness. The film is placed on the side opposite the source with an exposure angle of 90°. Single-wall RT should be used whenever possible for flat or circular objects. Subject contrast is small and exposure calculation is relatively simple.

28.

ELECTROMAGNETIC TESTING (ET)

Electromagnetic examination (ET), also known as eddy current testing, uses electromagnetic energy to detect surface and internal quality of welds. ET can be used to detect porosity, slag inclusions, internal cracks, external cracks, and lack of fusion on ferrous and nonferrous metals. Electromagnetic examination procedures must be standardized, often using full-scale or mock-up calibration standards with simulated discontinuities.

ET is a mix of magnetic testing and digital examination. The magnetic flow of the electrons are digitally graphed which is then viewed on a computer screen and interpreted.

To inspect longitudinal weld quality in welded pipe or tubing, an energizing coil and a detector coil are required. Examination is performed by passing the pipe or tubing longitudinally through the primary energizing coil, causing the probe-type detector coil to move across the longitudinal weld from end to end. The primary coil is energized with an alternating frequency that is suitable for the part being inspected and induces eddy currents into the part.

To achieve electromagnetic induction, the electric coil may be an encircling coil or an inside coil. An *encircling coil* is wound so that the test specimen passes through the center of the coil, causing the eddy currents to flow around the rod or tube being tested. *Inside coils* pass through the inside of tubing and eddy currents flow around the tubing.

29.

HYDROSTATIC TESTING (HYDRO)

Hydrostatic testing (hydro) uses water, air, and oil to test welds such as pressure vessels or pipe lines. the test is not difficult, although it requires some training, and can be low cost to perform. Hydrostatic testing is often used for *proof testing*, to demonstrate the ability of the welded structure to carry loads equal to or in excess of the anticipated service conditions. Hydrostatic testing must be used with care to prevent a catastrophic failure caused by release of stored energy, and there must be adequate venting to prevent the tested item from collapse (sucking in) when it is drained.

When performing hydrostatic testing on an atmospheric pressure storage tank, the the container is tested for its ability to withstand a certain level of pressure. For components built to the ASME Boiler and Pressure Vessel Code, this pressure is 150% of design pressure. For other components, the test pressure may be based upon a fixed percentage of the minimum yield strength. After a fixed holding time, the container is inspected for soundness by visually checking for leakage, or by monitoring the hydrostatic test pressure for any drop.

PART VI
DESTRUCTIVE TESTING

30.

DESTRUCTIVE TESTING

Destructive tests can be categorized as tensile tests (measuring the effects of a pulling force on a material), soundness tests (checking the condition of the weld), hardness tests, and toughness tests. The purpose of a hardness or toughness test is to compare the hardness or toughness of the weld metal in a specimen with the base metal to see if the mechanical properties of the base metal have been altered due to welding.

Destructive test types, the location of specimens, and specimen preparation procedures are indicated in the controlling fabrication code or standard.

When qualifying a welding procedure, maximum load, tensile strength, and failure location data from the test should be recorded on a welding procedure qualification record (WPQR).

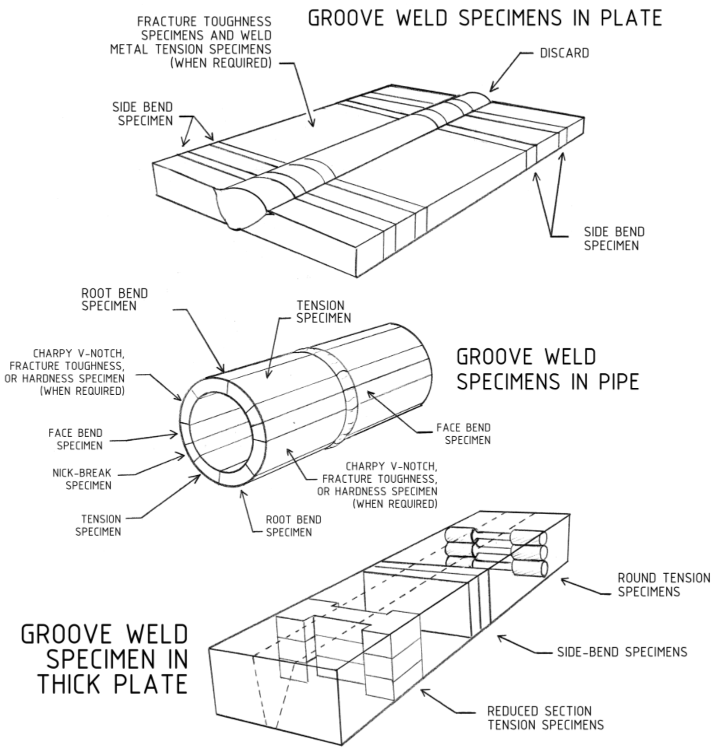
Metal fatigue failure is caused by a cyclic or repeated mechanical action on a member.

Specimens

Proper specimen preparation ensures that test results will not be affected by undesirable surface features. Safety practices must be followed when preparing specimens to prevent injury from grinding wheels, hot surfaces, or sharp edges.

Tensile specimens obtained from welded joints are typically rectangular, unless taken from locations where it is not possible to obtain a specimen with a rectangular cross section. Tensile specimens are usually dog-bone shaped so that the central portion of the specimen is narrower in cross section than the two ends.

Mechanical test specimen preparation is described in AWS B4.0, *Standard Methods for Mechanical Testing of Welds.* Specimen preparation may vary according to the type of weld. Groove weld specimens must be taken from specific locations in plate and pipe welds to ensure accurate results.



Strain Rates

The mechanical properties of a metal are strongly affected by the rate of straining. A metal tested at a low strain rate may break with a large amount of strain (elongation), but a metal tested at a high strain rate may break with little or no elongation. Metal is tough and ductile at a low strain rate and is brittle at a high strain rate.

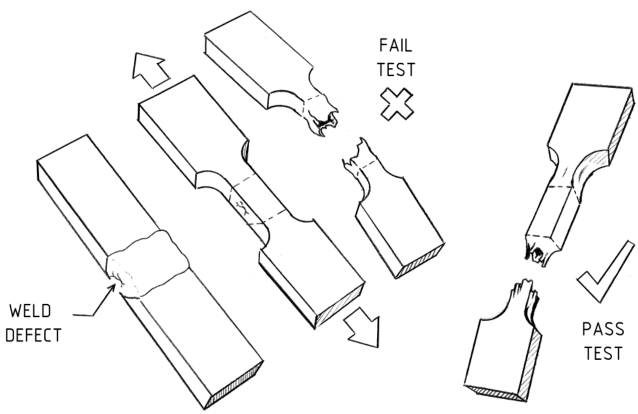
AWS Codes

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

31.

TENSILE TESTING

A tensile test is a destructive test that measures the effects of a tensile force, or pulling force, on a material. Tensile testing involves the placement of a weld specimen in a universal testing machine and stretching the piece until it breaks. Tensile force occurs when a mechanical load is applied axially, or parallel to the axis, to stretch a test specimen.

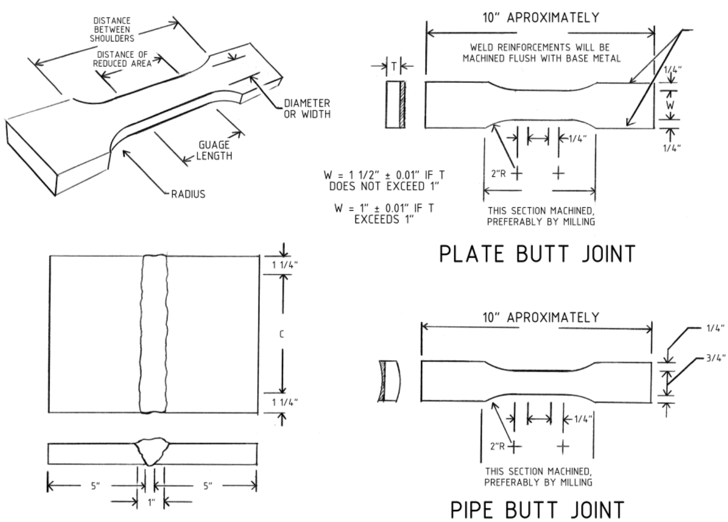


Tensile Test Pass or Fail

Specimens

The specimen is cut either from an all-weld area or from a welded butt joint for plate and pipe.

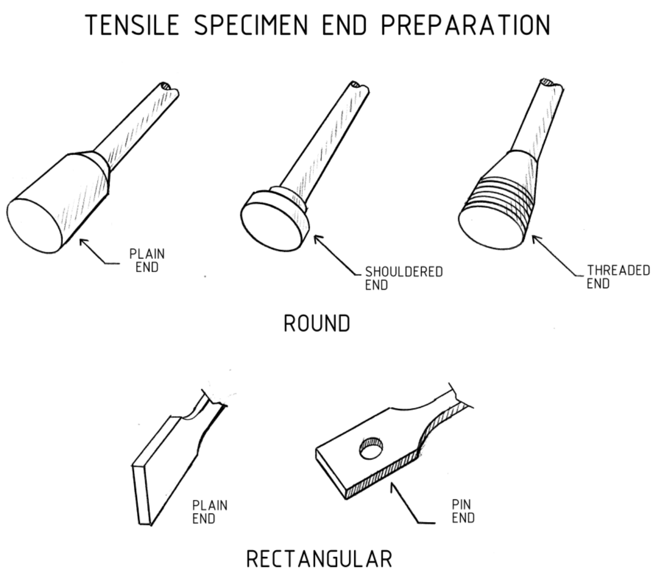
The specimen for an all-weld metal area should conform to specific dimensions, and it should be cut from the welded section so its reduced area contains only weld metal.



Tensile Test Specimen Dimensions

In general, tensile specimens obtained from welded joints are rectangular, unless taken from locations where it is not possible to obtain a specimen with a rectangular cross section, such as when testing filler metals.

The end shapes of tensile test specimens are matched to the gripping device of the tensile testing machine to ensure a secure and uniform grip.

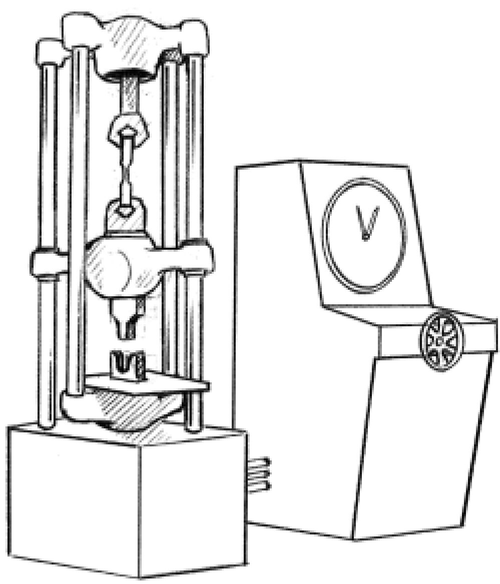


Tensile Test Specimen Ends

Rectangular specimens are generally made with plain ends, but occasionally pin ends are used. A *pin end* is a rectangular specimen that contains a hole for gripping.

Procedure

The tensile test procedure begins with fixing the specimen firmly in the grips of the testing machine. An *extensometer*, a device used for measuring the extension or elongation of the test specimen, is fitted to the specimen across its gauge length. The specimen is then stretched at a steady rate until it fails. The extensometer is removed before the specimen breaks.



Tensile Test Machine

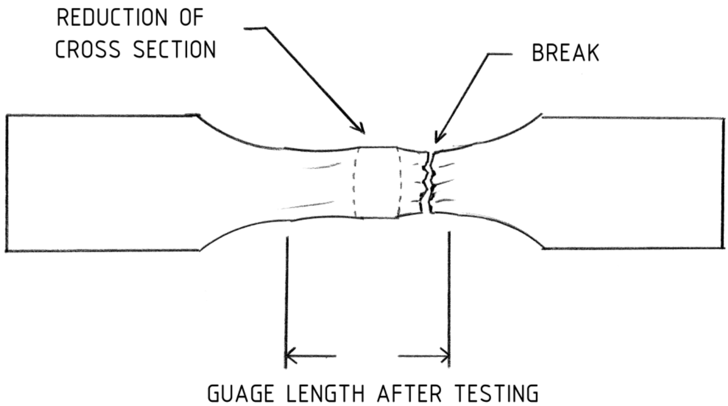
Load-Extensive Curve

As the test specimen is stretched, a load-extension curve, or stress-strain curve, is plotted on a graph.

- Point A is the *proportional limit*: the maximum stress at which stress is directly proportional to strain. Beyond Point A, strain is permanent.
- Point B is the *yield point*: the location on the stress-strain curve where an increase in strain occurs without an increase in stress.
- Between points B and C the curve falls, indicating a plastic strain. Point C is considered the lower yield point.
- Point E is *ultimate tensile strength*: a measure of the maximum stress or load that a metal can withstand.
- Point F is the point of failure or the point at which fracture occurs.

Reduction

When the tensile test is completed, the broken specimen is removed from the testing machine. The percent of elongation can be found by fitting the broken ends of the two pieces together and measuring the new gauge length. The new, increased gauge length and the reduced diameter at the narrowest point are measured. Measurement can be made on either side of the break.



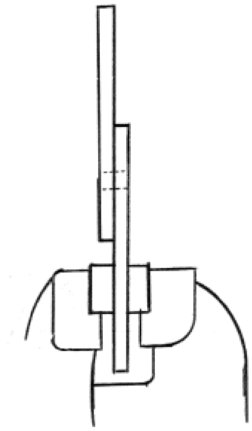
Tensile Test Successful Specimen

32.

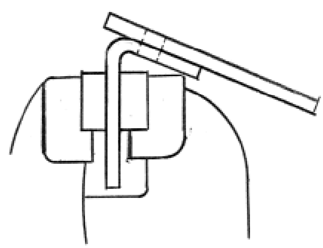
TENSILE TESTS: SHEAR AND PEEL

The *spot-weld tension shear test* has a similar set up as the Tensile Test. Two arms clamp the piece in place and it stretches, pulling the spot weld apart.

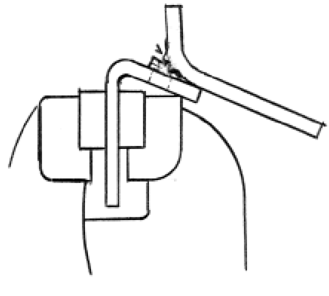
An inexpensive alternative to the spot-weld tension shear test is the peel test. A *peel test* is a shear test in which a specimen is gripped in a vise and then bent and peeled apart with pincers to reveal the weld. The weld size is measured and compared to that required for the joint. If the weld size is equal to or exceeds the standard size for the design, the production weld is acceptable. The peel test may not be suitable for high-strength base metal or for thick sheets of metal.



SPECIMEN IS GRIPPED IN VISE



SPECIMEN IS BENT AT POINT BELOW THE WELD



SPECIMEN IS PEELED THROUGH WELD AREA

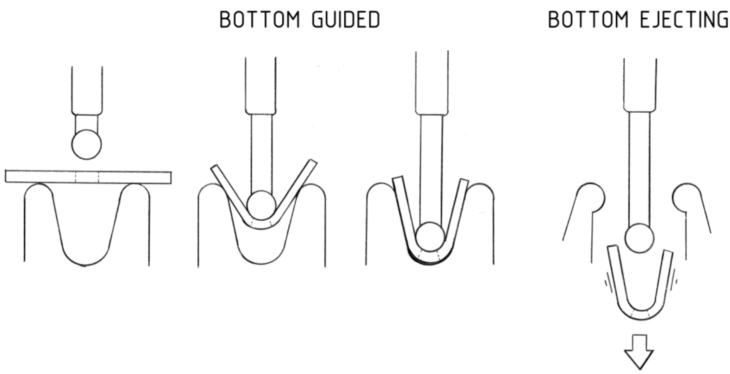
Peel Test Procedure

33. SOUNDNESS: GUIDED BEND TEST

Soundness tests are designed to determine if a weld is free of imperfections, such as inclusions, porosity, incomplete fusion, and cracks. The guided bend test is the most commonly used soundness test for groove welds, but nick-break and fillet weld break tests are also soundness tests.

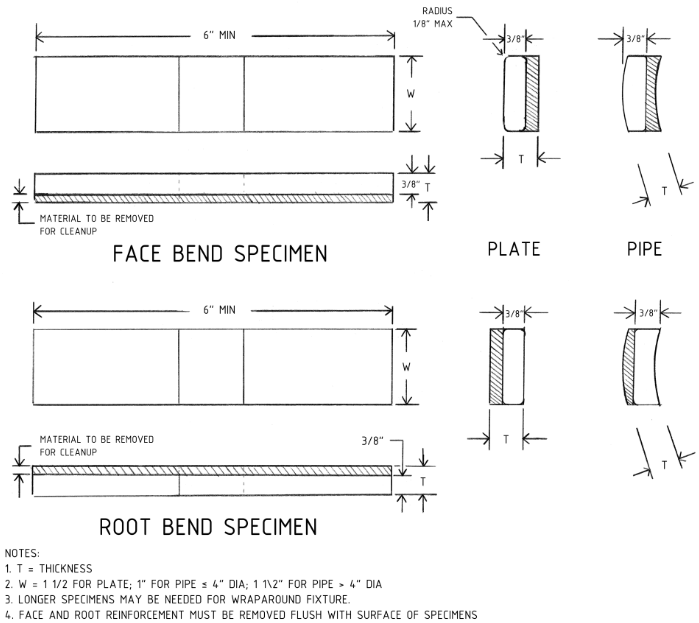
Guided Bend Test

Guided bend test fixtures can be bottom guided or bottom ejecting. The bottom guided bend fixture is designed to support the specimen in the die as it is bent. The bottom ejecting guided bend fixture allows the specimen to be ejected from the die after it is bent.



Bottom Guided vs Bottom Ejecting

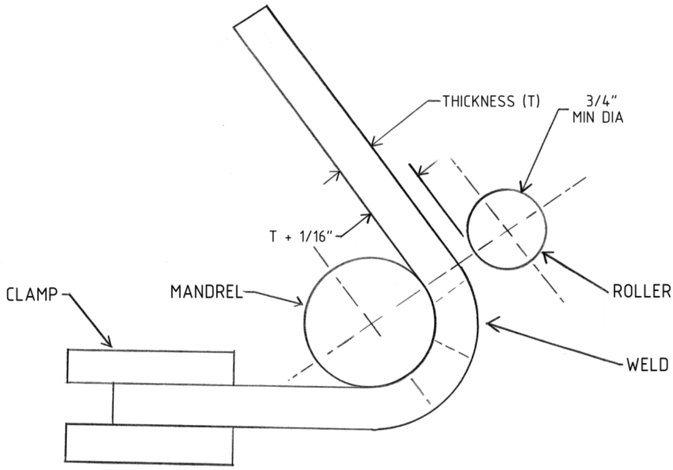
Typically, one face specimen and one root specimen are used for a standard guided bend test on plate up to 3/8″ thick. Above that thickness, side bend tests are used because the metal is too thick for a standard guided bend test. Four bend specimens are required for pipe, two face specimens and two root specimens. During a face bend, the face of the weld is stretched. During a root bend, the root of the weld is stretched.



Bend Test Specimen Dimensions

Wraparound Guided Bend Test

A wraparound guided bend test is a bend test in which a specimen is bent around a stationary mandrel. One end of the specimen is clamped to prevent it from sliding during bending, and a roller is used to force the specimen to bend around the mandrel. The weld and the HAZ must be completely within the bent portion of the specimen after testing. The test specimen is removed from the bend fixture when the outer roller has moved 180° from the starting point.



Guided Bend Test Procedure

34.

SOUNDNESS: MACRO-ETCH TEST

A *macro-etch test* is a test in which a specimen is prepared with a fine finish, etched, and examined using no magnification or low magnification.

After surface preparation, the specimen is cleaned with a suitable solvent to remove grease, oil, and other residues that may interfere with etching. Once the surface has been cleaned, it is etched with an appropriate etchant and examined.

The fillet weld break test with macro-etch is used for the qualification of welders and welding operators in accordance with AWS D1.1, *Structural Welding Code—Steel*. A slightly different version of the fillet weld break test is used to qualify tack welders.

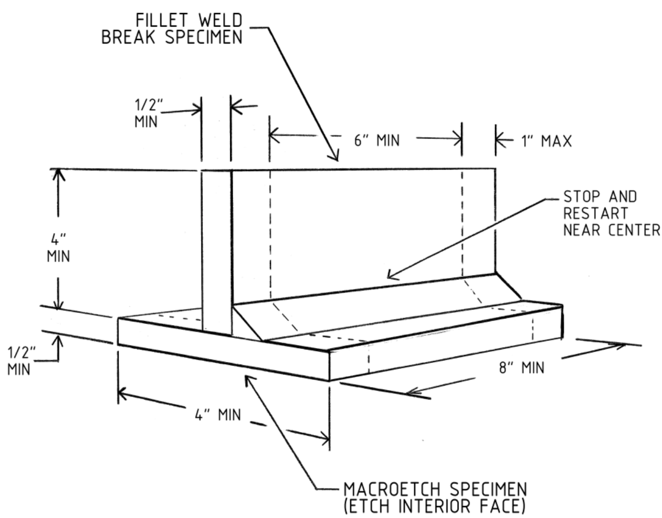
Etching can only be used to detect surface defects, or any discontinuities right at the cut.

35.

SOUNDNESS: FILLET WELD BREAK TEST

A *fillet weld break test* is a soundness test in which the specimen is tested with the weld root in tension.

The fillet weld break test with macro-etching is used for the qualification of welders and welding operators.

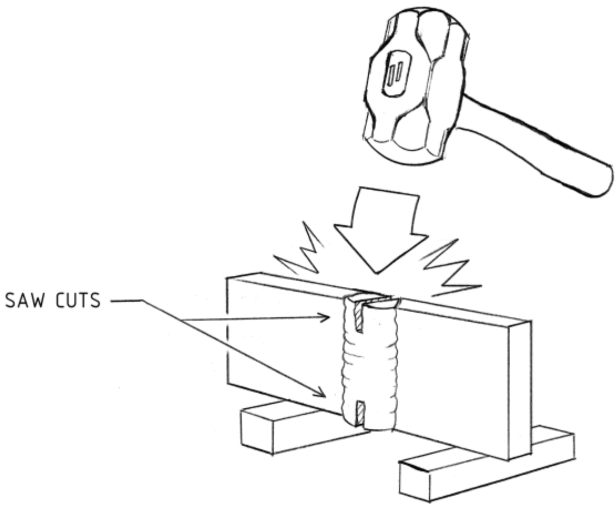


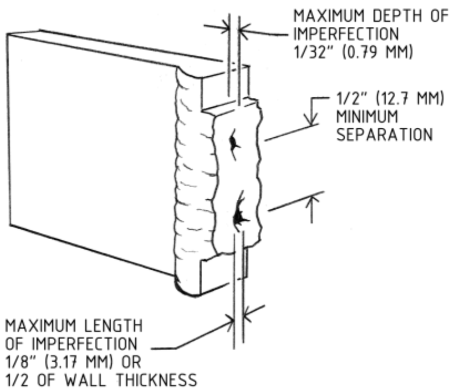
36.

SOUNDNESS: NICK-BREAK TEST

A *nick-break test* is a soundness test used to determine the internal quality of a weld. The objective of a nick-break test is to fracture a specimen through the weld so it can be examined for imperfections, such as porosity, inclusions, cracks, or incomplete fusion.

Once the specimen has been saw cut, it is then broken along the length of the weld and examined. If discontinuities are present, they are evaluated based on the acceptance criteria in the applicable code or standard. The nick-break test is specified by API 1104, *Standard for Welding Pipelines and Related Facilities,* to evaluate the quality of pipe welds.



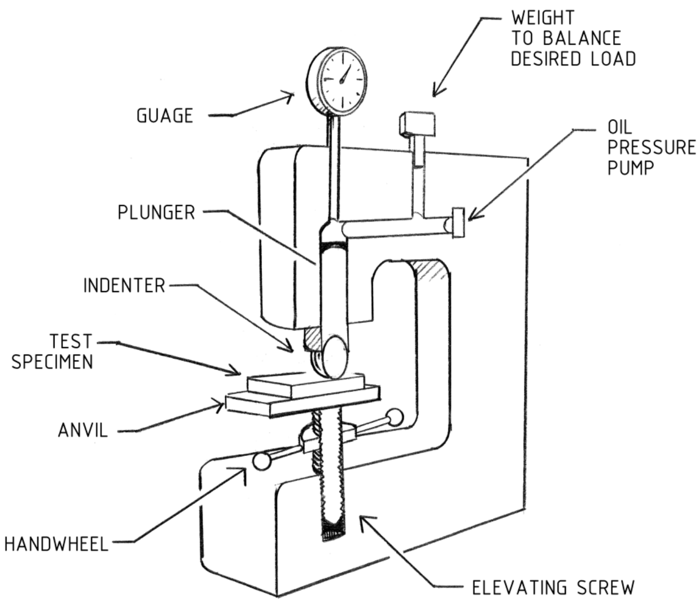


Nick Break Test Procedure

37.

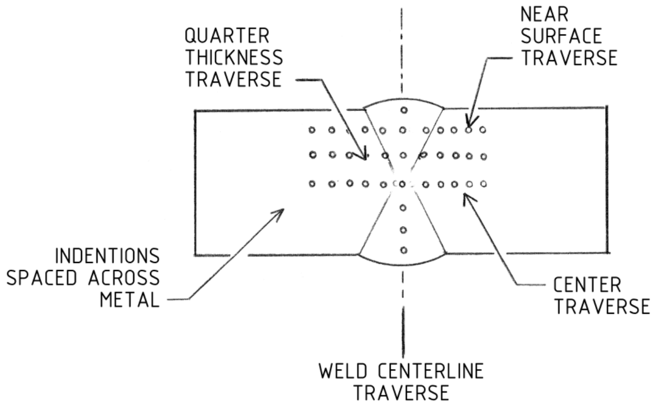
HARDNESS TESTS

A *hardness test* is a test used to determine the relative hardness of a weld area as compared with the base metal. Hardness is the ability of a metal to resist penetration or indentation. Indentation hardness testing is applied across an HAZ (heat-affected zone) and uses the surface impression produced by a standardized shape indenter and standardized load to determine hardness.



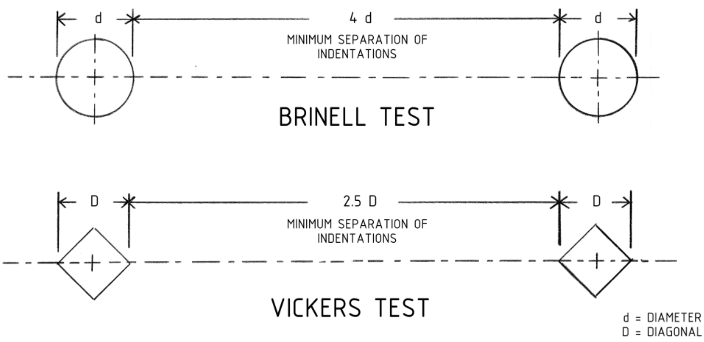
Hardness Test Machine

There are a few different type of hardness tests, including Brinell and Rockwell. The Rockwell hardness test is the most commonly used and versatile hardness test.



Hardness Test Indentations Locations

For evaluation of weld metal hardness, the edge of the indentation must be within the weld metal and no closer than 1/8″ from the weld metal interface with the base metal. The minimum spacing between indentations depends on the type of test. If the indentations are too close together, there will be disturbed zones of metal. The minimum separation between indentations should be four diameters (4 d center to center) for the Brinell and Rockwell hardness tests and two-and-a-half diagonals (2 1/2 D center to center) for the Vickers hardness test.

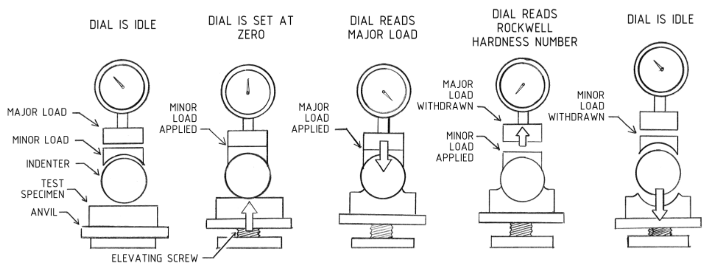


Indentation Spacing: Brinell vs Bickers

Rockwell Hardness Test

The *Rockwell hardness test* is an indentation hardness test that uses two loads, supplied sequentially, to form an indentation on a metal test specimen to determine hardness. The Rockwell hardness test is the most commonly used and versatile hardness test. The Rockwell hardness test is commonly used for weld and base metal measurements. The Rockwell testing machine has a variety of attachments that enable it to measure the hardness of a wide range of materials.

A 1/16″ diameter steel ball and a 120-diamond cone are the two types of indenters. A minor load of 10 kg is first applied, which helps seat the indenter and removes the effect of surface irregularities. A major load, which varies from 60 kg to 150 kg, is then applied.



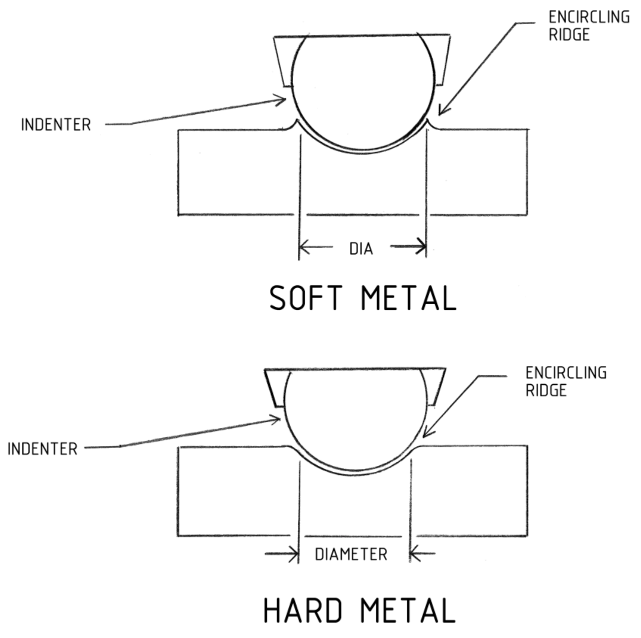
Rockwell Test Procedure

Brinell Hardness Test

The *Brinell hardness test* is an indentation hardness test that uses a machine to press a 10 mm diameter, hardened-steel ball into the surface of a test specimen. The load must remain on the specimen 15 seconds for ferrous metals or 30 seconds for nonferrous metals. Sufficient time is required for adequate flow of the material being tested; otherwise, the readings will be inaccurate. The test is used to determine base metal hardness. The Brinell hardness test is fully described in ASTM E 10, *Brinell Hardness Testing of Metallic Materials.*

The Brinell hardness number followed by the abbreviation “HB” indicates a hardness value calculated under standard conditions using a 10 mm diameter, hardened-steel ball; a 3,000 kg load; and an indentation time of 15 seconds to 30 seconds. However, the load applied to the steel ball depends on the type of metal being tested. A 500 kg steel ball is used for aluminum castings, and a 3,000 kg steel ball is used for ferrous metals. The diameter of the indentation is measured to 0.05 mm using a low-magnification portable microscope.

Care must be taken to measure the exact diameter of the indentation and not the apparent diameter caused by edge effects. Edge effects may result in a ridge or depression encircling the true indentation.



Measuring True Indentation Dimensions

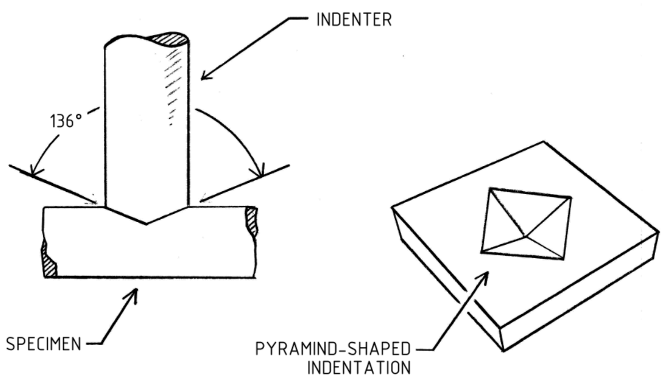
Micro Hardness Test

Micro hardness tests are indentation hardness tests that use very light loads of less than 200 g. Micro hardness tests are at the opposite end of the scale from the Brinell and Rockwell hardness tests. A polished surface along with the light loads allows the hardness of individual grains of metal or other micro constituents to be measured at regular intervals in the specimen.

There are two types of micro hardness tests. They are the Vickers micro hardness test and the Knoop micro hardness test. The primary difference between the two types of tests is the shape of the indentation they produce. The Vickers test produces a square (pyramid-shaped) indentation, and the Knoop test produces a rectangular (diamond-shaped) indentation.

Vickers Test

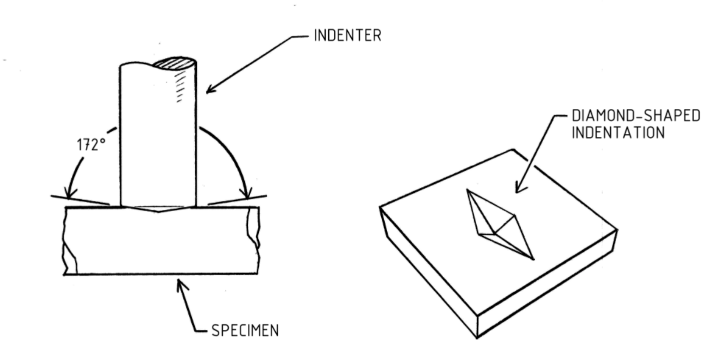
To perform the Vickers test, the polished specimen is placed on an anvil and raised by a screw until it is near the indenter. The starting lever is tripped, and the load is applied slowly to the indenter. A microscope is used to measure the diagonals of the pyramid-shaped indentation. Vertical and horizontal axes are measured and averaged to obtain the Vickers hardness number, which is followed by the letters HV. The Vickers hardness test is described in ASTM E 92, *Vickers Hardness Testing of Metallic Materials.*



Vickers Microhardness Test

Knoop Test

The procedure for performing the Knoop test is similar to the procedure for the Vickers test. However, the indenter is rectangular (diamond-shaped) instead of square. Also unlike the Vickers, the Knoop test only measures the long axis of the indentation. This measurement is then converted to a Knoop hardness number using a chart.



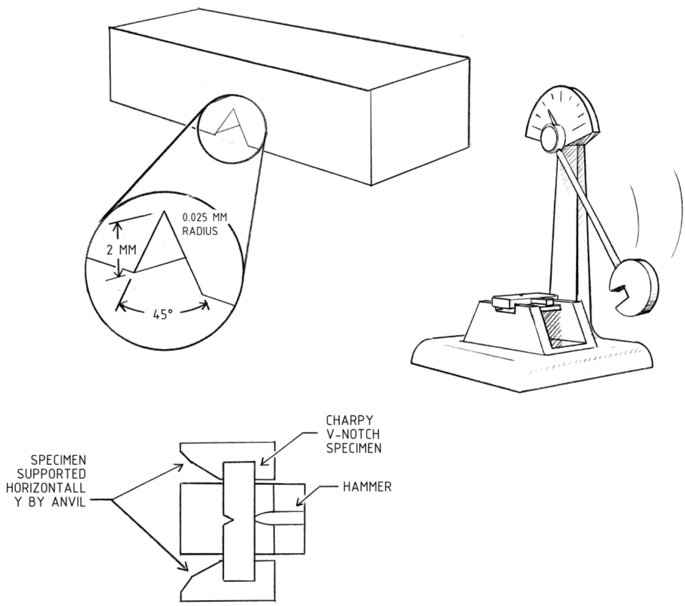
Knoop Microhardness Test

38.

TOUGHNESS: CHARPY V-NOTCH TEST

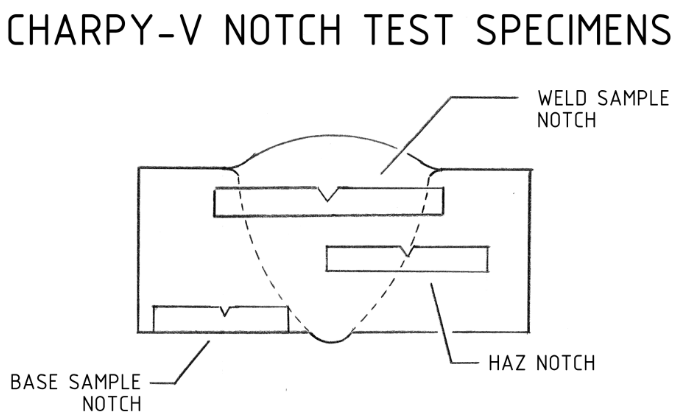
The Charpy V-notch test is a toughness test. It uses the energy produced by a dynamic load and measures the energy needed to break a small, machine-notched test specimen. Specimens are tested at different temperatures to ensure the materials will withstand the service conditions in which they will be used.

A Charpy V-notch test is performed in a universal pendulum impact tester. The specimen is placed horizontally against two supports at the bottom of the tester. The pendulum is raised to a standard height, giving it a potential energy of 240 ft-lb or 325 joules (J). The pendulum is released, and the specimen is struck and broken as the pendulum swings through its arc. The swing of the pendulum after it strikes the specimen indicates the energy absorbed on impact and is measured in foot-pounds or joules.



Charpy V-Notch Procedure

The small specimen size required for the Charpy V-notch test is also convenient because specimens may be cut at various orientations or locations within a part.



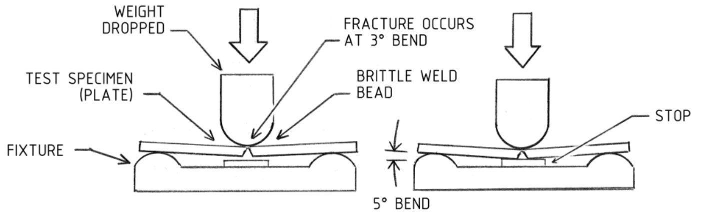
Since the properties of metals may vary according to orientation or location, it is often necessary in quality control programs to check for properties in orientations that would exhibit the lowest toughness. For example with plate products, a test specimen with a transverse orientation usually exhibits lower quality, or lower mechanical properties. With welds, specimens that have notch locations in the weld metal, HAZ, or base metal may exhibit significantly different notch toughness values.

39.

OTHER: DROP WEIGHT TEST

The drop weight test is a more reliable method than the Charpy V-notch test for measuring nil-ductility transition (NDT).

Cracking of the weld bead is initiated at 3° of bend. After that point, the weld bead continues to crack, which initiates a fracture in the plate. To ensure the strain induced in the plate is elastic, a stop is placed below the weld bead. The stop limits the amount of deflection of the plate to 5° of bend.



Drop Weight Test Procedure

PART VII
WELD DISCONTINUITIES AND FAILURES

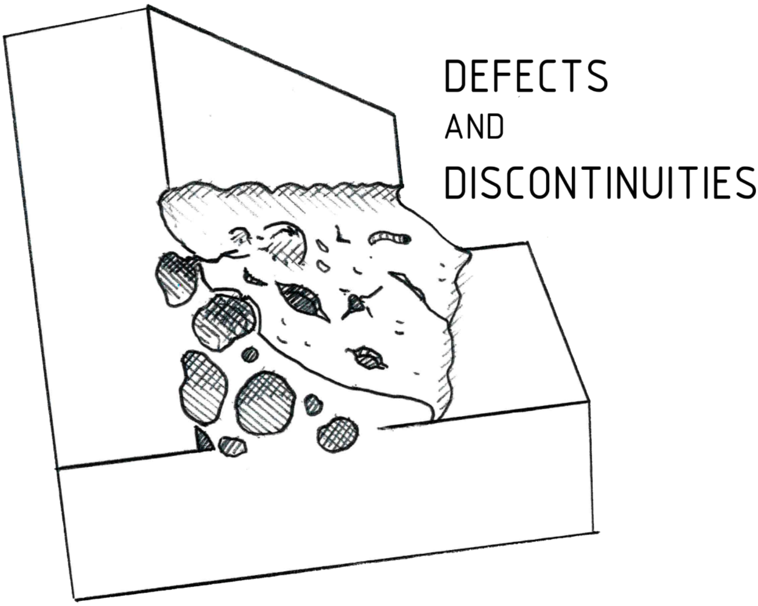
40.

WELD DISCONTINUITIES & DEFECTS

A *weld discontinuity* is an interruption in the typical structure of a weld. Weld discontinuities can occur as mechanical, metallurgical, or physical flaws in the weld metal, the heat-affected zone (HAZ), or the base metal. Their location varies depending upon the type of weld.

Weld discontinuity types include cracks, inclusions, cavities, incorrect shapes, incomplete fusion and incomplete penetration, lamination and delamination, and *miscellaneous discontinuities* (weld discontinuities that do not fit into other categories).

Cracks, inclusions, cavities, and incorrect shapes have been placed in their own sections in this book, due to the large number of sub-types each of these weld discontinuity types has.



Weld Defects

A weld discontinuity is not always considered a defect. *Weld defects* are weld discontinuities that by their shape or their accumulated effect are unable to meet the minimum acceptable requirements of the applicable fabrication standard or code.

The transition point between a discontinuity and a defect depends upon the fabrication standard or code that controls the welded joint design and quality. An unacceptable discontinuity under certain service conditions may be acceptable in a less demanding service or in another application. Refer to the requirements of the fabrication code or standard that governs the quality of the welded joint under consideration. A weld defect requires rejection of the part.

Detection

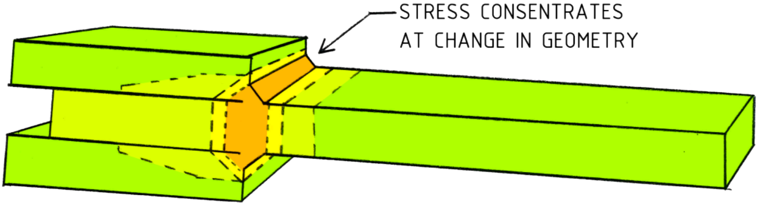
Discontinuities are detected by nondestructive examination (NDE). The most applicable (NDE) technique or techniques are selected to locate and measure the size and orientation of the discontinuity. The discontinuity size and orientation are then compared with what is allowable in the applicable fabrication standard or code to decide whether the discontinuity is a defect and whether the weld should be accepted or rejected.

41.

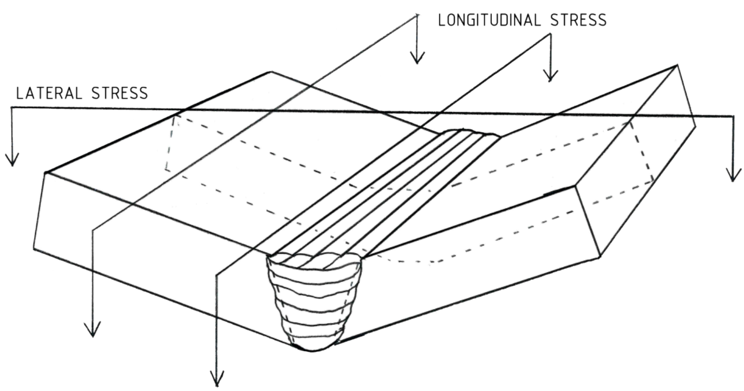
WELD STRESS

Weld stresses may be increased or concentrated in a specific area by discontinuities. Weld stresses are magnified when discontinuities reduce the cross-sectional area of the weld that is available to support the load. The average stress on a weld is in direct proportion to the reduction of the load-bearing cross-sectional area caused by the discontinuity. The lower the load-bearing cross-sectional area, the higher the stress.

If the load-bearing cross-sectional area of a weld is reduced sufficiently, structural failure may occur under load. Concentrated weld stresses occur at discontinuities that create abrupt changes of geometry, resulting in a notch effect. A *notch effect* is a stress-concentrating condition caused by an abrupt change in section thickness or in continuity of the structure. The sharper the change of geometry, the greater the stress concentration.



Tensile stresses perpendicular to the notch and shear stresses parallel to the notch are concentrated at the tip of the notch. Extremely high stress concentrations can develop at extremely sharp notches created by planar-type discontinuities such as cracks, laminations, or incomplete fusion. Such discontinuities may lead to catastrophic fracture in service. Discontinuities that concentrate stress can be extremely harmful.



Stress Directions

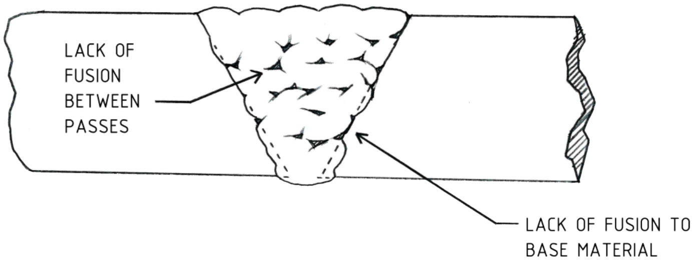
42.

INCOMPLETE FUSION AND INCOMPLETE PENETRATION

Incomplete fusion (lack of fusion) and incomplete joint penetration (lack of penetration) are similar discontinuities. They result from incomplete melting at the interface between weld passes or in the root of the joint.

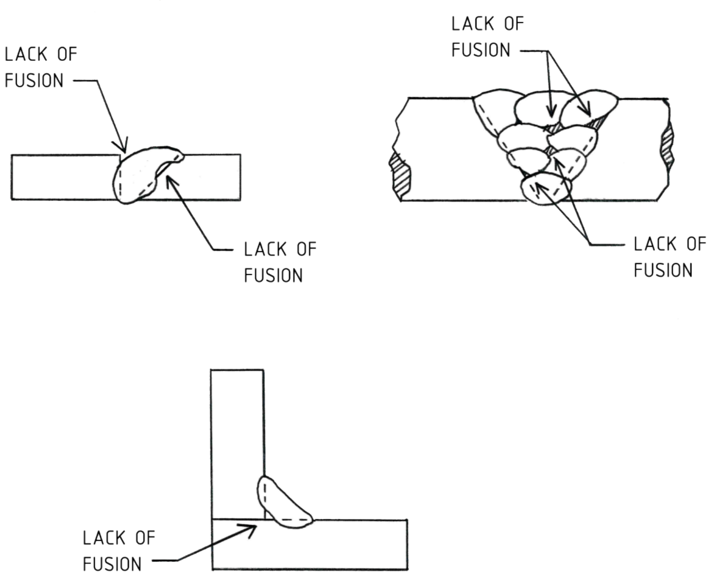
Incomplete Fusion

Incomplete fusion is a lack of union (fusion) between adjacent weld passes or base metal. It is usually elongated in the direction of welding, with either sharp or rounded edges. Incomplete fusion leads to undesirable stresses and is severely restricted in most fabrication standards and codes.



Incomplete Fusion Examples 1

Incomplete fusion may be caused by failure to raise the temperature of the surface layers of base metal or previously deposited weld metal to the melting temperature. It may also be caused by incorrect electrode manipulation by the welder.



Incomplete Fusion Examples 2

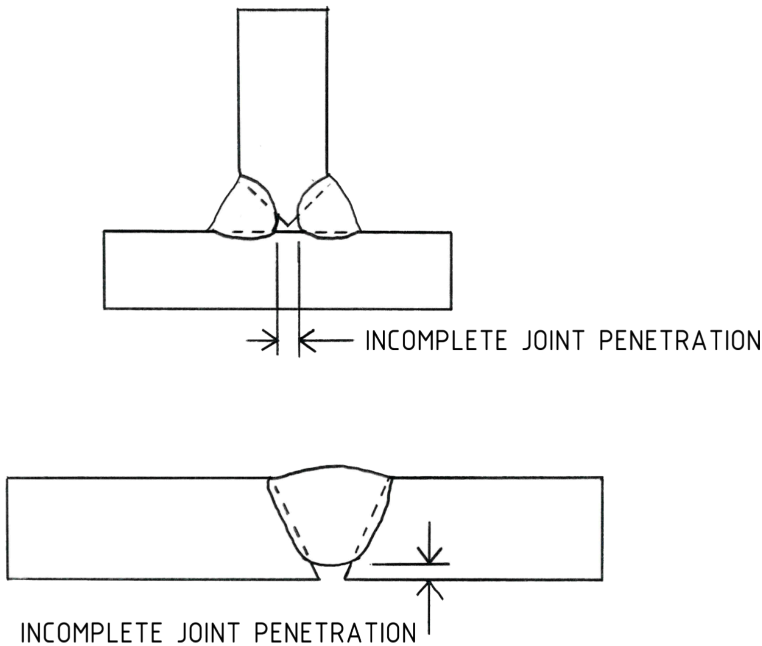
Incomplete fusion occurs more commonly with some welding processes than with others. For example, the reduced heat input in the short circuiting transfer mode of GMAW results in low penetration into the base metal. This may be desirable on thin-gauge materials and for out-of-position welding, but can also result in incomplete fusion, especially in the root area or along groove faces.

Incomplete Fusion Prevention

This may be achieved by reducing travel speed, increasing welding current, using a joint design that allows the electrode to access the joint, and using proper electrode manipulation. Incomplete fusion is also prevented by ensuring an adequate surface temperature to raise the temperature of the surface layers to the melting point, which allows the deposited metal to fuse with the surface below it.

Incomplete Penetration

Incomplete penetration is a condition in a groove weld in which weld metal does not extend through the joint thickness.



Incomplete Joint Penetration Examples

In arc welding, the arc is established between the electrode and closest part of the base metal. All other areas of the base metal receive heat principally by conduction. If the region of base metal closest to the electrode is a considerable distance from the joint root, heat conduction may be insufficient to attain adequate temperature to achieve fusion of the root.

There are a variety of other possible causes of incomplete fusion. It may occur when a groove weld is welded from one side only if the root face dimension is too great, if the root opening is too small, or if the groove angle of the V-groove is too narrow, even with an adequate root opening and a satisfactory joint design. It can also be caused by electrodes that are too large or that have a tendency to bridge; or by using abnormally high rates of travel or insufficient welding current.

Incomplete penetration is not always undesirable because some weld joints are designed to be a partial joint penetration (PJP) weld detail. The applicable fabrication standards and codes indicate permissible levels of incomplete penetration.

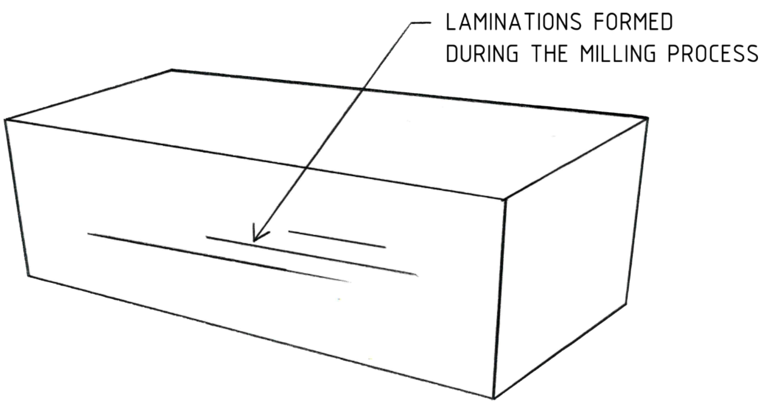
Incomplete Penetration Prevention

The most frequent cause of incomplete penetration is the use of an unsuitable joint design for the welding process or the conditions of the actual weld construction. Unsuitable joint designs make it difficult to reproduce qualification test results under conditions of actual production.

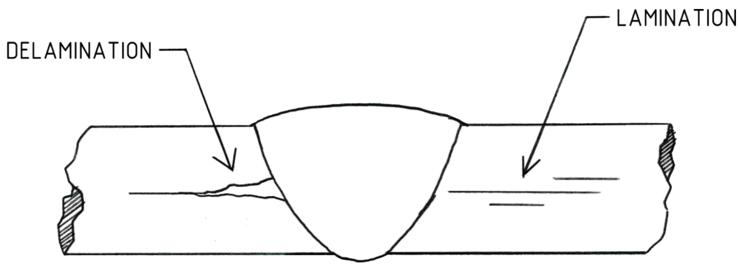
43.

LAMINATION AND DELAMINATION

A *lamination* is a discontinuity or defect that is aligned parallel to the working direction of a metal. Typically, a lamination is the result of ingot steel production. As a steel ingot cools, it may develop a cavity called a pipe. When the ingot is rolled, the pipe becomes elongated and forms a lamination in the steel.



Delamination is the separation of a lamination under stress. The stress could be caused by welding or bending. The applied stress causes the lamination to open up or separate.



The primary difference between the two is that a lamination is a base metal discontinuity that occurs during steel making, whereas delamination occurs when the base metal is worked.

44.

ARC STRIKES

Arc strikes are depressions or marks that occur on the surface of the weld by the welder accidentally striking the electrode on the base metal face away from the weld joint. This causes the area struck to melt and rapidly cool due to the massive heat sink of the surrounding base metal.

On certain materials, especially high strength steels, this can produce a localized heat affected zone that may contain martensite which increases the potential for cracking. Numerous failure of structures and pressure vessels can be traced back to the presence of a welding arc strike. Arc strikes are thus unacceptable.

Arc strike detection is achieved by visual examination (VT). Some fabrication standards and codes require arc strikes to be ground to a smooth contour and inspected to ensure soundness by an appropriate nondestructive examination method such as VT.

Arc Strike Prevention

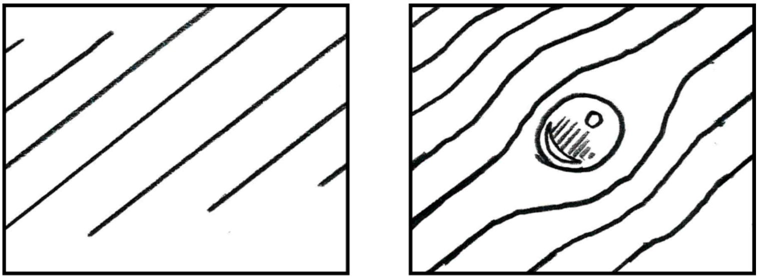
Arc strikes are prevented on certain types of work, such as pipe, by placing protective wrappings around the part to prevent accidental contact with the electrode.

45.

SPATTER

Spatter is a discontinuity consisting of metal particles expelled during fusion welding that do not form part of the weld. Only spatter which adheres to the base metal is a concern.

Typically, spatter is not considered to be a serious discontinuity unless it interferes with subsequent operations, such as nondestructive examination. However, large globules of spatter may have sufficient heat to cause a localized heat affected zone on the base metal surface and having a similar effect as an arc strike. Also, the presence of spatter on the base metal surface could provide a local stress riser, which could cause problems during service of the finished product.



CONTINUOUS CRYSTALIZED STRUCTURE

SPATTER INTERRUPTED CRYSTALIZED STRUCTURE

Spatter detection is achieved by visual examination (VT).

Spatter Prevention

Spatter can be reduced or possibly prevented by reducing the welding current and arc length. Anti-spatter spray is also available to prevent spatter for many welding applications.

For GMAW and FCAW, the addition of argon to the shielding gas mixture can drastically reduce spatter. Using spray transfer with GMAW instead of short circuiting is likewise very effective in reducing spatter.

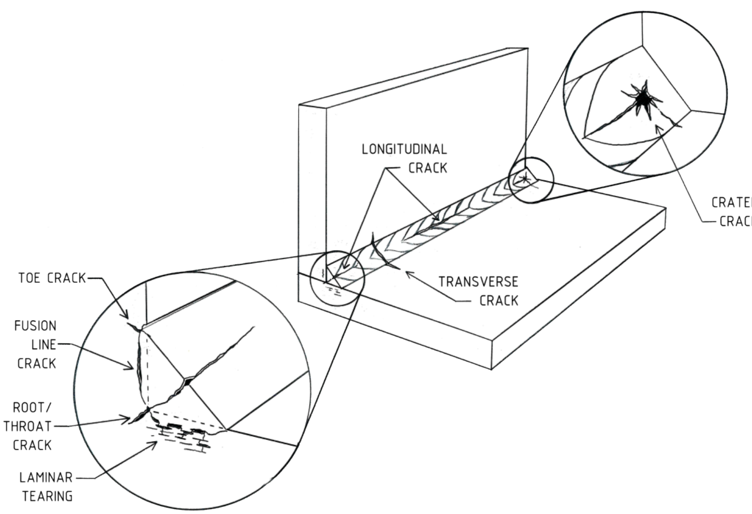
PART VIII

DISCONTINUITIES: CRACKS

46.

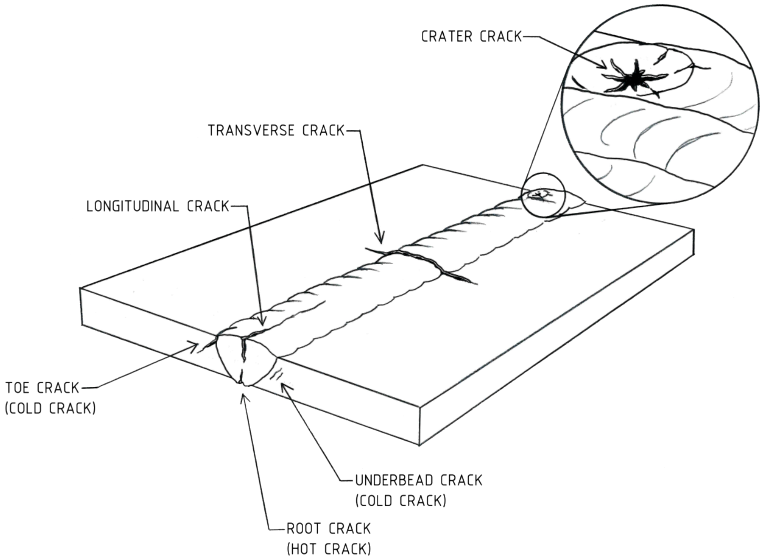
CRACKS

A *crack* is a fracture-type discontinuity characterized by a sharp tip and a high ratio of both length to width as well as width to opening displacement. Cracks are the most serious discontinuities in weldments and are not permitted per fabrication standards and codes because they create significant stress concentrations at their tips.



Cracks in a Fillet Weld

Cracks will rarely appear in a straight line. They will nearly always appear along the path of least resistance. Cracks may occur in the weld, the heat affected zone (HAZ), or the base metal when the localized stress exceeds the ultimate strength of the metal.



Cracks in a Groove Weld

When cracking is observed during welding, it must be removed before welding continues. Weld metal that is deposited over a crack can result in extension of the crack into newly deposited weld metal.

Classification of Cracks

Cracks are classified as hot cracks or cold cracks, and may be longitudinal or transverse in their orientation.

- A *hot crack* is a crack formed at temperatures above the completion of solidification. Hot cracks propagate between the grains of metal
- A *cold crack* is a crack that develops after solidification is complete. Cold cracks propagate both between and through the grains of the metal.
- A *longitudinal crack* is a crack with its major axis oriented approximately parallel to the weld axis.
- A *transverse crack* is a crack with its major axis oriented approximately perpendicular to the weld axis.

Types of Cracks

Crack types in welding include:

- Throat cracks
- Crater cracks
- Under bead cracks
- Lamellar tearing
- Toe and root cracks
- Fissures
- Liquid metal embrittlement

47.

TRANSVERSE CRACKS

Transverse cracks are cracks in a weld perpendicular to the axis of the weld and sometimes extending beyond the weld in the base metal. Transverse cracks in steel weldments are usually related to hydrogen embrittlement. Transverse cracks appear as tight, relatively straight cracks perpendicular to the weld axis.

Transverse Crack Prevention

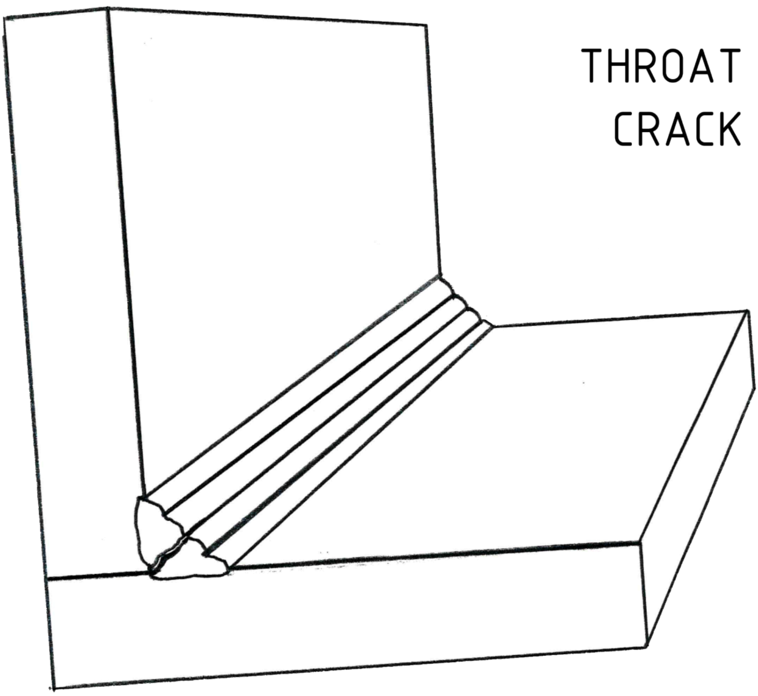
Transverse crack prevention depends on the specific welding situation. For example, transverse cracks may be caused by using incorrect filler metal composition, rapid cooling, or a weld that is too small for the part being joined.

Depending on the situation, transverse cracks may be eliminated by using the proper filler metal composition, higher welding current or preheat, or a larger filler metal and final weld dimension, respectively.

48.

THROAT CRACKS

Throat cracks are longitudinal, hot cracks in the middle of the surface (throat) of a weld, extending toward the root of the weld. They appear as relatively long cracks along the center line of the weld and are confined to the center of the weld.



Throat cracks may be the extension through successive weld passes of a crack that started in the first pass (root pass). A throat crack that starts in the root pass and is not removed or completely re-melted before deposition of the next pass tends to progress into it and then to each succeeding pass, until it appears at the surface. Final extension of the crack to the surface may also occur during cooling after welding has been completed.

Visual examination (VT) is often an adequate method of detection because throat cracks are usually open to the surface.

Throat Crack Prevention

Throat cracks are prevented by using joint designs that reduce joint restraint and excessive stresses in solidifying weld metal. The weld groove dimensions must be adjusted to allow deposition of a sufficient amount of filler metal to overcome excessive joint restraint.

The welding process variables must be adjusted to permit correct weld bead size for the joint thickness, sufficient heat input, and optimum travel speed to prevent excessive stresses during solidification.

Prevention may also be achieved using a more ductile filler metal or reducing the cooling rate through application of preheat.

49.

CRATER CRACKS

Crater cracks are star-shaped, hot cracks that extend from the center of the crater of the weld to the edge of the weld. Crater cracks are caused by failing to back-fill the crater before terminating the arc at the end of a weld.

Crater cracks are most often found in materials with high coefficients of expansion such as aluminum and austenitic stainless steels. Crater cracks may be the starting point for throat cracks, particularly when the crater formed is not filled to the full cross section of the weld.

Crater cracks are most commonly detected by visual examination (VT), as they are clearly visible to the naked eye as star-shaped fissures in the small crater formed at the termination of a weld pass.

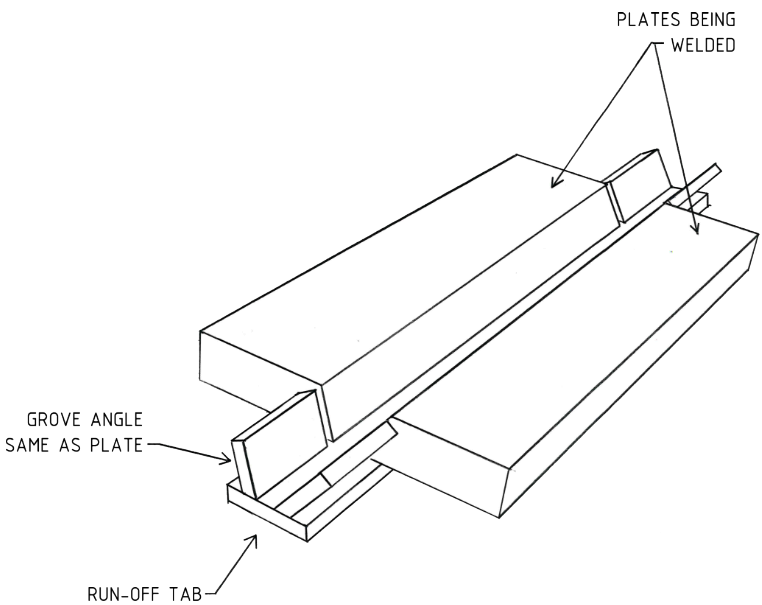
Crater Crack Prevention

Crater cracks are prevented by properly terminating the weld. Methods used to prevent cracks include:

- Back-stepping the arc into previously solidified material before breaking it

- Filling craters to a slightly convex shape prior to breaking the arc
- Using a run-off tab

A *run-off tab* is a piece of metal of the same composition and thickness as the base metal that is tacked to the metal to allow the weld to be completed. The run-off tab is later removed by cutting it off.



50.

UNDERBEAD CRACKS

Underbead cracks are cracks in the heat-affected zone (HAZ) that generally do not extend to the surface of the base metal. Underbead cracks may be longitudinal or transverse, depending on the direction of the principal stresses in the weldment. Underbead cracks are cold cracks and are usually short and discontinuous.

Under bead cracks could be hydrogen cracks that occur in steels susceptible to hydrogen embrittlement during welding. Dissolved hydrogen, which is released from the electrode or from the base metal, combines with martensite formed in the HAZ during rapid cooling, creating a narrow region that is extremely brittle and sensitive to cracking from residual stresses.

Under bead cracks are detected by ultrasonic examination (UT) or radiographic examination (RT) because the crack is usually below the surface and immediately adjacent to the weld. Because of their tightness and short length, under bead cracks may be difficult to detect.

Underbead Crack Prevention

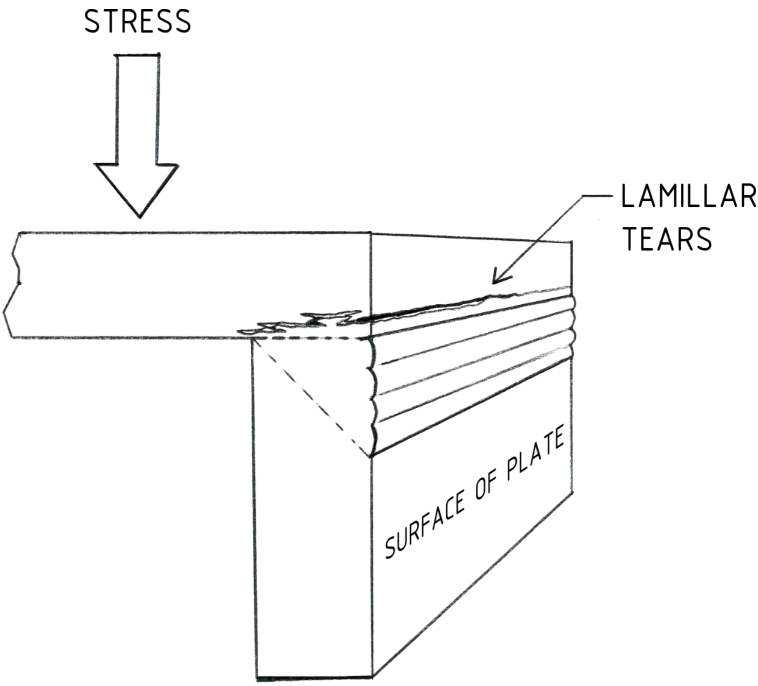
A drying procedure must be used to remove moisture that can absorb into the coatings on some types of electrodes when exposed to humid atmospheres. The procedure involves storing electrodes in a low-temperature oven, preheating the surface before welding to remove moisture, and post-heating immediately to encourage hydrogen to escape.

51.

LAMELLAR TEARING

Lamellar tearing is a subsurface cracking pattern in wrought steel base metal caused by welding. The cracking runs parallel to the working direction and has a terraced, step-like pattern.

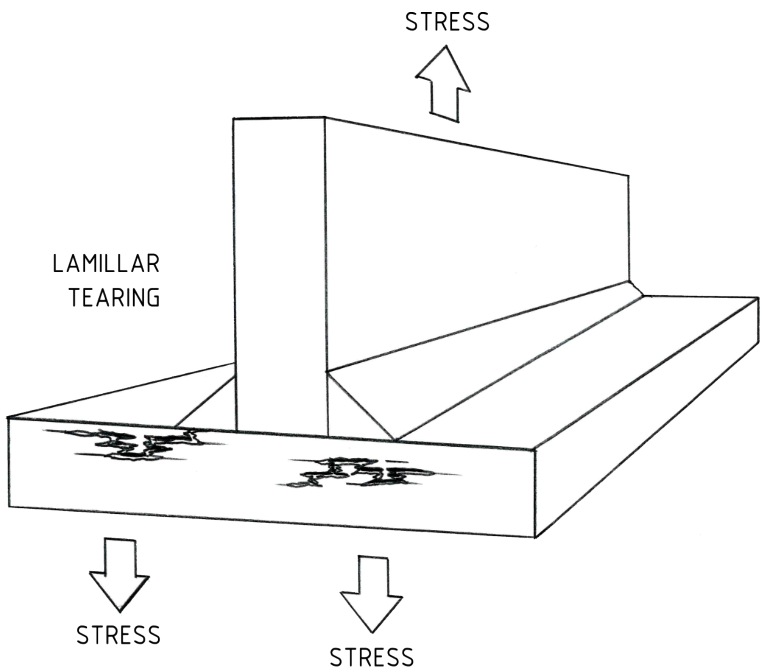
Lamellar tearing occurs when tensile stresses from welding develop through the thickness of the base metal and act upon planes of weakness running parallel to the metal surface causing them to separate. The planes of weakness are caused by nonmetallic inclusions consisting of metallic oxides, sulfides, and silicates.The inclusions are formed during solidification in the steelmaking process from additives to the melt or contamination from refractory in the mold. Hot or cold working elongates nonmetallic inclusions in the working direction if they are plastic at the working temperature. The net result of the elongated nonmetallic inclusions is to decrease through-thickness ductility. This results in lamellar tearing parallel to the direction of the inclusions.



Lamellar Tearing on Corner Joint

Lamellar tearing is most likely to occur when welding a steel plate using groove welds, fillet welds, or combinations of them.

T-joints may be especially susceptible to lamellar tearing. The two members of a T-joint are located at approximately right angles to each other in the form of a T. Under these conditions, high tensile stresses can develop perpendicular to the mid-plane of the steel plate. The magnitude of the tensile stresses depends on the size of the weld, the welding procedure, and the amount of joint restraint imposed by the welding design.



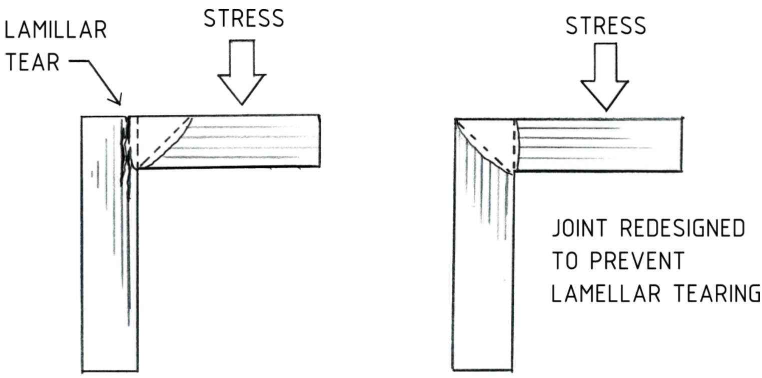
Lamellar Tearing on T-Joint

Lamellar tearing detection is difficult because it usually does not break to the surface. Radiographic examination (RT) and ultrasonic examination (UT) are the most applicable methods for detection of lamellar tearing, which has the appearance of step-like, jagged cracking, with each step nearly parallel to the mid-plane of the plate.

Lamellar Tearing Prevention

Lamellar tearing is prevented most reliably by the use of specially processed steel products that do not contain elongated nonmetallic inclusions. Such steel products are used in critical applications where lamellar tearing is detrimental.

Other methods of reducing lamellar tearing in regular steel products rely on reduction of the stress in the welded joint. These methods include changing the location and/or design of the weld joint to minimize through-thickness strains, using a lower strength weld metal, reducing hydrogen in the weld, using preheat and interpass temperatures of at least 200ºF, and peening the weld bead immediately after completion of a weld pass. However, peening should never be performed on the root pass or on the cover pass (the final pass). Peening the root may lead to issues with cracking, and peening the cover pass may mask discontinuities on the surface of the weld.



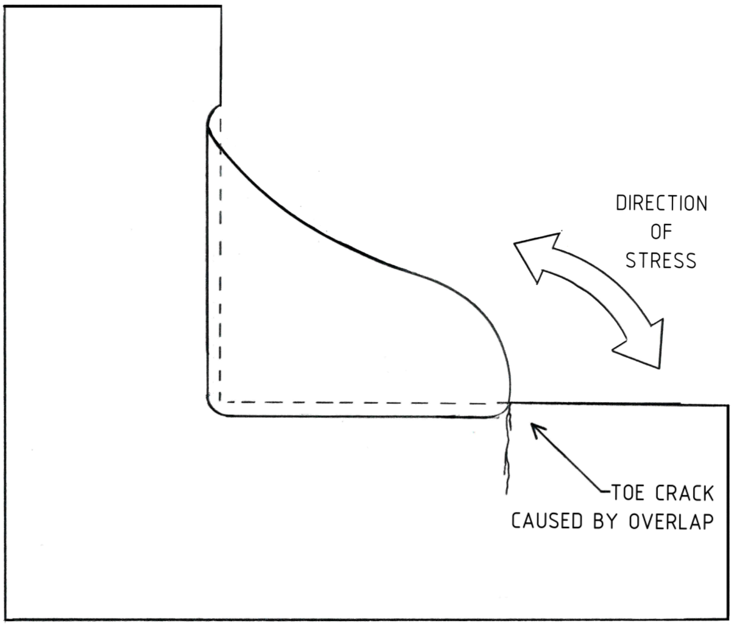
Lamellar Tearing Prevention

52.

TOE CRACKS AND ROOT CRACKS

Toe cracks and root cracks have similar causes but different appearances. They are both generally cold cracks and initiate in regions of high residual stress.

Toe cracks are cracks that proceed from the weld toe into the heat-affected zone (HAZ) and base metal. The *weld toe* is the junction of the weld face and base metal. Toe cracks are typically caused by stresses from thermal shrinkage acting on a brittle HAZ and are located along the toes of the weld.

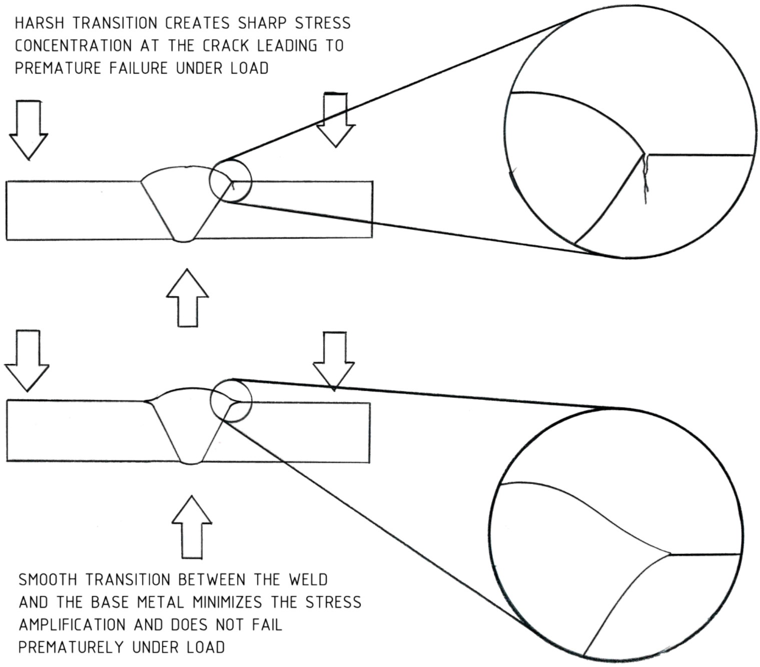


Stress Direction Causing Toe Crack

Root cracks are cracks that proceed into the base metal from the root of a weld. Root cracks are difficult to detect unless they have propagated through to the opposite side of the base metal.

Toe and Root Crack Prevention

Toe and root crack prevention requires welding procedures and techniques that eliminate embrittlement or excessive stresses in the HAZ of the base metal. With hard enable steels, toe and root crack prevention may be achieved by retarding the cooling rate of the base metal and HAZ with high preheat, or by stress relief after welding with post heating.



53.

LIQUID METAL EMBRITTLEMENT

Liquid metal embrittlement is intergranular penetration (or cracking) of the heat-affected zone (HAZ). *Intergranular penetration* is penetration of molten metal along the grain boundaries of the base metal that leads to embrittlement of the base metal. Liquid metal embrittlement can occur with specific combinations of base metals and molten metals, usually in the presence of stress. Liquid metal embrittlement appears as a relatively wide, jagged crack revealed under magnification.

Brazes are a common cause of liquid metal embrittlement in susceptible alloys. For example, many nickel alloys, when in a stressed condition, may crack from liquid metal embrittlement in contact with molten brazing metal.

Liquid metal embrittlement may also occur during welding from contamination of a base metal by other metals. For example, when welding austenitic stainless steels to galvanized steels, zinc contamination may cause liquid metal embrittlement of the austenitic stainless steel base metal. The zinc contamination may be introduced by grinding dust or direct contact between the two metals, such as when welding austenitic stainless steel to galvanized carbon steel.

Liquid Metal Embrittlement Prevention

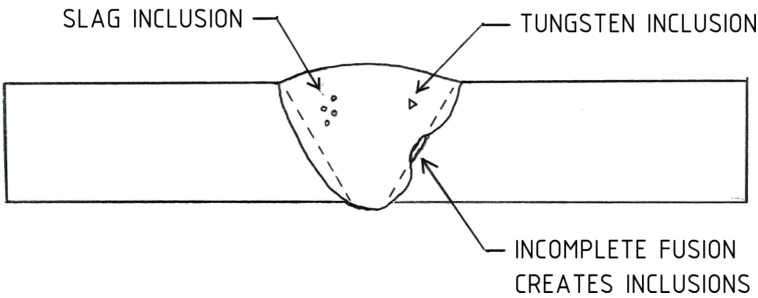
Liquid metal embrittlement is prevented by avoiding susceptible braze base metal couples or by ensuring cleanliness of the joint surfaces before welding or brazing. For example, when welding galvanized steel to austenitic stainless steel, all zinc must be removed by grit blasting a minimum of 2” from the joint face to ensure that the zinc does not melt and mix with the austenitic stainless steel, resulting in liquid metal embrittlement.

PART IX
DISCONTINUITIES: INCLUSIONS

54.

INCLUSIONS

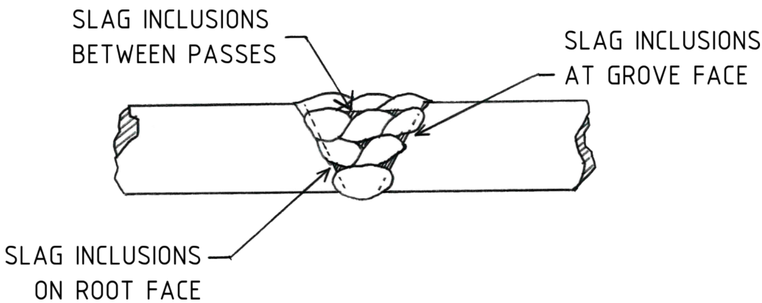
Inclusions are entrapped foreign solid material in deposited weld metal, such as slag or flux, tungsten, or oxide. Inclusion types include slag inclusions, oxide inclusions, and tungsten inclusions.



55.

SLAG INCLUSIONS

Slag is a nonmetallic product resulting from mutual dissolution (chemical reactions) of flux and nonmetallic impurities in some welding or brazing processes. *Slag inclusions* are nonmetallic materials that are formed by slag reactions and trapped in a weld.



Slag Inclusions from Incomplete Penetration

Slag inclusions can occur between passes or at the weld face. Slag inclusions can also occur in welds made by flux shielded welding processes such as SMAW, FCAW, and SAW.

Slag inclusions have a lower specific gravity (density) than the surrounding metal and usually rise to the surface of molten metal, unless they become entrapped in the weld metal.

Multiple-pass welds are more prone to slag inclusions than single-pass welds because slag from the preceding pass, if not completely removed when cleaning, will become entrapped in the subsequent pass.

Slag inclusions are detected by radiographic testing (RT) where they appear as dark lines, more or less interrupted, parallel to the edges of the weld. Slag inclusions are usually elongated and rounded, and run in the direction of the axis of the weld. Slag inclusions can be continuous, intermittent, or randomly spaced.

Slag Inclusion Prevention

Slag inclusions are prevented by using proper welding preparation, such as thoroughly removing slag from the weld and cleaning the weld between each pass of a multiple-pass weld. Failure to thoroughly remove slag between each pass increases the probability of slag entrapment and the production of a defective weld.

Complete and efficient slag removal requires that each weld bead be properly contoured and blend smoothly into the adjacent bead or base metal. Concave or flat beads that blend smoothly into the base metal or any adjoining beads minimize undercutting and avoid a sharp notch along the edge of the bead that can trap slag.

56.

OXIDE INCLUSIONS

Oxide inclusions are particles of surface oxides on the base metal or weld filler metal that have not melted and mix with the weld metal. Oxide inclusions occur when welding metals that have tenacious surface oxide films, such as stainless steels, aluminum alloys, and titanium alloys.

Oxide Inclusion Prevention

Oxide inclusion prevention is achieved by cleaning out the joint and weld area thoroughly before welding. The weld area should be thoroughly cleaned after each pass using a wire brush.

57.

TUNGSTEN INCLUSIONS

Tungsten inclusions are particles from the non consumable tungsten electrode that enter the weld. The occasional contact between the electrode and the work or the molten metal may transfer particles of the tungsten into the weld deposit. Improper grinding of the tungsten electrode, or using an electrode too small in relation to the amperage setting, may cause tungsten spitting that can also result in tungsten inclusions in the weld.

A limited number of tungsten inclusions may be acceptable according to the applicable fabrication standard or code, but it will depend on the thickness of the part being welded. Tungsten inclusions are detected by radiographic testing (RT). Tungsten inclusions appear as bright indications on the developed film. This is because tungsten is denser than the lead which is used to identify the image quality indicators (IQI) for RT film identification.

Tungsten Inclusion Prevention

Tungsten inclusions can be minimized by using a high-frequency for arc starting, using a copper striker plate, or by striking the arc on the filler metal being used. Tungsten inclusions can also be reduced by using the proper type and size of tungsten electrode, grinding electrode tapers longitudinally and using the correct amperage to prevent tungsten spitting, blunting the tip of a tapered electrode to prevent it from falling into the weld pool, and by being careful not to dip the tip of the electrode into the weld pool.

PART X

DISCONTINUITIES: CAVITIES

58.

CAVITIES

Cavities are weld discontinuities consisting of rounded holes of various types, either within the weld or at the surface of the weld.

Cavities can be caused by either gas entrapment during solidification of the weld or contraction (or "suck back") of the weld during solidification, which cannot be replaced by molten metal. Porosity and wormholes are cavity types formed by gases. Shrinkage voids are cavity type formed by contraction of the weld metal during solidification.

Please note: suck back is not a term used in welding, but it is a term used in industry. It is a "shop term", so when you talk with welders they will know what you're saying. Do not use that term with an inspector; the correct term is weld contraction.

59.

POROSITY

Porosity consists of cavity-type discontinuities formed by gas entrapment during solidification. Porosity may be surface porosity or subsurface porosity.

Surface porosity consists of discrete spherical or elongated holes on the surface of the weld. It is formed if dissolved gases cannot fully escape before the weld metal solidifies. It may be caused by insufficient shielding gas coverage. It may also be caused by excessive gas flow rates that create turbulence that expose the molten weld to oxygen in the air. It may be detrimental to fatigue strength if aligned in a direction perpendicular to the direction of stresses.

Subsurface porosity consists of discrete spherical or elongated holes within the body of the weld. Subsurface porosity distribution is classified as uniformly scattered, cluster, or linear.

- *Uniformly scattered* porosity exhibits a uniform distribution of pores throughout the weld metal, with size varying from almost microscopic to 1/8” in diameter.

- *Cluster* porosity voids occur in the form of clusters separated by considerable lengths of pore-free weld metal. Cluster porosity is associated with changes in welding conditions, such as stopping or starting of the arc.
- *Linear* porosity is characterized by an accumulation of pores in a relatively straight line. The number and size of the pores and their linear distribution with respect to the axis of the weld usually define linear porosity. Linear porosity generally occurs in the root pass.

Primary causes of porosity are dirt, rust, and moisture on the surface of the base metal or on the welding consumables. It may also be caused by insufficient shielding gas coverage.

Porosity is usually the least harmful type of weld discontinuity. Many fabrication standards and codes provide comparison charts that show the amount of porosity that may be acceptable. When porosity exceeds the amount allowable, it must be ground out and repaired. Porosity is detected by radiographic testing (RT) for subsurface porosity and by visual examination (VT) or liquid penetrant examination (PT) for surface porosity. With RT, subsurface porosity has the appearance of sharply defined dark spots of rounded contour.

Porosity Prevention

Porosity is prevented by improving welding housekeeping conditions that can cause the porosity. Good housekeeping includes the use of clean materials and well-maintained equipment and the proper alignment of fans and drafts.

Also, avoiding the use of excessive current and arc lengths can prevent porosity. High currents and excessive arc lengths may cause high consumption of the deoxidizing elements in the covering of shielded metal arc electrodes, leaving insufficient quantities available to combine with the gases in the molten metal during cooling.

Specific methods of preventing porosity depend on the type of welding process. For example, changing welding conditions such as gas flow rate and gas purity for gas shielded processes compensates for improper arc length, welding current, or electrode manipulation. Reducing travel speed may also decrease porosity.

60.

WORMHOLES

Wormholes are elongated or tubular cavities caused by excessive entrapped gas. Wormholes have the appearance of sharply defined dark shadows of rounded or elongated contour, depending on the orientation of the wormholes.

Wormhole porosity is considered the most severe type of porosity because it provides a leak path through the weld. This is especially serious when the vessel or pipe is intended to contain liquid.

Wormholes Prevention

Wormholes are prevented by methods that are similar to those that prevent porosity.

61.

SHRINKAGE VOIDS

Shrinkage voids are cavity-type discontinuities normally formed by shrinkage during solidification and are usually in the form of long cavities parallel to the root of the weld.

Shrinkage Voids Prevention

Shrinkage voids are prevented by providing sufficient heat input to maintain molten filler metal to all areas of a weld during solidification.

PART XI
DISCONTINUITIES: INCORRECT SHAPE

62.

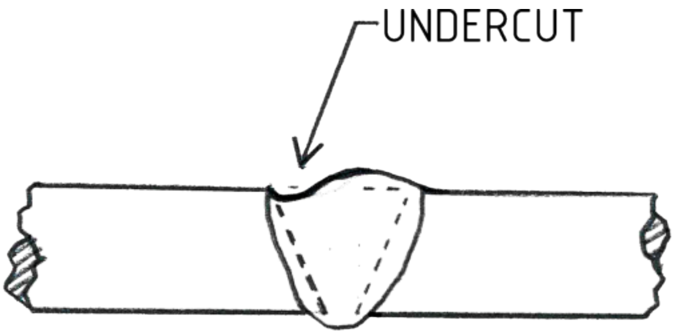
INCORRECT SHAPE

An incorrect shape in a weld includes any weld discontinuity that produces an unacceptable weld profile or dimensional nonconformance and that adversely influences performance of the weld under load. An insufficient cross-sectional area of a weld may result in a weld that is unable to support a load, or may allow a stress-concentrating notch, leading to fracture. Incorrect shape discontinuities are undercut, overlap, excessive weld reinforcement, underfill, and concave root surface.

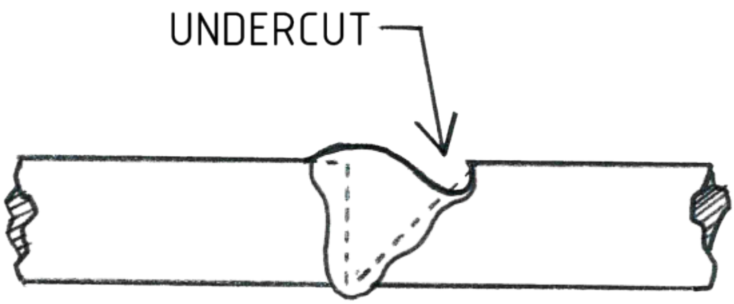
63.

UNDERCUT

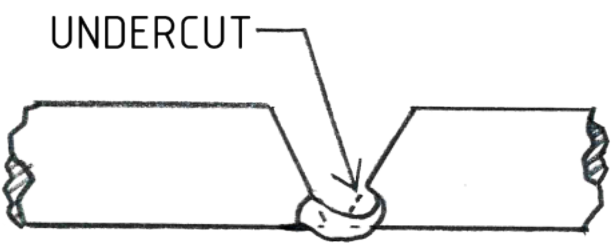
Undercut is a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal. Faulty electrode manipulation, excessive welding current, excessive arc length, and slow travel speed cause undercut.



DOUBLE BEVEL



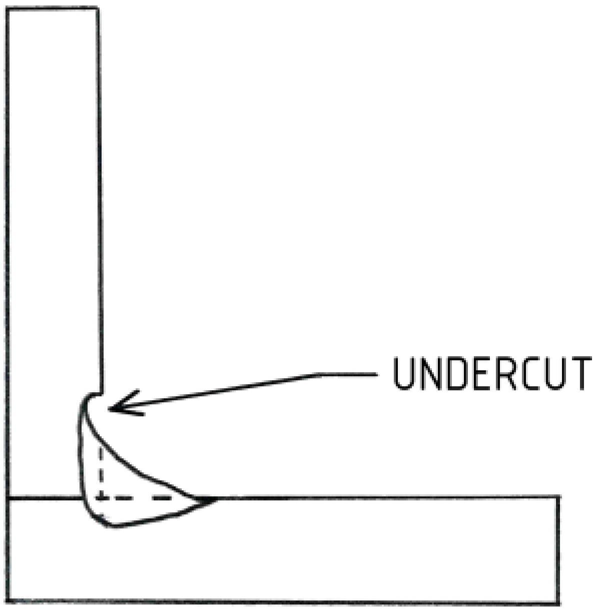
SINGLE BEVEL



ROOT PASS

Undercut Examples

Undercut of a completed weld is undesirable because it produces a stress concentration that reduces impact strength and fatigue resistance. Undercut is detected by visual examination (VT) in groove or fillet welds. VT is the simplest and most effective way of detecting and measuring undercut against the particular fabrication standards or codes.



Undercut in a Fillet Weld

Radiographic examination (RT) may also detect undercut in groove welds, where it appears as a dark line, sometimes broad and diffuse, along the edge of the weld.

Undercut Prevention

Undercut is prevented by the following methods: pausing at each side of the weld bead when using the weave bead technique; using proper electrode angles, using proper welding current for electrode size and welding position; reducing arc length; and increasing travel speed.

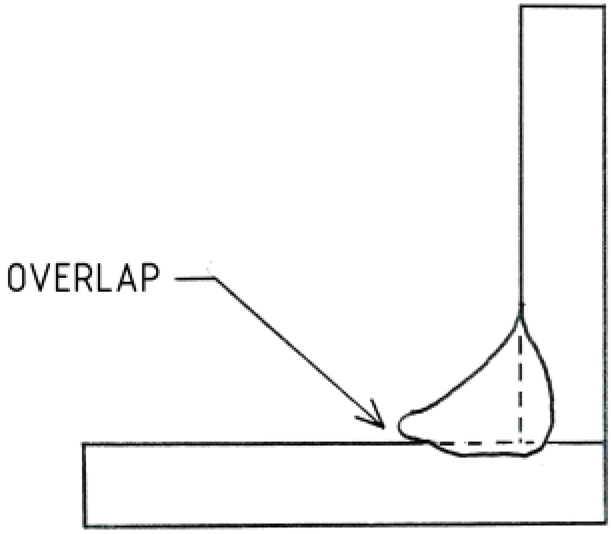
Undercut of the sidewalls will in no way affect the completed weld if it is repaired before the next bead is deposited in that location.

To repair an undercut, lightly grind its length to clean out any foreign material. Then apply a smaller weld deposit to fill in the undercut prior to starting the next weld. If the undercut is slight, however, it is possible for the welder to estimate how deeply the weld will penetrate and fill the undercut with the next pass. Undercut is sometimes repaired by grinding and blending or welding. Grinding should be performed with a pencil-type grinder.

64.

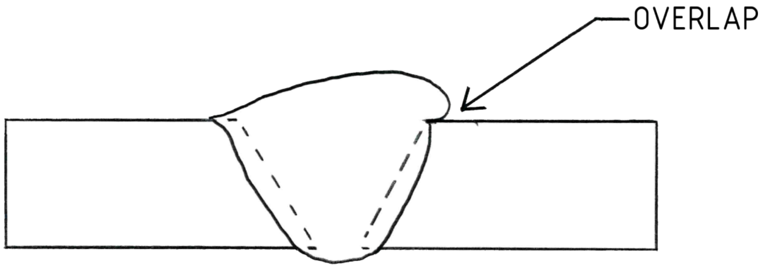
OVERLAP

Overlap is the protrusion of weld metal built up beyond the weld toe or weld root.



Overlapped Fillet Weld

Overlap is an area of incomplete fusion that creates a stress concentration and can initiate premature failure under load. Overlap is caused when current is set too low. It is detected by visual examination (VT). Overlap is considered a defect that must be removed by grinding according to the applicable fabrication standard or code.



Overlapped Groove Weld

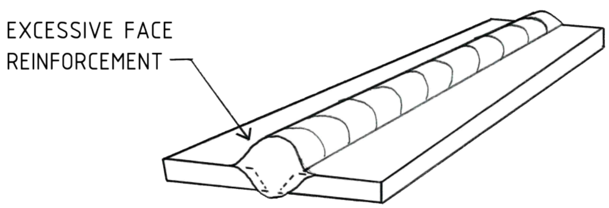
Overlap Prevention

Overlap is prevented by using a higher travel speed or welding current, reducing the electrode diameter, or changing the electrode angle so that the force of the arc will not push molten weld metal over unfused sections of base metal

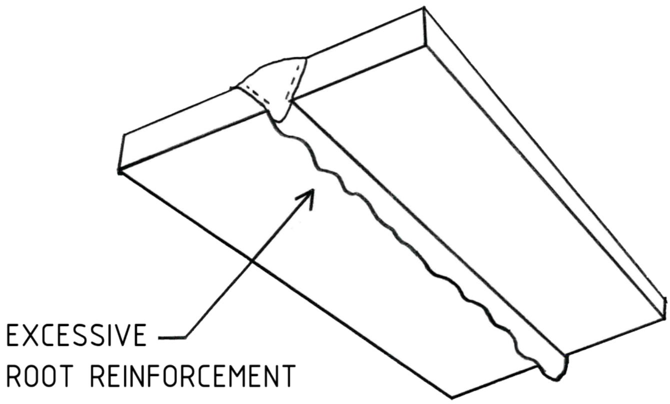
65.

EXCESSIVE WELD REINFORCEMENT

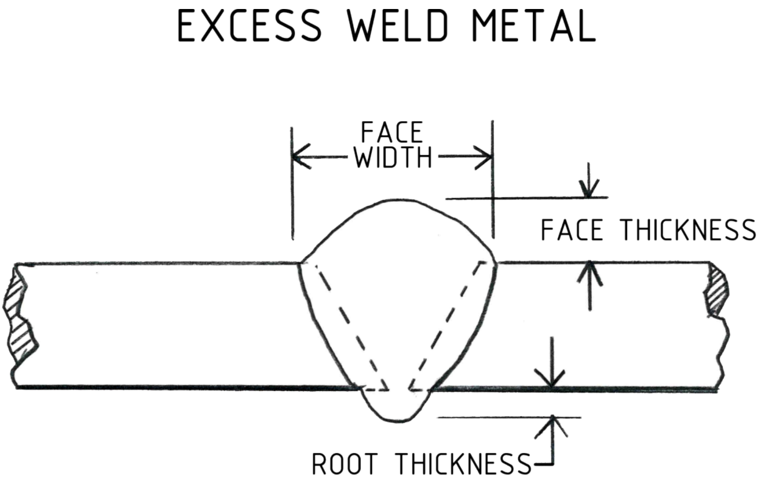
Excessive weld reinforcement is a weld metal built up in excess of the quantity required to fill a groove weld joint. Excessive weld reinforcement can be of two types – excessive face reinforcement or excessive root reinforcement.



Filler metal added to make a groove weld must be as thick as the base metal. A slight amount of reinforcement is usually permitted to avoid the cost associated with grinding the weld metal flush with the base metal. Excessive weld reinforcement, though not as severe as overlap, is undesirable because it thickens and stiffens the section and establishes a stress concentration along the toes of the weld.



Fabrication standards and codes usually limit the allowable amount of excess weld reinforcement. Various welding codes impose a maximum amount of reinforcement for the thickness of the material being welded. Thickness may vary from 1/16" to 1/8". Excessive weld reinforcement is detected by visual examination (VT) and measurement. If considered a defect, it must be removed, typically by grinding.



Excessive Reinforcement Dimensions

Excessive Weld Reinforcement Prevention

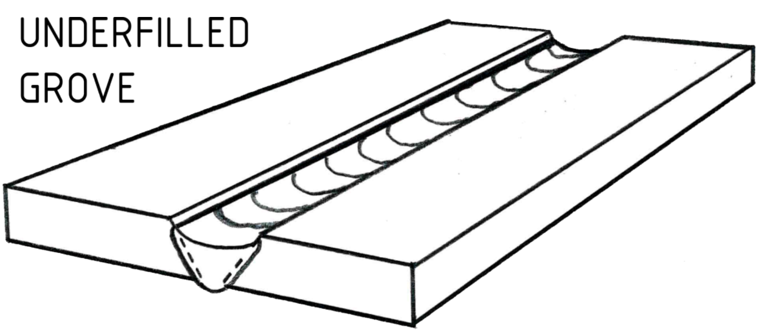
Excessive weld reinforcement is prevented by use of the correct welding current, proper welding technique, and appropriate number of weld passes to fill the joint.

66.

UNDERFILL

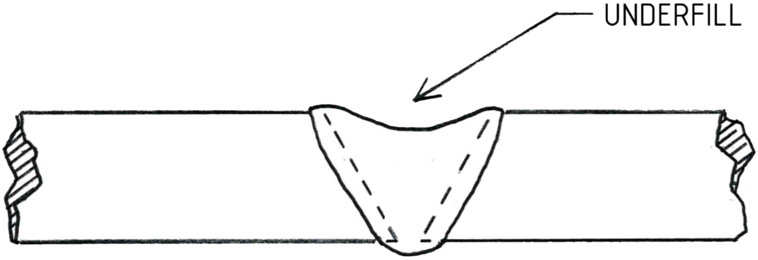
Underfill is a discontinuity in which the weld face or root surface extends below the adjacent surface of the base metal. Underfill occurs when a groove weld is not filled completely.

Underfill reduces the cross-sectional area of the weld below the amount required in the design.



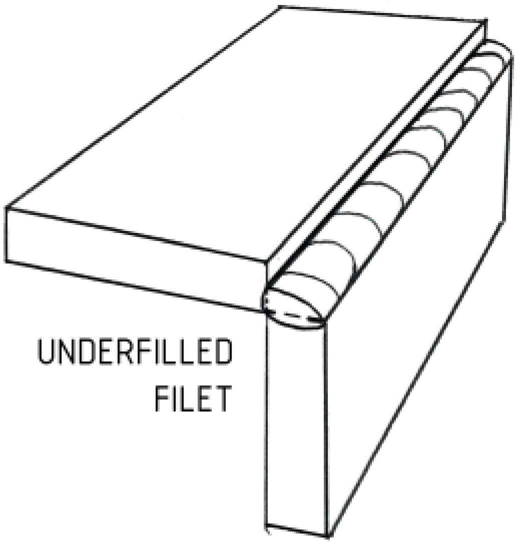
Underfilled Groove Weld

Underfill tends to occur primarily in the flat position in groove welding and in the 5G and 6G pipe welding positions.



Underfilled Fillet Weld

Underfill creates a region susceptible to structural failure from insufficient cross section to support the load. In fillet welds, underfill is exhibited by a less than normal throat as measured by the length of the leg. This is referred to as concavity. Underfill and concavity are detected by visual examination (VT).



Underfilled Outside Corner Joint

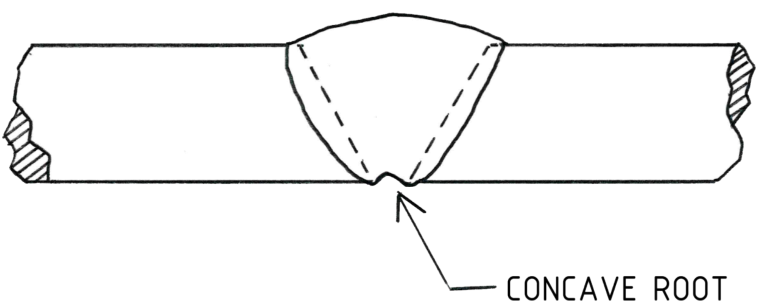
Underfill Prevention

Underfill is prevented by reducing welding current and voltage, reducing arc length and arc travel speed, and adding sufficient filler metal.

67.

CONCAVE ROOT SURFACE

A *concave root surface* is a depression in the weld extending below the surface of the adjacent base metal caused by an underfill in the root pass of a weld. If considered a defect, the surface may be suitably prepared or cleaned and additional weld metal added.



Concave Root Surface Prevention

Concave root surfaces are prevented in butt welds by reducing the root opening of the weld.

WELDING CODES FOR PIPE AND TUBE

AWS, ASME, and API are the main organizations who have codes specific to pipe welding in the US.

- AWS: American Welding Society (Most codes touch on either pipe or tube)
- ASME: American Society of Mechanical Engineers
- API: American Petroleum Institute (Specific to oil and gas industry standards)

AWS Codes

- **A2.4** Staard symbols for welding, brazing, and non-destructive examination
- **A3.0** Standard welding terms and definitions
- **A5.1** Specification for carbon steel electrodes for shielded metal arc welding
- **A5.18** Specification for carbon steel electrodes and rods for gas shielded arc welding
- **B1.10** Guide for the nondestructive examination of welds

- **B2.1** Specification for Welding Procedure and Performance Qualification
- **D1.1** Structural welding (steel)
- **D1.2** Structural welding (aluminum)
- **D1.3** Structural welding (sheet steel)
- **D1.4** Structural welding (reinforcing steel)
- **D1.5** Bridge welding
- **D1.6** Structural welding (stainless steel)
- **D1.7** Structural welding (strengthening and repair)
- **D1.8** Structural welding seismic supplement
- **D1.9** Structural welding (titanium)
- **D3.6R** Underwater welding (Offshore & inland pipelines)
- **D8.1** Automotive spot welding
- **D8.6** Automotive spot welding electrodes supplement
- **D8.7** Automotive spot welding recommendations supplement
- **D8.8** Automotive arc welding (steel)
- **D8.14** Automotive arc welding (aluminum)
- **D9.1** Sheet metal welding
- **D10.10** Heating practices for pipe and tube
- **D10.11** Root pass welding for pipe
- **D10.12** Pipe welding (mild steel)
- **D10.13** Tube brazing (copper)
- **D10.18** Pipe welding (stainless steel)
- **D11.2** Welding (cast iron)
- **D14.1** Industrial mill crane welding

- **D14.3** Earthmoving & agricultural equipment welding
- **D14.4** Machinery joint welding
- **D14.5** Press welding
- **D14.6** Rotating Elements of Equipment
- **D14.9** Specification for the Welding of Hydraulic Cylinders
- **D15.1** Railroad welding
- **D15.2** Railroad welding practice supplement
- **D16.1** Robotic arc welding safety
- **D16.2** Robotic arc welding system installation
- **D16.3** Robotic arc welding risk assessment
- **D16.4** Robotic arc welder operator qualification
- **D17.1** Aerospace fusion welding
- **D17.2** Aerospace resistance welding
- **D17.3** Aerospace friction stir welding (aluminum)
- **D18.1** Hygienic tube welding (stainless steel)
- **D18.2** Stainless steel tube discoloration guide
- **D18.3** Hygienic equipment welding

ASME Codes

- **B16.25** Butt-welding ends
- **B31.1** Power Piping
- **B31.3** Process Piping
- **B31.9** Building Services Piping
- **BPVC Section I** Rules for Construction of Power Boilers

- **BPVC Section II Part C**: Specifications for Welding Rods, Electrodes and Filler Metals.[a]
- **BPVC Section III** Rules for Constructions of Nuclear Facility Components | Subsection NCA | General Requirements for Division 1 and Division 2
- **BPVC Section IV** Rules for Construction of Heating Boilers
- **BPVC Section V** Nondestructive Examination
- **BPVC Section VIII** Rules for Construction of Pressure Vessels Division 1 and Division 2
- **BPVC Section IX** Welding and Brazing Qualifications

BPVC stands for Boiler and Pressure Vessel Code.

API Codes

- **RP 577** Welding Inspection and Metallurgy
- **RP 582** Welding Guidelines for the Chemical, Oil, and Gas Industries
- **1104** Welding of pipelines and related facilities
- **1169** Basic Inspection Requirements for New Pipeline Construction

RP stands for Recommended Practice.