WLD 141
Flux Cored Arc Welding I
(Gas Shielded)

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Opinions expressed are those of the authors And not necessarily those of the Foundation

PCC/ CCOG / WLD

Course Number:
WLD 141

Course Title:
Flux-Cored Arc Welding I (Gas Shielded)

Credit Hours:
4

Lecture Hours:
0

Lecture/Lab Hours:
80

Lab Hours:
0

Special Fee:
$24.00

Course Description

Develops knowledge and skills in the gas shielded flux-cored arc welding process in the flat, vertical, horizontal and overhead positions. Prerequisites: Department permission required. Audit available.

Addendum to Course Description

This is an outcome based course utilizing a lecture/lab format. This course includes classroom discussions, videos, and lab demonstrations of technical skills. Course outcomes will include: theoretical concepts, lay out, fabrication, welding, oxy-fuel cutting and safety.

Intended Outcomes for the course

Upon completion of the course students will be able to:

- Function safely in the PCC Welding Lab.
- Operate oxy-fuel portable and track cutting systems in accordance with industry standards.
- Understand and apply code requirements for FCAW E71T-1.
- Interpret blueprints to accurately lay out, prepare, and assemble weld joints.
- Weld single V-groove welds with E71T-1 to AWS D1.1 Structural Steel Welding Code.
- Operate an CAC-A (Carbon Arc Cutting - Air) system in accordance with industry standards.
- Apply visual and destructive examination principles and practices in accordance with AWS D1.1.

Course Activities and Design

This is a outcome-based course utilizing a lecture/lab format. This course includes classroom discussions, videos, and lab demonstrations covering technical skills. Course outcomes will include the following: theoretical concepts, layout, fabrication, welding, oxyfuel cutting, safety.

Outcome Assessment Strategies

The student will be assessed on his/her ability to demonstrate the development of course outcomes. The methods of assessment may include one or more of the following: oral or written examinations, quizzes, written assignments, visual inspection, welding tests and task performance.

Course Content (Themes, Concepts, Issues and Skills)

Function safely in the PCC Welding
Lab.

- Understand and practice personal safety by using proper protective gear
- Understand and practice power tool safety
- Understand and practice equipment safety for welding and oxy-fuel cutting systems
- Understand and maintain a safe work area
  - Recognize and report dangerous electrical and air/gas hose connections
  - Understand and practice fire prevention

Operate oxy-fuel portable and track cutting systems in accordance with industry standards.

- Demonstrate correct setup and shutdown procedures for the hand cutting and track cutting systems.
- Perform oxy-fuel cutting with guided practice.

Understand and apply code requirements for FCAW E71T-1.

- Demonstrate proper stick out and travel speed
- Demonstrate correct starting, stopping and restarting techniques
- Demonstrate proper bead placement for single V-groove welds

Interpret blueprints to accurately lay out, prepare, and assemble weld joints.

- Interpret lines, symbols, views and notes
- Lay out material per specifications
- Use the oxy-fuel cutting process to cut material to specified dimensions
- Assemble project per welding procedure specifications (WPS)

Weld single V-groove welds with E71T-1 to AWS D1.1 Structural Steel Welding Code in the following joint configurations and positions:

Demonstrate correct welding techniques in the following joints:

- Flat Position:
  - T-Joint
- Horizontal Position:
  - T-Joint
  - Single v groove
- Vertical Position:
  - T-Joint
  - Single V-groove
- Overhead Position:
  - T-Joint
  - Single V-groove

Operate an CAC-A (Carbon Arc Cutting - Air) system in accordance with industry standards.

- Demonstrate the effects of the following variables in position: electrode angle, amperage setting, air pressure, and travel speed.

Demonstrate correct CAC-A gouging techniques on single V-groove welds.

Apply visual and destructive examination principles and practices in accordance with AWS D1.1.

Explain visual inspection criteria
Evaluate welds using appropriate welding inspection tools
Assess weld discontinuities causes and corrections

Introduction to the Flux Cored Arc Welding Process

Safety and Shop Practices - FCAW Process

Although you may have already been exposed to the hazards of **SMAW**, there are hazards which are peculiar to the **FCAW** process due to differences in the basic operating characteristics of the equipment and the techniques used. Since the equipment used will have additional controls, it would be possible to encounter a great deal of spatter or have molten globules of material fall on you if the machine is not properly adjusted. Therefore, it becomes even more important that you are properly equipped with protective clothing. In many cases, especially with the **FCAW** process, considerably more heat is involved and experienced welders prefer to wear asbestos gloves, mittens, or other protective devices in addition to the usual leather gloves

Safety glasses must be worn in the shop at all times. When welding, if you find that your eyes are feeling strained or that the arc seems unusually bright, a darker lens in the welding helmet may be necessary for protection from the increased intensity of the rays associated with the welding process.

Adequate ventilation is very important to avoid fume poisoning or excessive smoke inhalation. Prior to starting work, always check to make sure that ventilation sources are adequate.

Since the gasses in the cylinders are under pressure, care must be taken when moving or changing cylinders. Always make certain that cylinders are securely anchored to avoid accidentally knocking them over. When the gun is not being used, it should be hung in such a manner that the trigger is not activated causing the wire to be discharged. When this happens, the wire becomes red hot very quickly and could give you severe burns or cause a fire. Inflammable materials must be removed from the area or suitably protected from sparks or slag. Tripping or falling may be prevented by keeping scraps, debris, and tools or equipment not being used out of the welder's way.

GLOSSARY

ARC LENGTH

Minus arc length	Is the result of low voltage and/or high electrode feed speed (current) which gives a shorter arc length. The tip of the electrode is below the surface of the base metal.
Plus arc length	Is the result of high voltage and/or slow electrode feed speed (current) which gives a longer arc. The tip of the electrode and a portion of the arc stream is clearly visible above the surface of the base metal.
Zero arc length	Or balanced arc is a condition obtained when the electrode feed speed is adjusted so that the current being supplied by the power source melts the electrode at a rate to maintain the tip of the electrode very nearly level with the surface of the base metal.
Inner Shield Electrode	Trade name for Self Shielded Flux Core electrode.
Contactor	A device for repeatedly establishing and interrupting electric power circuit.
Flow Meter	A metering device developed to control the flow of shielding gases. The flow of shielding gases is indicated on a flow meter tube that is calibrated for the gas being used in cubic feet per hour (cfh).
Gas diffuser	A device located in the gun that disperses the shielding gas into the nozzle. It also holds one end of the wire conduit firm and it a receptacle for the contact tip.
Gun (Arc Welding)	In semiautomatic, machine and automatic welding, a manipulating device to transfer current and guide the electrode into the arc. It may include provisions for shielding and arc initiation.
Gun conductor tube	(FCAW and GMAW)--A hose-like device through the electrode, current, shielding gas (if any), and coolant (when used) travels from the power source or wire feeder to the gun.
Travel Speed	Is the relative speed between the electrode and the work surface.

VOLTAGE

Arc Voltage	The voltage across the welding arc.
Open Circuit Voltage	The voltage between the output terminals of the welding machine when no current is in the welding circuit.
Weld Reinforcement	The weld metal on the face of the weld in excess of the original surface of the base metal.
Fusion Line	The junction of the weld metal with the un-melted base material.
Wire Conduit	A round tube located in the gun conductor tube through which the electrode travels from the wire feeder to the gun. This conduit may or may not be removable depending upon the manufacturer of the equipment.
Wire feeder	An assembly that provides the driving or pulling power to transport the electrodes through the gun conductor tube and the gun to the work. There are three types of systems: 1. PUSH: Where the drive rolls push the wire through the conductor tube. 2. PULL: Where the drive rolls are located in the gun and pulls the electrode through the conductor tube. 3. PUSH-PULL: Where a system of drive rolls are located at both ends of the conductor tube, one set in the gun that pulls and one set at the base of the conductor tube that pushes. Used mostly for soft or small diameter wires.

Shielded Flux Cored Process and Welding Variables

The shielded flux-core process involves welding with a flux core fabricated electrode in an atmosphere of carbon dioxide or a mixture of argon and carbon dioxide. Welding current is supplied from a constant voltage power source. Normally, direct current with electrode positive (reverse polarity) is used. This process offers many advantages, the greatest of which is excellent weld quality, welding speeds comparable to submerged arc welding without being handicapped by loose granular flux, and visibility of the welding area so that the welder can better control the process.

The shielded flux-core process results in a deeply penetrating arc. This deep penetration has great economic advantages. It reduces edge penetration for butt joints to a minimum, allowing considerably less weld metal with less welding time to complete the weld joints. The greater penetration of the arc permits small fillet welds that require much less welding time to have comparable strength and load-carrying capacity.

High deposition rates of weld metal are available with the flux-core process. High current density on the electrode and continuous welding make the high deposition rates possible. The greater amounts of weld metal deposited in a given length of time result in remarkable cost savings in the finished weldment.

The shielded flux-core process provides for the arc to be completely shielded by a low cost gas, carbon dioxide, which is another economic advantage. Welding grade CO2 with a dew point of at least -45° F. should be used at the rate of approximately 45 cfh (cubic feet per hour). Increased volume may be desirable for large size electrodes or with high travel rates. The molten weld deposit is fully covered and protected from the atmosphere by a dense, easily removed slag. This combination of gas shielded arc and slag covered weld deposit gives excellent weld soundness and mechanical properties. The chemical composition of the flux-core weld deposit is consistent because the alloying ingredients are fabricated into the electrode. With the deep penetration experienced with this process, up to 43% less weld metal is required in fillet welds. Deposition rates from 16 to 22 lbs. per arc hour are possible with machine application.

All-position electrodes are available in .045" and 1/16" diameters. These small diameter electrodes have been developed to produce excellent welds in out-of-position work. They provide equal leg lengths on fillet welds with very little spatter. Since slag cover is complete and removal -easy, cleaning time is reduced. This combination of quality welds, easy cleaning, and excellent usability makes outstanding economical features.

All-position electrodes are designed for welding mild steel and low alloy steels with CO2 gas or 75% argon - 25% C02 gas mixture. A 75% argon -25% C02 gas mixture may be used to improve arc characteristics in the out-of-position work and to provide increased wetting action, decreased penetration, and finer spray metal transfer. When using this gas mixture, reduce the voltage approximately 1 to 1-1/2 volts.

X-ray sound welds of the all-position electrodes are obtained when attention is given to these factors; proper contact recessed distance, electrical stick out should be 1/2"-to 3/4", and the correct contact tip size must be used.

Joint Design

The shielded flux-core arc welding process is capable of producing weldments with great savings of time and weld metal. Part of the savings results from the continuous welding with high deposition rates that are inherent to the process. The other part of the savings is achieved from the proper design of the weld joints to make full advantage of the deep penetration of sound weld metal.

The volume of weld metal required to complete a butt joint can be effectively reduced by reducing the root opening, by increasing the root face, and by using smaller bevel angles.

Because of the deep penetration of the arc, fillet welds can be reduced in exterior size and retain comparable or greater strength.

However, it should be kept in mind that it would be undesirable to obtain deep penetration when welding some of the alloy steels because of the resultant admixture of parent metal and filler metal.

Shielded Flux Cored Welding Variables

When the variables by which the process is operated are understood and controlled, consistently good welds throughout a wide range of welding conditions are easily obtained. Each variable listed below is important in obtaining a balanced welding condition which gives the best results.

Metal thickness, types of joint, and joint geometry must be taken into consideration when using the following variables:

I WELDING VOLTAGE
II WELDING CURRENT
III WELDING TRAVEL RATE
IV WELDING GUN ANGLE
V CONTACT TIP-TO-WORK DISTANCE

Effects of Welding Voltage

Arc voltage determines the arc length. The best or balanced arc voltage for the shielded flux-core process is achieved when the arc length is such that the tip of the electrode is about level with a flat plate surface. The weld metal transfer across the arc is confined (or buried) below the plate surface, resulting in a spatter-free welding condition with good penetration, and weld bead appearance (see appropriate drawing). A balanced arc condition is referred to as "Zero-Arc Length" in this discussion.

Higher arc voltage results in a longer arc. The tip of the electrode and a portion of the arc stream are above the surface of a flat plate when the arc voltage is high. The arc stream is cone-shaped with the vertex at the electrode tip. The base of the arc stream cone is larger with a longer arc. A larger area of the base metal is heated, resulting in a wider and flatter weld bead. Excessive arc length contributes to heavy spatter and gives an irregular weld bead appearance (see appropriate drawing). This arc condition is called "Plus Arc Length."

Lower arc voltage results in a shorter arc. The tip of the electrode and the arc stream are below the surface of a flat plate when the arc voltage is low. The base of the arc stream cone has a smaller area and heats less base metal which gives a narrower and higher weld bead shape. This shorter arc is prone to weld metal spatter that splashes out of the molten pool and has a cutting, knife-like action at the leading edge of the arc (see appropriate drawing). This arc is referred to as "Minus Arc Length."

Effects of Welding Current

The electrode feed speed is the variable that controls the welding current from a constant voltage power source. The power source supplies the amount of current (amperes) necessary to melt the electrode at the rate required to maintain the preset voltage and resultant arc length.

An increase in the electrode feed speed (all other normal welding variables constant) requires more electrode to be melted to maintain the preset voltage and arc length. Higher current is automatically supplied by the power source and the deposition rate (lb./hr.) increases. More weld metal and more heat in the base metal are applied per unit length of weld, resulting in deeper penetration with larger weld beads.

A decrease in the electrode feed speed (all other welding variables constant) results in less electrode to be melted to maintain the preset voltage and arc length. Less current is automatically supplied by the power source and the deposition rate (lb./hr.) decreases. Less weld metal and less heat eat in the base metal are applied per unit length of weld, resulting in less penetration and smaller weld beads.

The electrode feed speed (current) is reduced and the voltage adjusted to "Zero Arc Length”. This gives a smoother arc behavior and a more desirable weld bead shape than is obtained with a "Plus Arc Length."

The electrode feed speed (current) is increased and the voltage adjusted to "Zero Arc Length". The resulting weld bead has a better shape and contour than is obtained with a "Minus Arc Length," at the same travel rate.

Effects of Weld Travel Rate

The relative speed between the electrode and the work surface is the "Weld Travel Rate" and has a marked effect on the weld penetration and bead appearance.

Slower travel rates give proportionally larger weld beads and more heat input in the base metal per unit length of weld. The longer heating times of the base metal increase the, depth of penetration and the increased weld deposit per unit length results in a higher and wider bead contour. The increase of weld metal and heat input continue until the speed is reduced to a point where the volume of the molten weld metal and slag becomes so great that the molten materials flow into the crater beneath the arc and give an insulating effect between the arc and the base metal. The heating of the base metal beneath the arc is reduced and the molten weld metal heats a wider area of the base metal, resulting in a wide bead with shallow penetration. This effect is readily visible during welding.

Progressively increased travel rates give opposite effects. Less weld metal is deposited with lower heat input per unit length of weld. This gives a narrower weld bead and less penetration. Excessively fast travel rates result in ropy, irregular bead shapes with difficult slag removal and undercut.

The relative speed between the electrodes and the work surface is the "Weld Travel Rate" and has a marked effect on the weld penetration and bead appearance.

EFFECT OF GUN ANGLE

Welding Gun Angles

Drag angle is the angle the welding gun is tilted from perpendicular in the direction of travel with the top section of the gun in advance of the p point of welding. The gas shield is then directed over the molten pool. (See appropriate drawing.)

Push angle is the angle the welding gun is tilted from perpendicular to the direction of travel with the top section of the gun behind the point of welding. The gas shield is then directed ahead of the molten pool. (See appropriate drawing.)
The arc stream plays ahead on the cold base metal when a pushing gun angle is used and reduces the intensity of the heat on the work. This lowers the penetration and helps to prevent burn-through on thin gage metals.

Dragging gun angles are usually desirable because the operator has a better view of the arc and better control. A dragging gun angle of 2 degrees to 15 degrees is recommended on heavier weldments.

Effect of Contact Tip-to-Tip Work Distance

The contact Tip-to-Work Distance, or "Electrode Stick-Out" is the length of the electrode extending from the tip of the contact tip to the work surface. This extended length is the part of the electrode that carries the welding current, and is subject to resistance heating, sometimes called "electrode preheat."

Low resistance and electrode preheat are encountered with 3/4" of electrode stick-out (minimum recommended). A 1-1/2" stick-out (maximum recommended) causes high resistance and electrode preheat. The constant potential power source, however, continuously supplies the correct amount of current to maintain the preset constant arc voltage and arc length at any fixed electrode feed speed

Penetration is slightly affected by the stick-out length, within the recommended range, and the deposition rate is constant provided, the electrode feed speed is unchanged. The same amount of electrode is, melted per unit length of weld, and there is little or no change in the weld bead shape.

Fast spatter build up on the nozzle and the contact tube results when the electrode stick-out is too short. Spatter and irregular arc action occur when the electrode stick-out is too long.

Reducing the electrode stick-out to 3/4" -requires more current (amperes), which is automatically supplied by the power source, to melt the less preheated electrode and maintain the preset arc length. In (see appropriate drawing) bead 1 shows the result of 3/4" electrode stick-out with the electrode feed speed reduced to give the same current value as the original in bead 2. Less electrode is melted and the deposition rate (lb./hr.) is reduced.

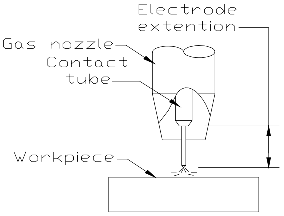


Figure 7-2. Electrode extenion. The actual electrode extenion is from the end of the ontact tip to the of the electrode. The proper term is "eltrical stickout" and is defined on weld procedure with the letters ESO.

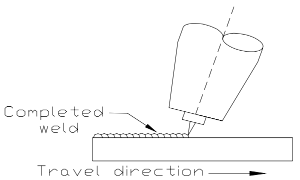


Figure 7-4. Backhand or pull welding technique. This technique requires more skill on the part of welder, since the weld joint is defficult to see because of the position of the gas nozzle.

The lower welding current and smaller amount of weld metal deposited results in lower heat input (base metal heating) per unit length of weld and a smaller weld bead with reduced penetration.

Increasing the electrode stick-out to 1-1/2" results in:

1) More preheating of the extended electrode
2) Less current required to melt the electrode while maintaining the preset arc length. The electrode feed speed was increased in (see appropriate drawing), to give the original current value of bead 2.

Increased electrode feed speed results in a higher deposition rate (lb./hr.). Increased deposition and heat input (base metal) per unit length of weld results in a larger weld bead with greater depth of penetration.

Science On steel

The contents of this packet include:

- *Introduction*
- *Out-of-Position FCAW*
- *Low Hydrogen Capability*
- *Flux Composition*
- *Composition and Mechanical Properties of Weld Metal*
- *Fume Generation*
- *Electrode – Shielding Gas Match*
- *Development of New Seamless E71T-1 Electrodes*
- *Advantages/Disadvantages of E71T-1 compared to E7018 or ER70S-3*

Introduction

Flux cored arc welding (FCAW) is the most used welding processes in the United States today. The gas shielded FCAW process can be used as a semi-automatic process or a fully automatic welding process. The gas shielding can be either 100% CO_2 or mixtures Ar- CO_2. Typical gas mixtures like Ar-25%CO_2 are used to improve out-of-position capability, reduce spatter, improve Charpy impact toughness and promote a near-spray transfer. E71T-1 electrode for FCAW is a multi-pass electrode used in all positions with DCEP for good penetration. E71T-1 electrode for FCAW combines the advantages of slag-shielding of E7018 shielded metal arc welding electrode with the high productivity of gas metal arc welding. In fact, the productivity of FCAW far exceeds that for GMAW because of the desirable arc characteristics produced by the flux core in E71T-1. The only disadvantage of gas shielded FCAW is that it should not be used where wind can blow away the gas shielding. Typically, gas shielded FCAW is used in the shop or in wind-protected areas.

Out-of-Position FCAW

Unlike GMAW with spray or globular metal transfer, the gas shielded FCAW process with E71T-1 electrode is capable of out-of-position welding because the flux provides the fast freezing rutile-based slag to support the molten weld pool. The gas most commonly used to protect the slag and molten metal pool is CO_2. However, despite the improvements in arc characteristics provided by the flux (in the core of the electrode), the presence of 100% CO_2 gas shielding still generates substantial spatter and globular mode of metal transfer. With increasing additions of argon to a mixture of Ar-CO_2 up to the commonly used C25 gas (75%Ar-25%CO_2), the globular mode is replaced by a near-spray mode of transfer with very little spatter. Even is some cases, mixtures of 90%Ar-10%CO_2 are used for improved Charpy impact toughness, high out-of-position deposition rate, pure spray transfer, and reduced fume generation. Furthermore, when increased weld metal Charpy impact toughness is required as for bridge construction, pressure vessels, earthmoving equipment, and shipbuilding, the gas mixtures containing 75%Ar-25%CO_2 must be used. Compared to welds deposited with pure CO_2, weld metal deposited with 75%Ar-25%CO_2 contain reduced volume of oxide inclusion. These microscopic non-metallic oxide inclusions reduce upper shelf Charpy impact toughness and raise the ductile-to-brittle transition temperature.

The reason why the T-1 type electrode is so versatile for out-of-position welding is the rutile flux that is used in the core. Rutile, which is also known as titania or TiO_2, is a high-melting, viscous, fast-freezing component of the E71T-1 flux. These freezing characteristics of rutile, provides out-of-position capability by supporting the molten weld pool during solidification. More tonnage of E71T-1 electrodes is produced each year for construction than any other type of electrode for any process.

Low Hydrogen Capability

The chemical and mechanical properties of weld metal deposited by E71T-1 are designed to be similar to those of E7018 stick electrode. The flux used for E71T-1 differs from that used for E7018 principally in that E71T-1 eliminates the need for:

(1) Silicate binders (to bond the flux cover on stick electrodes), and
(2) Gas-producing ingredients like $CaCO_3$.

Since the most popular types of E71T-1 use either 100%CO_2 or 75%Ar-25%CO_2 gas shielding, the flux is designed to provide maximum toughness and minimum spatter. There are no hydrogen-producing ingredients in the flux for E71T-1. However, the rutile-based flux is susceptible to hydrogen contamination due to improper storage in a moist environment.

Because of the increased demand for low hydrogen FCAW, low-moisture (low hydrogen) E71T-1 electrodes are available. These electrodes use the AWS hydrogen "H" designation. For example, E71T-1H4 is a very low hydrogen electrode that will deposit no more than 4 ml/100g of weld metal. This level of hydrogen is as low as the best E7018 shielded metal arc electrode.

Flux Composition

The weight of flux in the core of an E71T-1 flux cored wire comprises about 20% to 40% of the total weight of the whole wire (iron sheath and flux core). From Table 1, the major flux ingredients in E71T-1 are rutile and silica that are two excellent slag formers. Gas producers like $CaCO_3$ are not used since ample gas coverage is provided by the externally supplied shielding gas.

The flux must provide several important functions: arc stabilization, slag to protect the weld pool, slag of proper viscosity to support the weld pool for out-of-position welding, deoxidizers to cleanse the weld pool, slag detachability, smooth weld contour, reduced spatter, and alloying to achieve desired mechanical properties.

Table 1 Flux ingredients in E71T-1 flux cored electrodes shielded by CO_2
(Olson et al, ASM International Handbook, 1993, Vol. 6, pp. 55-63)

Flux Ingredient	Typical %	Purpose
SiO_2	21	Slag former
Al_2O_3	2.1	Slag former
TiO_2	40.5	Slag former, arc stabilizer
CaO	0.7	Fluxing agent
Na_2O	1.6	Arc stabilizer
K_2O	1.4	Arc stabilizer
CO_2 (as carbonate)	0.5	
Metallics (Fe, Mn, others)	balance	Deposition rate, alloying, deoxidizers

Composition and Mechanical Properties of Weld Metal

The chemical composition and mechanical properties of weld metal deposited by E71T-1 electrode is governed by the American Welding Society Specification (AWS) A5.20. These requirements are given in Table 2.

Table 2 Chemical and mechanical properties required by AWS A5.20 for multi-pass weld metal deposited by E71T-1 and typical properties for comparison.

	E71T-1 (per AWS A5.20)	Typical E71T-1 (75%Ar-25%CO_2)	Typical E71T-1 (100%CO_2)
C	0.15max	0.07	0.04
Mn	1.75max	1.47	1.31
Si	0.9max	0.75	0.60
P	0.04max	0.014	0.014
S	0.04max	0.016	0.016
Tensile Strength	72 ksi	96 ksi	89 ksi
Yield Strength	60 ksi	86 ksi	78 ksi
% Elongation	22 %	26 %	25 %
CVN Toughness (at 0º F)	20 ft-lbs	40 ft-lbs	31 ft-lbs

From Table 2, the advantages in using 75%Ar-25%CO_2 shielding gas with E71T-1over pure CO_2 is evident. Because CO_2 is an active gas, the high temperature arc causes:

$$CO_2 \rightarrow CO + O$$

The oxygen reacts with C, Mn and Si to forming slag products which float out of the weld. For example,

$O + Si \rightarrow SiO_2$ (floats out in slag)
$O + Mn \rightarrow MnO$ (floats out in slag)
$O + C \rightarrow CO$ (gas)

As a result, Table 2 shows that there less C, Mn and Si in the as-deposited weld metal when pure CO_2 shielding gas is used. Because a large percentage of SiO_2 and MnO are retained in the weld pool as non-metallic inclusions, the Charpy V-notch (CVN) impact toughness for weld metal deposited with pure CO_2 is always less than similar weld metal deposited with 75%Ar-25%CO_2. Similarly, the tensile properties such as tensile strength, yield strength and % elongation are all improved with 75%Ar-25%CO_2 shielding gas (instead of pure CO_2) as shown in Table 2.

Fume Generation

The presence of CO_2 can greatly increase fume emission. As shown above, CO_2 gas decomposes into two active ingredients: CO + O. Both CO and O oxidize flux and metal ingredients to form vapor or fume products. As a result, the greater the CO_2 content in the shielding gas, the greater will be the amount of fumes generated during welding. Since Ar is inert, it does not oxidize with any of the flux and metal ingredients. The greater the % argon in the shielding gas, the less will be the fume level. Table 3 illustrates the fume generation effect for gas-shielded FCAW. From this table, FCAW with 100% CO_2 shielding produces the greatest amount of fumes. Increasing the amount of argon in the shielding gas reduces the fume level. Notice, even solid wire GMAW with 100% CO_2 shielding produces a substantial amount of fumes. From Table 3, the least amount of fumes is produced with solid wire GMAW and 95%Ar-5% CO_2 shielding.

Table 3 Fume Generation in Gas-Shielded FCAW using E71T-1 Electrode and GMAW for Comparison

Gas Shielding	Fumes (g/hr)
FCAW – 100% CO_2	72
FCAW – 75%Ar-25% CO_2	36
GMAW – 100% CO_2	30
FCAW – 90%Ar-10% CO_2	20
GMAW – 95%Ar-5% CO_2	12

Electrode – Shielding Gas Match

When welding steel with E71T-1 electrode, it is extremely that the shielding gas used is that recommended by the manufacturer. This is because the flux cored electrode composition is matched to the oxidizing potential of the shielding gas. For example, if the recommended shielding gas for a particular manufacturer's E71T-1 electrode is 100% CO_2, then the flux will containing substantial amounts of Si and other deoxidizers to reduce the oxidizing effect of CO_2. On the other hand, if the manufacturer recommends the use of C25 (75%Ar-25%CO_2), then the flux core will contain much less deoxidizers. It is very important to use the manufacturer's recommendations. If 100% CO_2 is used with an E71T-1 electrode designed for 75%Ar-25% CO_2, the resulting mechanical properties will show inferior Charpy impact toughness and reduced ductility. Conversely, if 75%Ar-25% CO_2 is used for an E71T-1 electrode designed for 100%CO_2, the as-deposited weld metal will be saturated with unused deoxidizers like Si and Al. When present in excess quantities, both Si and Al will embrittle the steel weld metal, producing inferior Charpy toughness and reduced ductility.

Development of New Seamless E71T-1 Electrodes

The latest innovation in flux cored welding is the development of the seamless electrode. These were recently developed in Germany and Japan and are rapidly gaining market-share. The thin iron sheath used to manufacture seamless flux cored wire is not mechanically bonded; instead, it is welded shut by high-frequency resistance welding. The welded seam is so "seamless" that these E71T-1 electrodes are copper plated just like solid E70S-3 wires for GMAW. The great advantage of seamless electrodes are primarily very low hydrogen (as good as solid wire electrodes) and the copper plating for rust resistance and longer contact tube life.

Advantages/Disadvantages of E71T-1 compared to E7018 or ER70S-3

FCAW with E71T-1 electrodes have many advantages over comparable E7018 stick electrodes (SMAW) and ER70S-3 solid wire electrodes (GMAW). The major reason why E71T-1 electrodes are far more popular than both E7018 and ER70S-3 is the combined benefits of outstanding deposition rate, travel speed, and out-of-position capability of E71T-1. In addition, because of the deoxidizers used in E71T-1, less cleaning of the faying surfaces of the plate is required with E71T-1 than is required with E70S-3 (GMAW) electrode. Less skill is required with E71T-1 (FCAW) than is needed for GMAW, SMAW or GTAW. Although E71T-1 is used only with DC current, small additions of potassium are added to the flux core for outstanding arc stabilization. This As shown in Table 2, the mechanical properties E71T-1 weld metal are excellent. As with GMAW, the FCAW process can be used in both semi-automatic and fully automatic modes of operation. However, E71T-1 is ideally suited for high production, hand-held welding indoors.

The disadvantages of E71T-1 electrodes used in FCAW include the requirement to clean the thin layer of slag after each welding pass and the danger of loosing the gas shielding due to wind. Therefore, E71T-1 gas-shielded welding must be performed indoors or in wind-protected areas. Unlike GMAW, smoke and fumes produced by E71T-1 electrode must be removed. Since the tubular wire used for FCAW is not as resilient as solid wire, the E71T-1 electrode must be handled with more care to prevent accidental breakage.

Checking and Adjusting Your Wire Feed Speed

Welders need to know how to figure their wire feed speed (WFS), the speed at which the wire comes out of the gun in inches per minute (IPM). Why is this so important? There are several answers to this question, one of them, of course, having to do with figuring how much wire you use and therefore its cost on a given weld. We'll work on this later. Another importance of WFS is that it is often specified by the Welding Procedures, and you need to know if you are welding in the appropriate range of wire feed speed. Finally and probably most importantly, a welder needs to understand the interrelationship between wire feed speed, amperage, and voltage and their influence on achieving a balanced arc condition.

Well, as you know, this is the math section, so let's start with how to figure your wire feed speed. You may ask why you can't just set the WFS dial to a number in the range given in the Weld Procedures and go from there? You can start there, and for newer equipment, it will probably work just fine. But older welding equipment varies considerably, and some have a wire speed dial whose numbers have absolutely nothing to do with inches per minute (IPM). These are often expressed in numbers 1 - 10. Some machines have a WFS/IPM dial which makes more than one revolution, but nothing to count how many revolutions have occurred. Without actually measuring the wire, you may not be able to determine the wire feed speed, because you may not be able to know how many times the dial has done 360 degrees. Also, even newer welding equipment gets old and loses calibration, and you just cannot count on the WFS/IPM dial accurately reflecting the speed output. You need to be able to measure the speed you get and adjust your dial to a setting that actually gets your speed within range.

Let's go over that procedure:

1. First, cut the wire flush to the nozzle on your gun

2. If the dial has IPM settings, set the WFS dial to a number within the WFS range given in the procedures of one of your projects.
   If the dial has 0 - 10 or another non-IPM setting, adjust it mid-range, e.g. "5."

   If you are using a newer machine, like the Lincoln Power Wave 455, which has an IPM wire feed speed dial, you should understand that even a newer machine might not always give out what you set them to, so it's a good idea to go through this procedure to check the WFS/IPM dial accuracy.
   Basically, you need to be able to do this.

3. Squeeze the trigger for exactly 6 seconds.
4. Measure the amount of wire that came out of the nozzle, to the nearest 1/16".

5. Multiply this number by 10 to get the number of inches for a full minute (6 sec x 10). You may need to use the fraction (**a b/c**) key on your calculator as you will probably be dealing with a mixed number. Round to the nearest whole number, that is, to the nearest inch.

Math On Metal

How to Read and Write A Decimal

1000^{S}	100^{S}	10^{S}	1^{S}	.	10^{ths}	100^{ths}	1000^{ths}	10,000^{ths}
				.				

The four steps to reading a decimal in the proper way:

1. Say the number to the left of the decimal point as it's written without using the word "and";
2. Say the word "and" to indicate the decimal point;
3. Say the number to the right of the decimal point as it's written;
4. Then say the name of the place value of the last digit to the right.

Example: 372.681 **Step 1. three hundred seventy-two**
Step 2. and
Step 3. six hundred eighty-one
Step 4. thousandths

This number is read: three hundred seventy-two and eight hundred sixty-one thousandths.

If there is only a zero or no digit at all to the left of the decimal point, then you only need to follow steps 3 and 4 above.

Example: 0.02 Step 3. two
Step 4. hundredths

This number is read: two hundredths.
(The same would be true if the number were written as just .02)

Practice With Decimals: Reading and Writing

In which place is the underlined digit?

1. 1.74 ______________
2. 96.582 ______________
3. 7.2975 ______________
4. 813.96 ______________
5. 327.845 ______________
6. 84.215 ______________

Write in words.

7. 3.45 ____
8. 0.583 ____
9. 100.01 ____
10. 0.028 ____
11. 400.1 ____
12. 0.004 ____
13. 0.019 ____
14. 80.022 ____

How to convert a Decimal to a Fraction

There are three steps in converting a decimal to a fraction

1. **Say** aloud the name of the decimal- use the proper name, not shop slang

2. **Write down** what you say, putting the number on the top and place name on the bottom

3. **Reduce** the fraction if necessary

Example: .125

Say: ‘One hundred twenty-five thousandths’

Write: $\frac{125}{1000}$

Reduce: 1/8

Note: to quickly reduce the fraction, enter it into your calculator using the fraction key. Enter 125/1000 as
125 a b/c 1000 =

1/8 will show up on your display

Shielded Flux Cored Process and Welding Variables

NAME: ________________________________ DATE: ____________________________

Answer the following questions. If necessary, refer to Information Sheets or your textbook for the answers

1. The shielded flux-core process uses a gas as well as the flux for shielding. What gas or mixture of gases are used?

2. Welding current is supplied by two types of power sources, constant current, and constant voltage. Which of the two would be used for the flux-core process?

3. The shielded flux-core process results in a deeply penetrating arc. Name three advantages of this quality.

   A.

   B.

   C.

4. There are five (5) important variables when using the flux-core process. Name all five variables:

   A.

   B.

   C.

   D.

   E.

5. Describe when the best or balanced arc voltage for the flux-core process is achieved.

6. What is the term used for the balanced arc condition?

7. Describe the results of higher voltage in relation to the arc stream.

8. Describe what term is used with a higher arc voltage condition.

9. The term "minus arc length" is a result of what condition?

10. Higher current is automatically supplied by the power source by an increase in the

_________________.

11 Is the gun angle a drag or a push angle when the gun is tilted from the perpendicular to the direction of travel?

12 When welding thin metals, which gun angle would be preferred?

13 Is an increase in spatter a result of a short stick-out or a long stick out?

14 What is the recommended recessed distance of the contact tip?

DIRECTIONS: Circle TRUE or FALSE on Questions 15 - 18.

15. TRUE - FALSE: A slower travel rate may result in a wide bead with shallow penetration.

16. TRUE - FALSE: With the welding current and voltage set for normal welding, an increase in travel rate will result in deeper penetration.

17. TRUE--FALSE: Wire stick out has no effect on penetration.

18. TRUE - FALSE: A constant voltage power source will supply the correct amount of current to maintain the preset arc voltage and arc length at any fixed electrode speed.

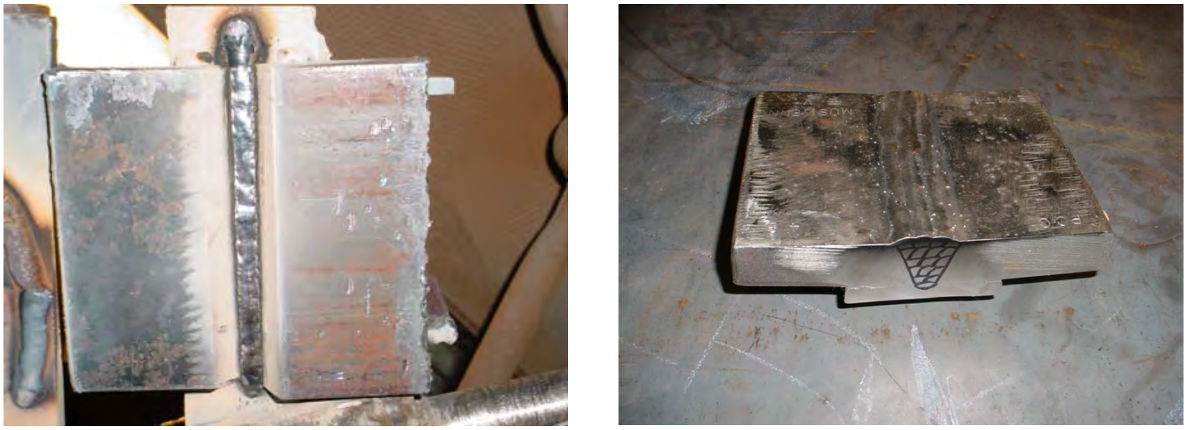
Craftsmanship Expectations for Welding Projects

The student should complete the following tasks prior to welding.

1. Thoroughly read each drawing.
2. Make a cutting list for each project. Cut at least two project assemblies of metal at a time. This will save a great amount of time.
3. Assemble the welding projects per drawing specifications.
4. Review the Welding Procedure portion of the prints to review welding parameter information.
5. See the instructor for the evaluation.

Factors for grading welding projects are based on the following criteria:

Metal Preparation	Project Layout	Post Weld Clean-up
Oxyacetylene Cut quality	**Accurate (+/- 1/16")**	**Remove Slag/Spatter**
Grind all cut surfaces clean	**Limit waste**	**Remove sharp edges**



Example of a High Quality Weld

Weld Quality per AWS D1.1

VT Criteria	Cover Pass
Reinforcement (groove welds)	**Flush to 1/8"**
Fillet Weld Size	**See specification on drawing**
Undercut	**1/32" deep**
Weld Contour	**Smooth Transition**
Penetration	**N/A**
Cracks	**None Allowed**
Arc Strikes	**None Allowed**
Fusion	**Complete Fusion Required**
Porosity	**None Allowed**
Overlap	**None Allowed**

Shop Pre-Test Bend Test Procedure for 1" Test Plate

Bend tests are used to determine the ductility and soundness of a weld joint. The test will determine if fusion was obtained in the weld joint. Use the following procedure in preparing and bending your coupons.

1. Reference the AWS D1.1 Structural Welding Code to determine the dimensional layout of the bend coupons (use this diagram for all positions).
2. Flush back up strip off of the plate. **Note: flushing of the backing strip maybe removed by flushing provided that at least 1/8 inch of its thickness is left to be removed by grinding.**
3. Layout four 3/8" thick coupons and cut using the track burner**. Do Not Bend coupons greater than 3/8" thick. This will damage the machine.**
4. Allow coupon to air cool. **Do Not Quench!**
5. Grind coupon's smooth, ensuring grinding marks are going with the length of the coupon's and all edges are rounded.
6. Request permission from your instructor to use the bend test machine.
7. CAUTION: ***Keep hands and fingers clear when operating equipment.***
8. Ensure guard is in the correct position. The coupons sometimes eject out the end of the machine rapidly.
9. Place coupon in the machine taking care to not position your hands/fingers in the way. Locate weld in the center of the die. Position coupons for side bends only.
10. Actuate the machine by the lever on top of the machine and stand clear of end where the coupon will exit.
11. Inspect the coupon for fusion type defects. **Reference AWS D1.1 Structural Welding Code, for acceptance criteria**.

Inspection by instructor: **Instructors signature:** ______________________________

Date: ________________ **Student signature:** ______________________________

Bend Test Procedure
For 1" Test Plate

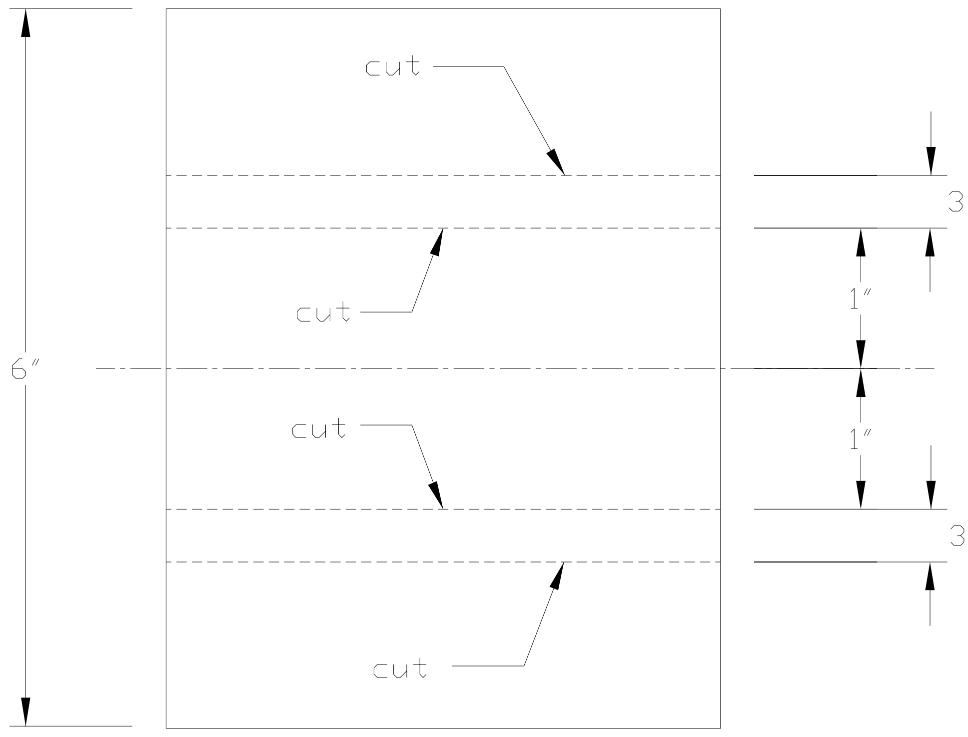
Bend tests are used to determine the ductility and soundness of a weld joint. The test will allow the welder to determine if she or he has obtained fusion in the weld joint. Use the following procedure in preparing and bending your coupons.

1. Flush back up strip off of the plate at the flushing station.

2. Layout four 3/8" coupons and cut using the track burner**.** **Do Not Bend** coupons greater than 3/8 " thick it will damage the dies in the bending machine!

SHOP TEST

BEND TEST COUPON PREPERATION FOR SHOP TEST



TEST COUPONS SHALL BE FREE OF ALL DEFECTS SUCH AS UNDERCUT, POROSITY, SLAG INCOMPLETE FUSION, AND OTHER DEFECTS PER AWS D1.1

Inch	MM
1/16″	1.6
1/8″	3.2
1/4″	6.4
1/2″	12.7
1″	25.4

Part No.	Required	Size(WxLxT)	S.I. Conversion

Portland Community College
Welding Technology

Tolerance (Unless otherwise Specified)
Dimensional ± 1/16″ Angle ± 5°

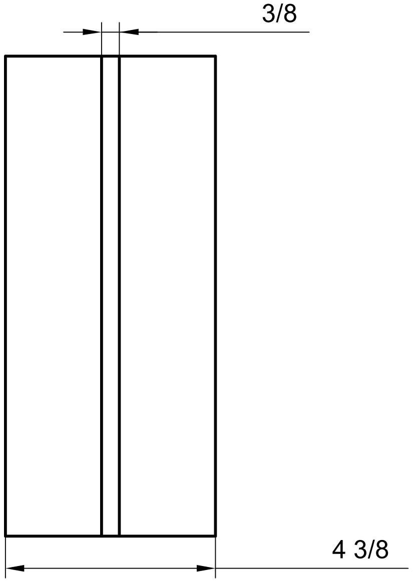
WLD 141 Bend Test Layout

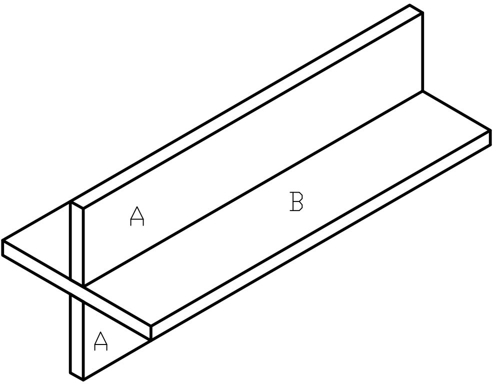
Drawn By:
John Deering

Size:
Qc No.
Rev.

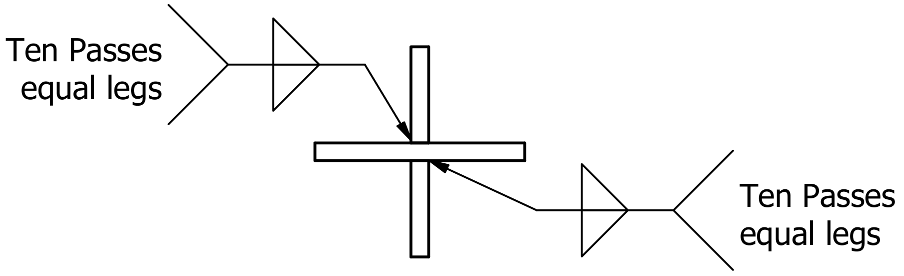
Chk By:
Date: 5/22/05
Approve Date
Sheet

Fillet Weld practice plate (X4)





Notes:
1/2" material may be substituted for 3/8"



Linear Tolerances: +/-1/16
Angular Tolerances: 2°30'

Part	Quantity	Thickness	Width	Tolerance	Length	Tolerance
A	8			+		+
				–		–
B	4			+		+
				–		–

TITLE
111 1F, 2F ,3F, and 4F

LAST UPDATED
03/30/22

UNITS
in

SHEET
1 / 1

THIRD ANGLE PROJECTION

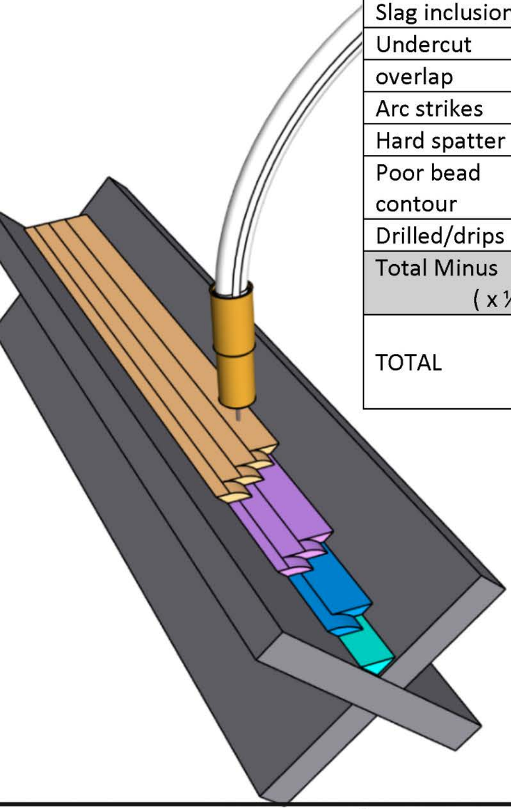
SCALE
1:4

SIZE
A

Project 1

1F

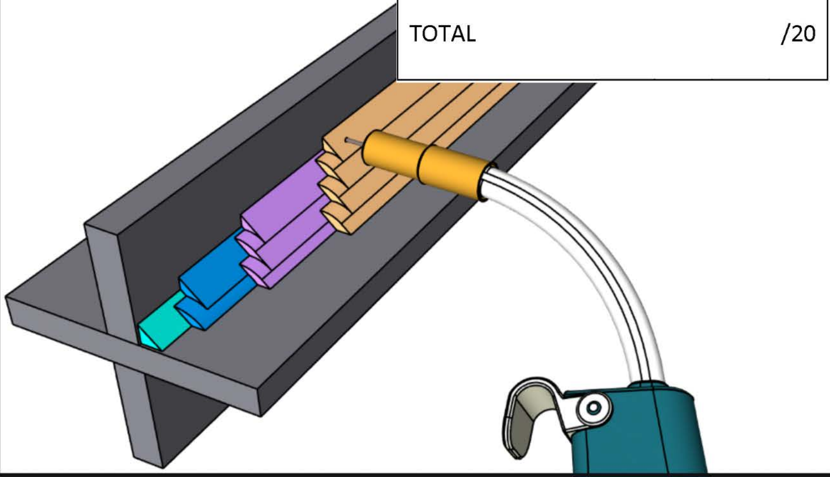
SIDE	1	2	3	4
Poor bead-to-bead contour				
Unequal leg size				
Porosity				
Slag inclusion				
Undercut				
overlap				
Arc strikes				
Hard spatter				
Poor bead contour				
Drilled/drips				
Total Minus (x ½)				
TOTAL				/20



Project 2

2F

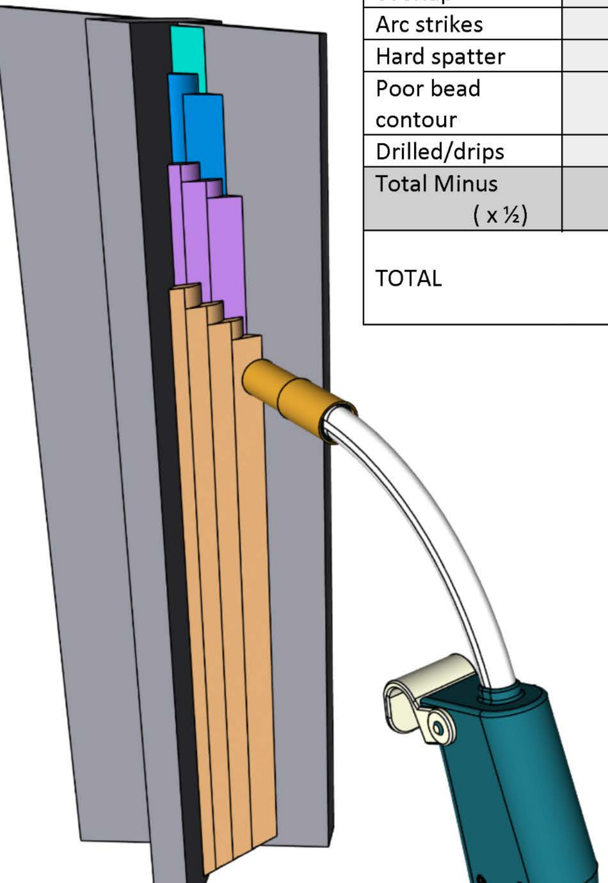
SIDE	1	2	3	4
Poor bead-to-bead contour				
Unequal leg size				
Porosity				
Slag inclusion				
Undercut				
overlap				
Arc strikes				
Hard spatter				
Poor bead contour				
Drilled/drips				
Total Minus (x ½)				
TOTAL				/20



Project 3

3F

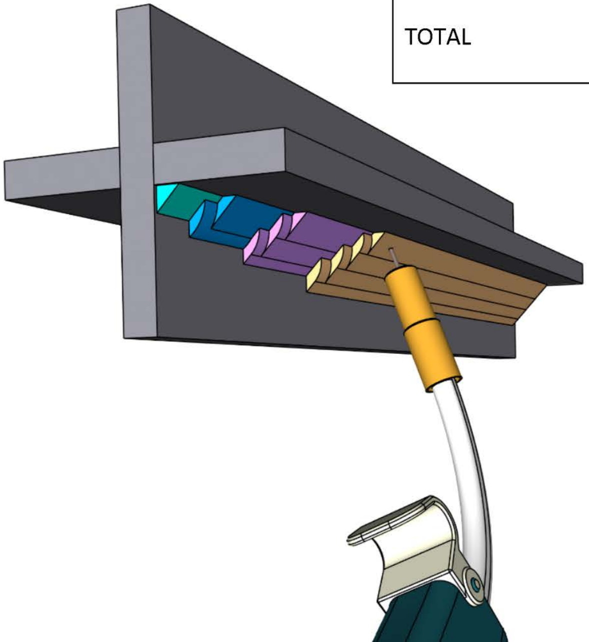
SIDE	1	2	3	4
Poor bead-to-bead contour				
Unequal leg size				
Porosity				
Slag inclusion				
Undercut				
overlap				
Arc strikes				
Hard spatter				
Poor bead contour				
Drilled/drips				
Total Minus (x ½)				
TOTAL				/20

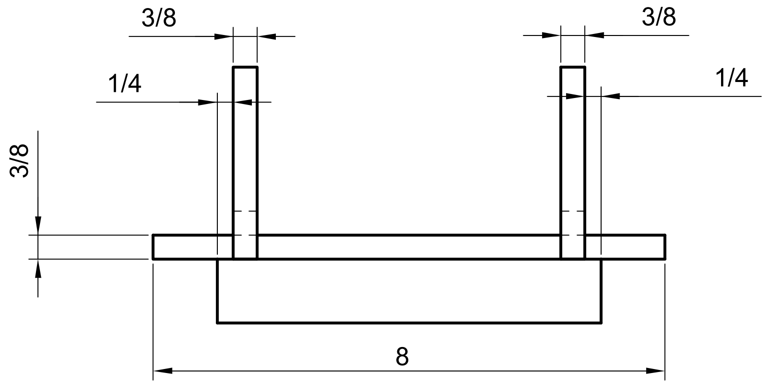


Project 4

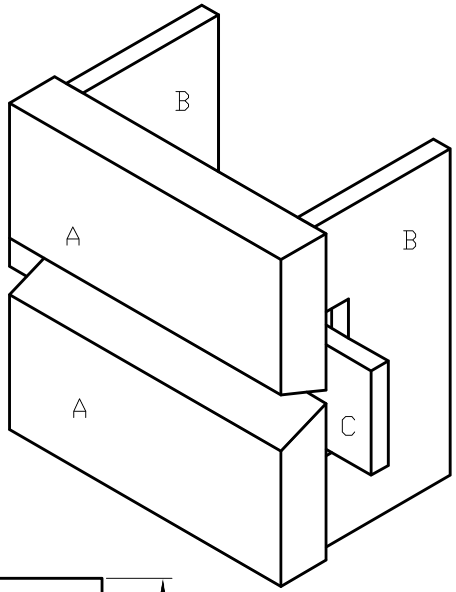
4F

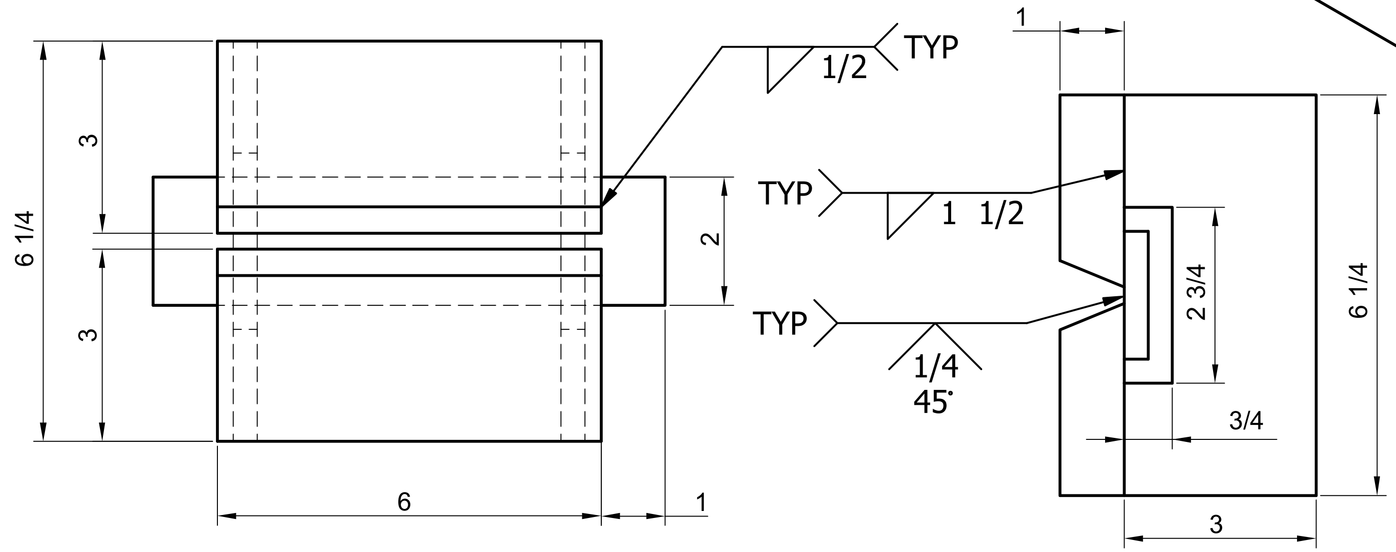
SIDE	1	2	3	4
Poor bead-to-bead contour				
Unequal leg size				
Porosity				
Slag inclusion				
Undercut				
overlap				
Arc strikes				
Hard spatter				
Poor bead contour				
Drilled/drips				
Total Minus (x ½)				
TOTAL				/20





ONE INCH GROOVE (X3)





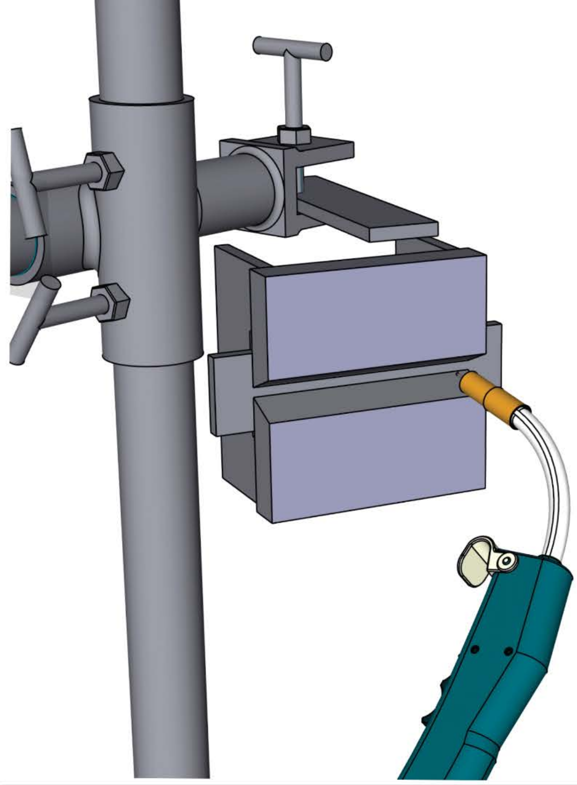
Notes:
Student will fabricate 3 sets of plates, one for each position listed in the title block.
Strong-backs are required on each set of plates.
Root pass, cover pass, and side-bends need to be inspected and graded by your instructor.

Linear Tolerances: +/-1/16
Angular Tolerances: 2°30’

Part	Quantity	Thickness	Width	Tolerance	Length	Tolerance
A	6			+ –		+ –
B	6			+ –		+ –
C	3			+ –		+ –

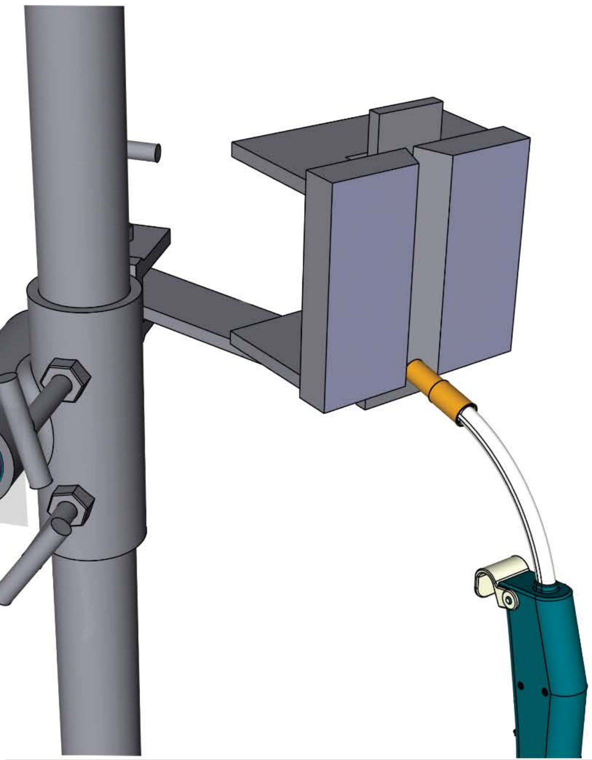
TITLE
2G, 3G, and 4G

LAST UPDATED	UNITS	SHEET
03/30/22	in	1 / 1
THIRD ANGLE PROJECTION	SCALE	SIZE
	1:3	A



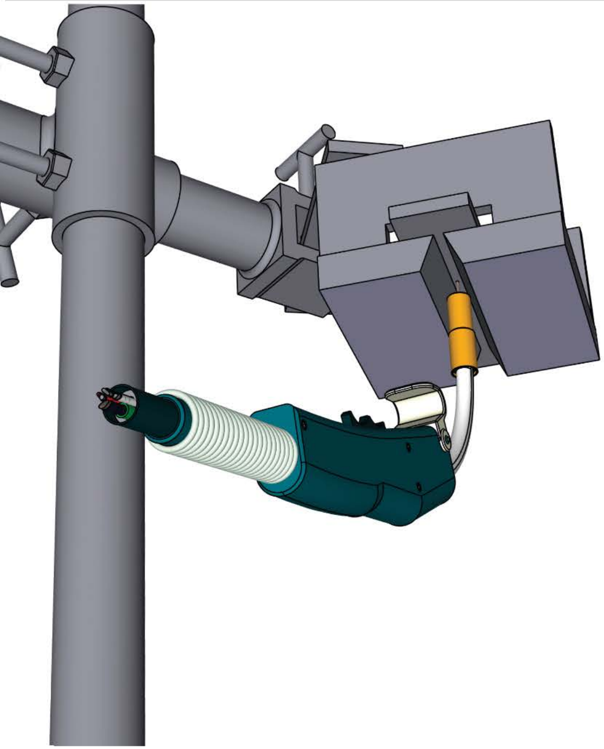
2G

ROOT			COVER			BENDS	1	2		Total
Incomplete fusion			Poor bead contour			Cracking				
porosity			Porosity			Discontinuities exceeding 1/32”				
Slag inclusion			Slag inclusion			Discontinuities exceeding 1/8”				
overlap			Overlap			Failed bend				
			Arc strikes							
			Under fill							
			Undercut							
			Excessive reinforcement							/20



3G

ROOT			COVER			BENDS	1	2		Total
Incomplete fusion			Poor bead contour			Cracking				
porosity			Porosity			Discontinuities exceeding 1/32”				
Slag inclusion			Slag inclusion			Discontinuities exceeding 1/8”				
overlap			Overlap			Failed bend				
			Arc strikes							
			Under fill							
			Undercut							
			Excessive reinforcement							/20



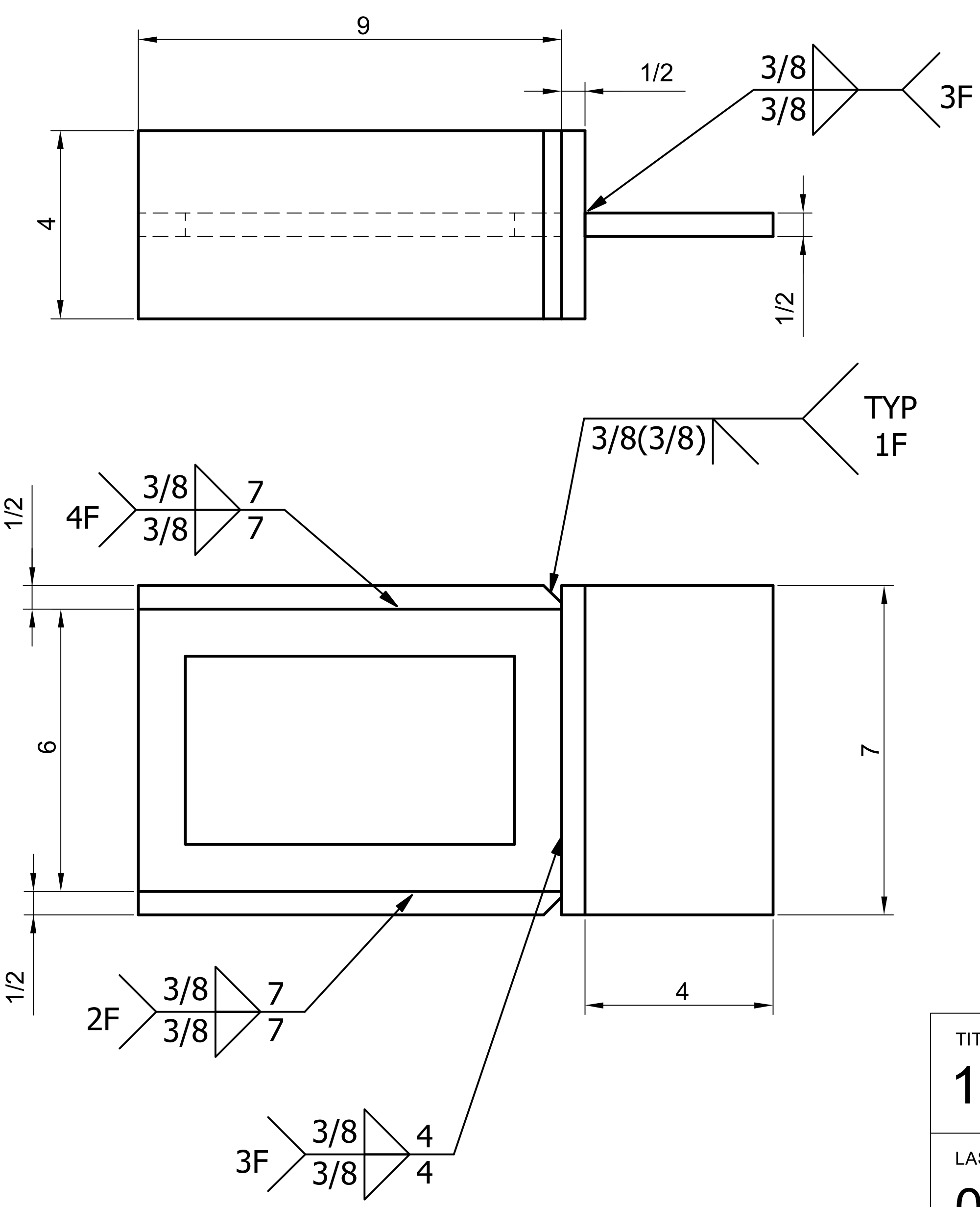
4G

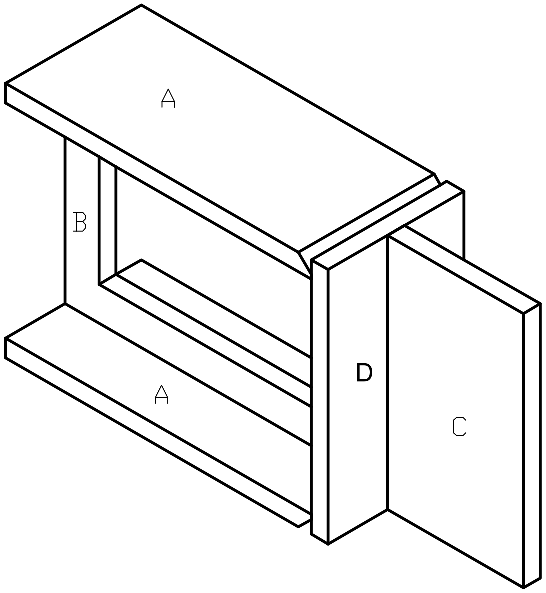
ROOT			COVER			BENDS	1	2		Total
Incomplete fusion			Poor bead contour			Cracking				
porosity			Porosity			Discontinuities exceeding 1/32”				
Slag inclusion			Slag inclusion			Discontinuities exceeding 1/8”				
overlap			Overlap			Failed bend				
			Arc strikes							
			Under fill							
			Undercut							
			Excessive reinforcement							/20

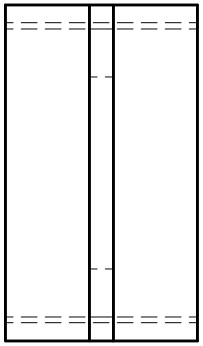
Final Exam

Part One
This portion of the final exam is a closed book test. Consult with your instructor to determine items that you may need to review. Once you determine that you are ready for the exam, request it from your instructor. Complete the exam and write all answers on the answer sheet provided. Once completed, return the exam to your instructor for grading.

Part Two
This portion of the exam is a practical test where you will fabricate and weld a weldment from a "blue print." The evaluation of this portion of the exam will be based on the rubric.







Part "C" shall be cut from the center of part "B" using the oxy-fuel hand cutting process.

Parts A, B, and D, shall be welded together before part "C" is removed from the center of part "B".

141 FINAL PRACTICAL

TITLE
141

Linear Tolerances: +/-1/16
Angular Tolerances: 2°30’

LAST UPDATED
03/30/22

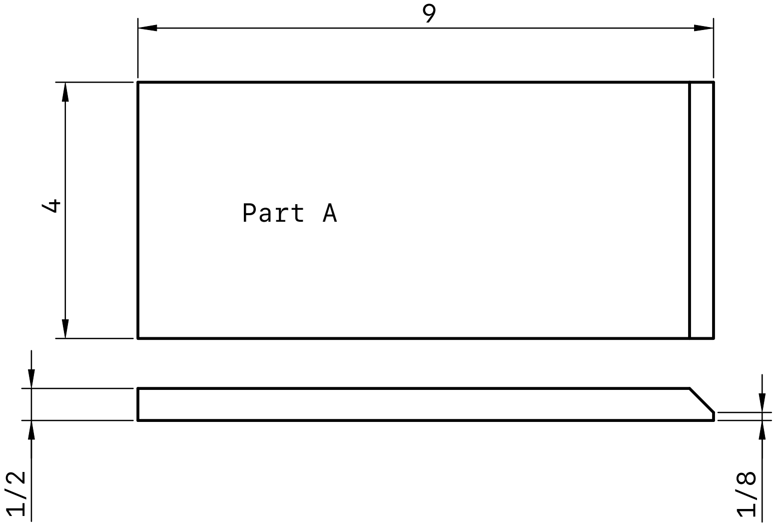
UNITS
in

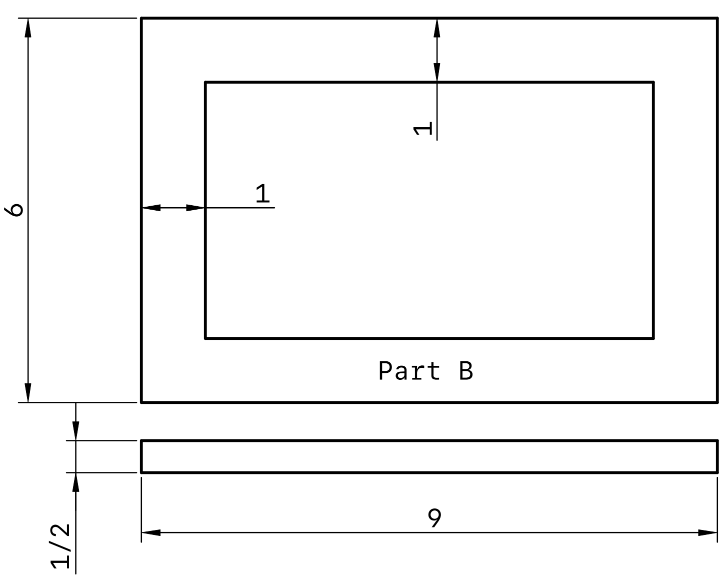
SHEET
1 / 1

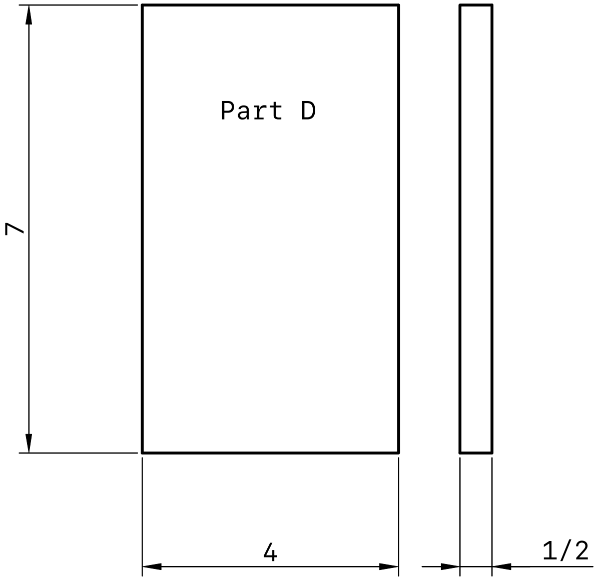
THIRD ANGLE PROJECTION

SCALE
1:4

SIZE
A







Part C is not shown. Part C shares the same dimensions as part D. Part C shall be hand cut from center of part B after joining of parts A,B,and D.

TITLE Body 03		
LAST UPDATED 03/30/22	UNITS in	SHEET 1 / 1
THIRD ANGLE PROJECTION	SCALE 1:3	SIZE A

Final Grading Rubric for practical exam
Class Name: WLD 141

Name: ___________________________________ Date: _________________________

Hold Points are mandatory points in the fabrication process, which require the inspector to check your work. You are required to follow the hold points.

Points Possible	***Hold Points***	***Instructor's Evaluation***
5 points	**Blueprint Interpretation and Material Cut List** 5 points = 0 errors, all parts labeled and sized correctly 3 points = 1 error in part sizing and/or identification 2 points = 2 errors 1 point = 3 errors 0 points = 4 or more errors	
10 points	**Material Layout and Cutting (Tolerances +/- 1/16")** 10 points Layout and cutting to +/-1/16" Smoothness of cut edge to 1/32" 7 points Layout and cutting to +/- 1/8" Smoothness of cut edge to 1/16 **REWORK REQUIRED IF OUT OF TOLERANCE BY MORE THAN 1/8 INCH**	
10 points	**Fit-up and Tack weld (Tolerances +/- 1/16")** 10 points Tolerances +/- 1/16" Straight and square to +/-1/16" 7 Points Tolerances +/- 1/8" Straight and square to +/-1/8" **REWORK REQUIRED IF OUT OF TOLERANCE BY MORE THAN 1/8 INCH**	
15 points	**Weld Quality** Subtract 1 point for each weld discontinuity, incorrect weld size and incorrect spacing sequence.	
28 points	***Minimum points acceptable. This equates to the minimum AWS D1.1 Code requirements.***	
	Total Points	**/40**

Final Grade Calculator	**Score**	**Percent**	
Projects			
Written Final/Bookwork			
Final Practical			

Final Grade:

WLD 141 FCAW: Project Assessment Form
Student Name:_________________ Date_________

Flat Position	Assessment	Instructor Signature
T-Joint		

Horizontal Position	Assessment	Instructor Signature
T-Joint		
V-Groove		

Vertical Position	Assessment	Instructor Signature
T-Joint		
V-Groove		

Overhead Position	Assessment	Instructor Signature
T-Joint		
V-Groove		