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# Welding Basics for the Process Engineer

*Instructor: John C. Huang, Ph.D, PE*

**2020**

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

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# Welding Basics for the Process Engineer

*W.N. Weaver, PE and John C. Huang, PhD, PE*

## 1. INTRODUCTION

Most process engineers do not have direct contact with individuals doing welding, however, most engineers do deal with equipment, pipes or structures created by welding. Therefore a basic understanding of the art / science of welding is essential for many engineers to accomplish their jobs.

Welding originated with the blacksmith and has spread to most industries:

Structures
Automobiles
Aircraft
Ships
Pipelines
Electronics
Appliances
Toys

Welding is essentially the joining together of two pieces of metal by melting while they are in or almost in contact. Although certain polymeric materials can be welded we will concentrate on metal based alloys. The metal edges are fused together once the proper temperature is reached. Sometimes additional metal is added to complete and fill the joint. This fusion process can be accomplished in numerous ways. The following are samples of some of the welding techniques

1. Bringing the edges to high heat in a forge and fusing with a hammer blow is the technique the blacksmith uses
2. Melting the edges with a combustion flame, this is accomplished using oxygen and a fuel gas such as acetylene
3. Melting the edges with an electric arc, this is probably the most common technique and exists in a variety of forms
4. Friction caused by rotating one part against another causing melting, this is generally used for the production of objects (chain links, appliances, etc.) rather than the fabrication of industrial facilities

A look around most industrial plants, any appliance store, under an automobile, at a bridge over a river, at the skeleton of a skyscraper or at the internals of most machines will give you an idea of the range of welding. We cannot hope to develop a working knowledge of all of the welding procedures in use, however we can obtain a basic understanding of a few and extrapolate that knowledge to cover most of the rest.

The following material will concentrate on Technique 3 above. Before we study that we should have some idea why we want to use welding.

## 2. WHY WELDING?

Welding is one of many joining techniques used in industry. Some of the others are:

| | |
|---|---|
| Brazing | Folded joints (as in sheet metal) |
| Soldering | Interlocking tabs |
| Through bolting | Permanent clamps |
| Through riveting | Adhesives |
| Threaded openings | |

Each of the above has several options from which to select; and each option has specific characteristics relating to strength, life span of the connection, cost and ease of application.

Likewise welding offers multiple options as to technique, operational complexity, cost, strength, life span, resistance to loads, and ease of application. In most cases a welded joint has fused together two pieces of metal so that they become one piece of metal at that spot in the structure. Welding is the choice in many cases because of one or more of the following characteristics:

Ease of use
Portability of equipment for use in remote areas
Strength or rigidity of joint
Low cost of application
Speed of creating the joint
Ease of learning the technique
Simplicity of the equipment needed
Options for the appearance of finished joint
Potential to completely hide the joint
Resistance to corrosive attack
Long life span of joint
Ability to form joints under water
Ability to accomplish a strong joint even if the pieces do not have a close fit
Ability to produce a pressure tight joint

## 3. TYPES OF WELDING

There are about fifty (50) types of welding listed in most welding text books. Some have very limited application as an example electron beam welding. Although this is a true welding process it is not likely to be efficient when what you need to accomplish is the installation of 4 inch schedule 80 pipe lines or the building of a bridge.

For this material we will concentrate on welding techniques used in creating an industrial facility. The joints we need to make are in structural members, rolled or flat plates for equipment, pipe and machined parts. We are not looking at processes used to manufacture products, such as Electric Resistance Welding, ERW, used to make pipe or spot welding for automobiles and appliances, but at the processes used to build the facility to make the pipe, automobile or the paint used on other items.

The construction of a manufacturing facility may utilize several welding processes at the construction site; the most common being the following:

| | |
|---|---|
| OFW | Oxygen Fuel Welding (Fuel can be acetylene, propane, natural gas, hydrogen, etc.) |
| TIG | Tungsten Inert Gas (Essentially a manual process, gas can be helium, argon or several different mixtures, the tungsten carries the electric arc current providing heat for metal fusion but does not become part of the weld itself) |
| MIG | Machine Inert Gas (A wire is machine fed to the weld in a semiautomatic process using an inert gas to protect the weld zone, the wire becomes part of the welded joint) |
| Flux shielded | Typical "stick" welding (manual, using a metal rod coated with a shielding gas generating coating) referred to as Shielded Metal Arc Welding. The sick (electrode) becomes part of the weld. |
| Flux core | Similar to MIG (no gas but instead a hollow wire with shielding gas generating chemicals inside, the wire becomes part of the welded joint.) |

The last four above all use electrical power to provide fusion heat. All of the above provide a protective gas cloud around the weld to protect the melted metal from contamination.

At some point in most engineering careers the engineer will have to specify a weld, inspect a weld or determine if a specified weld is appropriate for the task at hand. Spending time understanding the various welding processes and looking at welded structures in your facility will pay dividends in your ability to work with this common industrial technique. It's easier to understand welding if we clarify certain aspects one at a time.

## 4. TYPES OF JOINTS

There are five basic weld joint types. The word "joint" refers to the configuration (the relationship of positions between pieces) of the two pieces of metal to be welded. See Figures 1 through 5.

| | | | |
|---|---|---|---|
| The joints are: | FIGURE 1 | Butt Weld | example: pipe welds, end joints in structural beams and columns |
| | FIGURE 2 | Lap Weld | example: pipe welding using socket |

| | | |
|---|---|---|
| | | weld fittings, structural splice plates |
| FIGURE 3 | Tee Weld | example: pipe anchors, structural shape stiffening, creating a "tee" structural member from flat plate sections |
| FIGURE 4 | Outside Corner Weld | example: certain types of pipe connections to vessels, box beams for structures |
| FIGURE 5 | Edge Weld | example: decking plates on top of structural shapes |

SPECIFICATION ITEM. This selection of joint type is a point in the engineer's welding specification decision making process.

With these five configurations any assembly can be put together. Other weld configurations may be combinations of the above or just difficult to recognize. For example a plug weld is truly a lap joint weld, See Figure 6. Along the length of a weld the configuration may change for example from a corner weld to an edge weld depending on the metal configuration and the structure being created.

## 5. DEFINITIONS

We've already used a few unusual words so before we get in deep let's have some definitions.

| | |
|---|---|
| Welding | A process whereby one piece of metal is joined to another by melting or fusing the two pieces together, a joining where the grains of the two pieces of metal are commingled. |
| Heat Affected Zone | A width of metal on either side of the weld where the welding heat has discolored the base metals and may have altered the grain structure. |
| Base Metal | The original pieces of metal prior to the welding process (example: ends of two pieces of pipe prior to welding) |
| Shielding Gas | A "cloud" of gas around the weld which prevents atmospheric oxygen or nitrogen from contaminating the weld and causing chemical reactions within the base metal resulting in a weak, brittle or corrosion prone weld. This protective cloud can be created from a coating on or in the welding rod which under the effects of welding heat is vaporized into a cloud, by injecting an inerting gas (helium, argon, etc.) into the weld area from a gas bottle or from the combustion gases ($CO_2$) created in oxygen fuel gas welding. |
| Fusion | Melting of two pieces of metal positioned so that the liquefied metals flow together because of gravity or other operator applied forces. |
| Filler Metal | A third piece of metal being added to the joint by hand in oxygen |

| | |
|---|---|
| | fuel and TIG welding, from a machine (wire feed) in MIG and flux core welding and a rod of coated metal in coated electrode welding (Shielded Metal Arc Welding). |
| Flux | This word has a variety of meanings but here is used to mean the coating on a metal welding rod or inside a hollow wire, the coating generates the shielding gas cloud but also produces a layer of slag which cleans the metal and continues to offer protection from atmospheric damage until the weld has cooled sufficiently. In some cases the flux helps make the welding arc stable. |
| Slag | A layer of fused material covering a just completed weld caused by the coating on the welding rod; in some processes sand is used as the "flux" and the coating is then glasslike from the melted sand. This fused material will usually fall off on its own but should always be removed before painting or use, some of these slags become corrosive when wet. |
| Joint | The configuration or placement of items to be welded; a welded seam. |
| Electrode | In shielded metal arc welding a metal rod (electrode) coated with flux, for most facility welding they range in size from 1/32" to 3/8" in diameter and generally 9" to 12" long. They are available in a variety of metal alloys, different tensile strengths and different flux coatings for a wide range of applications. |
| Pre Heat | The process of heating up the area of the metal to be welded prior to performing the weld to reduce chances of cracking and warping. The need to do this is shape and alloy dependent. |
| Post Heat | The process of heating up the area of the metal which has been welded to reduce chances of cracking and warping, frequently accompanied with an insulating blanket covering. The need to do this is shape and alloy dependent. |
| Slag | A glass like covering over a finished weld, also an inclusion in a weld. |
| Inclusion | Foreign (not weld or base metal) material trapped inside a weld when it solidifies. This causes a weak spot in the weld metal. |
| Void | Air or gas material trapped inside a weld when it solidifies. This causes a weak spot in the weld metal. |

For now we can proceed with this base, we'll define new words as they occur.

## 6. TYPES OF WELDS I

For the butt weld there are two weld types which are primarily related to how deeply the weld penetrates into the base metal of both pieces.

A Full Penetration weld, see FIGURE 7, means that if you cut across the weld then you will see that the fusion process has proceeded in such a way that the metal pieces are melted and fused from one side to the other.

This type of weld may require multiple "passes" to accomplish depending on the metal thickness. See FIGURE 8, MULTIPLE PASS WELD.

Passes When a single weld line is made between two pieces of metal it is called a single pass weld, additional welds may be made on top of the first pass resulting in a multiple pass weld. These additional passes are used to accomplish a full penetration weld in thick material.

Obviously the other type of weld is then less than full penetration welds. See FIGURES 9 & 10, PARTIAL PENETRATION WELDS.

Why would anything less than a full penetration weld ever be acceptable? This is an engineering decision that depends on what the weld is to accomplish. This is another point in the engineer's welding specification decision making process.

See FIGURE 11. PIPE WELD and FIGURE 12. BEVELED PIPE WELD

With this weld it is obvious that no internal weld can be easily made, a full penetration weld then must all be accomplished for outside the pipe. The technique required is to bevel the ends of each pipe section so as to produce a smaller metal thickness, which can be welded from one side as a full penetration weld and finished by making a second and perhaps third pass. Generally the thickness through which a full penetration weld can be made with most welding equipment is limited to about 0.250".

RULE #1. Increasing the amperage on an electric welding machine allows for a heavier weld pass to be made. For most fabrication it is generally not a good idea to attempt to make a single pass full penetration weld in very thick material. Beveling and some other techniques are a superior approach for this task.

SPECIFICATION ITEM: As an engineer specifying, inspecting or reviewing weld procedures you need to decide if a full penetration weld is critical to the thing being built.

Consider the first partial penetration pipe weld. As an example assume in your company's pipe code this pipe is limited to not more than 25 pounds per square inch gage (psig) pressure even though the base pipe is required to be schedule 40 carbon steel. Based on metal thickness and alloy the base pipe material probably has a safe operating pressure limit of 300 psig and the partial penetration weld will possibly provide a safe operating pressure of one-half the base pipe rating.

Some questions to assist in deciding on weld penetration needs.

- Do you need to spend the extra money to have full penetration welds made?

- Is the small interior gap between pipe ends a corrosion concern?
- Are there significant external loads on the pipe that create concern about pipe flex causing failure at this thin spot?
- Under the code for the material inside the pipe or the pipe code are you allowed to have less than full penetration welds?

Below are several examples under which you might not want to spend the money for the full penetration weld:

The pipe is a gravity drain for clean water and is uniformly supported
The pipe is to be used to bring fresh air into a compressor room under slight negative pressure generated by the compressor suction
The pipe is used to carry rainwater from a central roof drain to the building exterior drains
The pipe will be used as a sleeve through a wall or in a concrete floor

Each weld needs to be reviewed for:

Intent of weld
Strength required
Codes the welds must meet

## 7. TYPES OF WELDS II

In addition to the type of joint there is another critical weld classification and that is "weld position." The basic positions are:

| | |
|---|---|
| Flat | The weld joint to be made is lying flat as if on a table |
| Horizontal | The weld joint lies parallel to the Earth's horizon |
| Vertical | The weld joint runs vertically up and down relative to the Earth's surface |
| Overhead | The weld joint is flat and above the welder's head |

A certified welder in most certification systems is certified in all or some of the above positions. In his design the engineer needs to understand how the weld is to be made, joint type and position, and what limitations those items place on his design. Generally a flat weld is easier to perform and more likely to be cost effective and successful than an overhead weld. Vertical welds sometimes must be made welding up from the bottom and sometimes welding down from the top, both affect weld quality and cost.

SPECIFICATION ITEM: Designs which requires a decision on weld position may become a selection point in the engineer's welding specification decision making process.

## 8. TYPES OF WELDS III

Welds made using electric current are of three basic types:

| | |
|---|---|
| AC | Alternating current to the electrode |
| DC Negative | Negative side of Direct Current welding voltage connected to metal being welded (Negative Polarity) |
| DC Positive | Positive side of Direct Current welding voltage connected to metal being welded (Positive Polarity or Straight Polarity) |

Most industrial welding is performed using DC voltage either positive or negative polarity. Restrictions apply to welding with AC current that make it less usable for structures and pressure containing equipment.

This welding selection is generally fixed by certain codes, ASME, API and AWS being three of them.

SPECIFICATION ITEM: This selection of the applicable welding code to be used is generally made based on what is being welded:

| | |
|---|---|
| ASME | For pressure vessels |
| ASME BPE | For pharmaceutical pipe and equipment |
| ASME | For process and utility piping |
| API | Storage tanks |
| AWS | Structures |
| Plant Pipe Codes | Pipes and fittings |

There is frequently code overlap and the engineer needs to understand how this impacts his selection.

## 9. TYPES OF WELDS IV

In addition to the above weld characteristics we have several final shapes and types of welds:

Fillet welds may be concave or convex (See Figure 2, Lap Joint)
Some welds have a "weaving" pattern while others are merely straight lines.
Some welds use a "back step" motion to ensure full penetration

There are:

| | |
|---|---|
| Spot Welds | Generally used for small equipment, automobiles and appliance manufacturing. |
| Tack Welds | Used to hold metal pieces in position for final welding. |
| Skip Welds / Stitch Welds | Short welds used to connect light weight metal section which are under minimal loading. |
| Plug Welds | Welds through a hole in one plate atop of another plate. |
| Hard Facing Welds | Puts a hardened material surface on a base metal, for example on the teeth of earth moving equipment. |
| Etc. | |

Special types of joints and welds are not normally part of building a facility and any contact with these will generally be through vessel and equipment fabricators. In which case they will fall under the various codes.

## 10. THE HUMAN SIDE

Today the word "welder" generally refers to either the machine or the person doing the welding. There are several levels of qualification for the person, a few of the possibilities are listed below:

General welder – no certifications
Structural Welder – certification or no certification
Pipe Welder – certification or no certification
Coded Pressure Vessel Welder – must be certified

Generally the procedure is to test the welder (person) on a specific type of weld, if he passes all of this testing for a specific type of joint he is then qualified on that joint; he may require re-testing on a yearly or more frequent basis depending on several factors.

When the engineer is specifying the weld then he is sometimes also specifying the qualifications of the person who will do the welding. For example if the weld is to be performed on an ASME stamped pressure vessel then the welder (person) must be certified for the rating of the vessel, the type of weld, metal type, and metal thickness. Additional certifications may be required for the filler metal, inerting gas and welding machine. All paperwork relative to the weld needs to be secured with the vessel original U-1 forms.

Generally welding under various codes requires some study to determine which one rules for the specific weld. A repair on a pressure vessel falls under ASME while a structural repair might fall under AWS or another code. The engineer needs to understand what is being welded and do the research to determine which code if any applies.

## 11. THE SAFETY SIDE

Obviously welding produces heat, depending on the process the temperature ranges from 2,000 to more than 9,000 degrees Fahrenheit. Various types of metal cutting operations may produce temperatures higher than these. Either way sufficient heat is generated to provide ignition for almost any material. Electrically driven welding frequently produces large quantities of sparks. There should always be a fire watch person around to inspect before, during and after all welding in facility construction. Fire extinguishers are required and on occasion a water wet down of the area prior to welding is essential. Inspection of or closing off and filling with water any low spots where flammable vapors might collect is a point to be covered in the pre-welding inspection. Spark shielding is sometimes required and elimination of flammable and combustible liquid, solids and vapors in the area of the welding is a necessity. Safety concerns must be addressed by the engineer in his specification.

In addition to heat and infrared radiation there is ultraviolet radiation to be shielded against. The ultraviolet light, UV, which is the result of the electric arc used in multiple types of welding, must be shielded to prevent skin and eye damage. Where weld point shielding is not possible all persons need to have personal protective equipment rated for the amount of ultraviolet generated in the welding process. Damage from ultraviolet radiation can occur at some distance and may offer particular hazards to persons wearing certain types of contact lenses. In the unusual situation where animals (farm or pets) are around then they also need protection from the arc generated UV.

Finally some types of welding produces toxic fumes; for example welding galvanized metal, cadmium plated metal and metals contaminated with various chemicals including paint are examples of welding which can generate hazardous conditions. Some fluxes generate noxious fumes. Most of these can be controlled by the use of local ventilation.

## 12. COMMUNICATING YOUR WELDING NEEDS

Welding belongs to a relatively mature industry, which has developed an excellent system of communication between the design engineer and the welder. Most welds can be specified using a series of symbols developed by the American Welding Society and other organizations. These symbols have been standardized for many years and are familiar to most welders. Samples are shown in Figure 13.

For the engineer who is specifying a particular weld the method which provides the least room for error is the AWS symbol rather than words. An alternate is the creation of drawings and procedures for each weld to be made, this approach is frequently used in production plants, sometimes in building facilities.

## 13. INSPECTING WELDS

Welding inspections can be accomplished in a variety of ways, the following are the most common.

Non Destructive Testing

A. Visual inspection of welds
B. Visual inspection of internal welds using video camera techniques (common in pipe inspection utilizing the bore scope)
C. X-Rays
D. Ultrasonic
E. Magnetic Particle
F. Dye Penetrant
G. Hydrostatic testing (for pipe and vessels)
H. Eddy Current Testing

Destructive Testing

I. Cut, polish and chemical etch
J. Bend and pull testing

A. and B. provide surface inspection only
C and D provide internal indications of entrapped material (generally slag), cracks and air pockets.
E. Depending on the equipment used this method will provide indications of surface, shallow or deep discontinuities in the weld metal.
F. Provides an indication of fine surface cracking which may occur in certain types of welds.
G. Is not really an inspection but a common test for weld quality, joint strength and integrity
H. Provides a range of testing including determination of some physical properties and provides a statistical analysis approach to overall weld quality for one individual and one machine.
I. Offers the possibility of grain size determination which relates to metal strength.
J. Requires a large sample be cut and subjected to testing until failure

There are other destructive tests yielding specific information about the weld. A and B inspections can be performed by the specifying engineer, the others requires certain types of licensing and considerable training. For insurance purposes the engineer should probably request weld inspections by an AWS Certified Welding Inspector or whomever your insurance company recommends. When hazardous materials, high pressures or high temperatures are involved the choice of inspectors becomes critical.

## 14. PREPARING THE WELDING SPECIFICATION

The engineer needs to consider some or all of the following points when he is specifying a structure, piping, or equipment as welded objects:

1. Determine the type of weld to be used
2. Determine the degree of penetration to be obtained
3. Determine how the weld joints will be positioned for welding
4. Determine which codes apply to the welds and thus the welder certifications
5. Determine what testing will be used to inspect the welds
6. Determine what safety precautions are required

## CONCLUSION

Welding is a valuable tool for the engineer to use to create facilities and objects and this technique provides a rapid, well established and inexpensive approach to fabrication. Understanding the basics makes proper designing easier. The welding process offers a wide range of opportunities to the engineer for fabrication of his designs.

The field of welding is broad with many applications in industry and we have certainly not covered all aspects of the process here. Several universities offer degrees in welding engineering, this offering is indicative of the breadth of the field.

## REFERENCES

American Welding Society, Miami, Florida
"Welding Inspection" by the American Welding Society
ANSI B31 codes for piping
ASME codes for pressure vessels
ASME BPE 1998 codes for bioengineering equipment
API Tank Codes
"Welding Principles and Applications" Jeffus & Johnson, Delmar Publications, Inc.