CLASSROOM STUDENT REFERENCE MATERIAL: GMAW Modes of Metal Transfer
GMAW Modes of Metal Transfer

Objectives:
1. Describe the three basic forms of metal transfer used in GMAW

Terms:

Defect: Discontinuity or discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability. See also discontinuity.

Discontinuity: An interruption of the typical structure of a weldment, such as a lack of homogeneity in the mechanical, metallurgical or physical characteristics of the material or weldment. A discontinuity is not necessarily a defect. See also defect.

Globular Transfer: A type of metal transfer in which the electrode produces a large ball of metal when it touches the workpiece. This deposits large amounts of metal into the weld puddle.

Short Circuit Metal Transfer: A type of metal transfer that occurs when the wire electrode touches the workpiece and produces a short circuit and high current. The high current level causes a violent transfer of metal, which creates the weld.

Spray Transfer: Metal transfer in which molten metal from a consumable electrode is propelled axially across the arc in small droplets.
Introduction

Having an understanding of the modes of metal transfer characteristics is essential for welding and fabrication. The modes of metal transfer have both advantages and limitations. Choosing the right process for the material to be welded will lead to faster weld times and fewer discontinuities and distortion—thus a more efficiently run fabrication shop. When mistakes are made, it costs the company time and money in rework and repairs. If the mistakes are not caught prior to the part being put into service, it could lead to future weld failure causing possible injury or, in extreme cases, death. Most employers strive to keep their shop running efficiently by employing highly skilled welders to help eliminate any rework or repairs. Welding operators with a strong welding skill set and an understanding as to why a particular mode of transfer is most effective for efficiency and quality will always be in high demand.

Short-Circuit Metal Transfer

Short-circuiting metal transfer, known by the acronym GMAW-S, is a mode of metal transfer whereby a continuously fed solid or metal cored wire electrode is deposited during repeated electrical short-circuits.

The short-circuiting metal transfer mode is the low heat input mode of metal transfer for GMAW. All of the metal transfer occurs when the electrode is electrically shorted (in physical contact) with the base material or molten puddle. Central to the successful operation of short-circuiting transfer are the diameter of electrode, the shielding gas type and the welding procedure employed. This mode of metal transfer typically supports the use of 0.025 in. - 0.045 in. (0.6 - 1.1 mm) diameter electrodes shielded with either 100% CO₂ or a mixture of 75-80% argon, plus 25-20% CO₂. The low heat input attribute makes it ideal for sheet metal thickness materials. The useable base material thickness range for short-circuiting transfer is typically considered to be 0.024 in. – 0.20 in. (0.6 – 5.0 mm) material. Other names commonly applied to short-circuiting transfer include short arc microwire welding, fine wire welding, and dip transfer.

Advantages of Short-Circuiting Transfer

• All-position capability, including flat, horizontal, vertical-up, vertical-down and overhead.

• Handles poor fit-up extremely well, and is capable of root pass work on pipe applications.

• Lower heat input reduces weldment distortion.

• Higher operator appeal and ease of use.

• Higher electrode efficiencies, 93% or more.
Limitations of Short-Circuiting Transfer

- Restricted to sheet metal thickness range and open roots of groove joints on heavier sections of base material.

- Poor welding procedure control can result in incomplete fusion. Cold lap and cold shut are additional terms that serve to describe incomplete fusion defects.

- Poor procedure control can result in excessive spatter and will increase weldment cleanup cost.

- To prevent the loss of shielding gas to the wind, welding outdoors may require the use of a windscreen(s) to prevent the loss of gas to the wind.

Description of Short-Circuiting Transfer

The transfer of a single molten droplet of electrode occurs during the shorting phase of the transfer cycle (Fig. 1). Physical contact of the electrode occurs with the molten weld pool, and the number of short-circuiting events can occur up to 200 times per second. The current delivered by the welding power supply rises, and the rise in current accompanies an increase in the magnetic force applied to the end of the electrode. The electromagnetic field, which surrounds the electrode, provides the force, which squeezes (more commonly known as "pinch") the molten droplet from the end of the electrode.

Figure 1. Short Circuit Metal Transfer

Because of the low-heat input associated with short-circuiting transfer, it is more commonly applied to sheet metal thickness material. However, it has frequently found use for welding the root pass in thicker sections of material in open groove joints. The short-circuiting mode lends itself to root pass applications on heavier plate groove welds or pipe.
Globular Transfer

Globular metal transfer is a GMAW mode of metal transfer whereby a continuously fed solid or metal cored wire electrode is deposited in a combination of short-circuits and gravity-assisted large drops. The larger droplets are irregularly shaped.

During the use of all metal cored or solid wire electrodes for GMAW, there is a transition where short-circuiting transfer ends and globular transfer begins (Typically at 125 amps [A]). Globular transfer characteristically gives the appearance of large irregularly shaped molten droplets that are larger than the diameter of the electrode (Fig. 2). The irregularly shaped molten droplets do not follow an axial detachment from the electrode; instead they can fall out of the path of the weld or move towards the contact tip. Cathode jet forces, which move upwards from the workpiece, are responsible for the irregular shape and the upward spinning motion of the molten droplets.

The process at this current level is difficult to control, and spatter is severe. Gravity is instrumental in the transfer of the large molten droplets, with occasional short-circuits.

During the 1960s and 1970s, globular transfer was a popular mode of metal transfer for high production sheet metal fabrication. The transfer mode is associated with the use of 100% CO₂ shielding, but it has also seen heavy use with argon/CO₂ blends. For general fabrication on carbon steel, it provides a mode of transfer just below the transition to axial spray transfer, which has lent itself to higher speed welding.
The use of globular transfer in high production settings is being replaced with advanced forms of GMAW. The change is being made to GMAW-P, which results in lower fume levels, lower or absent spatter levels, and elimination of incomplete fusion defects.

**Advantages of Globular Transfer**

- Uses inexpensive CO₂ shielding gas but is frequently used with argon/CO₂ blends.
- Capable of making welds at very high travel speeds.
- Inexpensive solid or metal cored electrodes.
- Welding equipment is inexpensive.

**Limitations of Globular Transfer:**

- Higher spatter levels result in costly cleanup.
- Reduced operator appeal.
- Prone to cold lap or cold shut incomplete fusion defects, which result in costly repairs.
- Weld bead shape is convex and welds exhibit poor wetting at the toes.
- High spatter level reduces electrode efficiency to a range of 87 – 93%.

**Axial Spray Transfer**

Axial spray metal transfer is the higher energy mode of metal transfer whereby a continuously fed solid or metal cored wire electrode is deposited at a higher energy level, resulting in a stream of small molten droplets. The droplets are propelled axially across the arc.

To achieve axial spray transfer, binary blends containing argon + 1-5 % oxygen or argon + CO₂, where the CO₂ levels are 18% or less. Axial spray transfer is supported by either the use of solid wire or metal cored electrodes. Axial spray transfer may be used with all of the common alloys including aluminum, magnesium, carbon steel, stainless steel, nickel alloys, and copper alloys.

For most of the diameters of filler metal alloys, the change to axial spray transfer takes place at the globular to spray transition current. A stream of fine metal droplets that travels axially from the end of the electrode characterizes the axial spray mode of metal transfer. The high puddle fluidity restricts its use to the horizontal and flat welding positions.

For carbon steel, axial spray transfer is applied to heavier section thickness material for fillets and for use in groove-type weld joints. The use of argon shielding gas compositions of 95%, with a balance of oxygen, creates a deep finger-like penetration profile, while shielding gas mixes that contain more than 10% CO₂ reduce the finger-like penetration profile and provide a more rounded type of penetration.
The selection of axial spray metal transfer is dependent upon the thickness of base material and the ability to position the weld joint into the horizontal or flat welding positions. Finished weld bead appearance is excellent, and operator appeal is very high. Axial spray transfer provides its best results when the weld joint is free of oil, dirt, rust, and mill scale.

Advantages of Axial Spray Transfer

- High deposition rates.
- High electrode efficiency of 98% or more.
- Employs a wide range of filler metal types in an equally wide range of electrode diameters.
- Excellent weld bead appearance.
- High operator appeal and ease of use.
- Requires little post weld cleanup.
- Absence of weld spatter.
- Excellent weld fusion.
- Lends itself to semiautomatic, robotic, and hard automation applications.
Limitations of Axial Spray Transfer

- Restricted to the flat and horizontal welding positions.
- Welding fume generation is higher.
- The higher-radiated heat and the generation of a very bright arc require extra welder and bystander protection.
- The use of axial spray transfer outdoors requires the use of a windscreen(s).
- The shielding used to support axial spray transfer costs more than 100% CO₂.

The welding industry is all about production, deposition rates, electrode efficiency, and bottom line. Employers want their product manufactured as fast as possible with good penetration, appearance, and no discontinuities. A lack of understanding on part of the welding operator or weld engineer could lead to major repairs, discontinuities, and defects. Having highly skilled employees with an understanding on the relationship between amperage, voltage, WFS, and CTWD with in the different modes of metal transfer is vital to producing quality welds.
CLASSROOM LESSON PLAN:
GMAW Modes of Metal Transfer
GMAW Modes of Metal Transfer

Course:  GMAW

Objective(s):
1. Differentiate between the three basic forms of metal transfer used in GMAW

Resources:
Handouts
☐ HO1: Know Your Role
☐ HO2: Know Your Role Answers
☐ AQ: GMAW Modes of Metal Transfer Assessment

Welding Lab Materials
☐ VRTEX®

Reference Materials
☐ LP1: GMAW Modes of Metal Transfer Lesson Plan
☐ SR1: GMAW Modes of Metal Transfer Student Reference
☐ PPT1: GMAW Modes of Metal Transfer Student Reference

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Spray Transfer: Metal transfer in which molten metal from a consumable electrode is propelled axially across the arc in small droplets.

Situation:
Before this lesson, students should have completed the Principles of Welding and Safety modules.
Interest Approach (Motivation):
GMAW is widely used in the welding industry due to the high production rate it produces. The modes of transfer help control the heat input while maintaining the same high production high deposition rate. Your knowledge of these modes of transfer will be vital as you begin your career in the welding industry. You might start your first job welding on a particular type of material in a given welding position for a period of time; however, you never know where you will end up. Understanding the welding processes and how the arc transfers the filler material to the base metal will be extremely important. Welding is all about controlling the arc, heat input, and distortion by identifying the best mode of transfer and shielding gas. With technology changes comes a need for smarter welder/operators.

For example: If a piece of equipment is being manufactured and the customer would like to reduce the amount of passes and have the weld bead appear flat and smooth. The company has a positioner that can rotate the part. Using your knowledge of the modes of transfer, you suggest using GMAW-P for the following reasons:

Advantages:
1. GMAW-P can be used in out of position welding.
2. Eliminates incomplete fusion defects.
3. Reduces fume levels.
4. Reduces spatter.
5. Capable of travel speeds greater than 50 IPM.
6. Reduces level of heat induced distortion.
7. Handles poor fit up.
8. Saves time.
9. Eliminates the need for a weld positioner.

Limitations:
1. Welders will have to be qualified/certified in all positions in GMAW-P.
2. New, more expensive welder or module might need to be purchased for GMAW pulsed transfer.
3. Blend of gas is more expensive to operate.

Use the VRTEX to demonstrate the two modes of metal transfer that will be discussed in the class today.
### Instructional Directions / Materials

Recommend student-inquiry method of instruction, including guided discussion, readings, and demonstration-performance.

Use examples, real examples of welds, projects, tools, supplies.

Keep it simple. The best instructors are able to clearly describe processes using basic terms, simple explanations and lots of applied examples.

Begin every lesson with a short review of previous learning—daily reviews strengthen previous learning and lead to fluent recall.

### Content Outline, Instructional Procedures and/or Key Questions

Use the lines below to record your previous material to review.

- 
- 
- 
- 
- 

Objectives:

1. Differentiate between the three basic forms of metal transfer used in GMAW

What are the five variables associated with GMAW that will be associated with modes of metal transfer?

- Voltage
- Amperage
- Wire feed speed
- CTWD
- Shielding gas

All of these variables are linked together to affect quality and performance of the GMAW weld.
Instructional Directions / Materials

Distribute HO1: Know Your Role. Have students fill in the blanks while the instructor discusses the material. (HO2: Know Your Role Answers may be used by the teacher to check responses or may be used for students who need more scaffolding.)

Content Outline, Instructional Procedures and/or Key Questions

Short Circuit Transfer

- Transfer of a single molten droplet of electrode
- Occurs up to 200 times per second
- The electromagnetic field that surrounds the electrode provides force that squeezes the molten droplet from the end of the electrode (pinch effect).
- Low heat input commonly applied to sheet metal thickness material
- Solid wire electrodes for short circuit transfer range from .020 to .045 diameter wire.

Advantages:

- All-position capability
- Lower heat input
- Higher operator appeal
- Higher electrode efficiencies
- Capability to perform root pass work on pipe
- Handles poor fit-up extremely well

Limitations:

- Restricted to sheet metal thickness range and open roots of grooves on heavier sections of base material.
- Poor welding procedure control can result in incomplete fusion.
- Welding outdoors may require windscreens.
- Poor procedure control can result in excessive spatter, and will increase weldment cleanup costs.

Teacher Tip: The short circuit transfer mode is the foundation of many advanced GMAW processes.

Short circuit transfer is used to weld exhausts on cars.

Short circuit transfer is great for welding thin material.

PPT1: Modes of Metal Transfer

Show slide #5.

Use the VRTEX to demonstrate this mode of metal transfer.

PPT1: Modes of Metal Transfer

Show slide #6. Discuss with the students the advantages and limitations of the short circuit transfer mode.
PPT1: Modes of Metal Transfer
Show slide #7 and discuss the globular transfer mode.

Teacher Tip: The use of globular transfer is being replaced by advanced forms of GMAW. The GMAW-P mode of transfer is being used due to its lower fume levels, lower spatter levels, and elimination of incomplete fusion defects.

Globular Transfer Mode:
- A continuously fed solid or metal cored wire electrode is deposited in a combination of short circuits and gravity-assisted large droplets
- Was popular mode of metal transfer for high production sheet metal fabrication during the 1960s and 1970s
- Associated with the use of 100% CO₂ shielding
- For general fabrication on carbon steel, it provides a mode of transfer just below the axial spray mode with Argon/CO₂ blends.
- Higher speed welding

Advantages:
- Uses inexpensive CO₂ shielding gas, but frequently used with argon/CO₂
- Capable of making welds at very high speeds
- Uses inexpensive solid or metal cored electrodes
- Uses inexpensive welding equipment

Limitations:
- Higher spatter levels result in costly clean up
- Cold lap or cold shut incomplete fusion defects may result in costly repairs
- Weld bead shape is convex, and weld exhibits poor wetting at the toes
- Higher spatter levels reduces the electrode efficiency to a range of 87-93%
- Reduced operator appeal
Axial Spray Transfer Mode

- A higher energy mode of metal transfer
- A continuously fed solid or metal cored wire electrode is deposited at a higher energy level resulting in a stream of small molten droplets

Advantages:

- High deposition rates
- High electrode efficiency
- Excellent bead appearance
- Little post weld clean up
- Excellent weld fusion

Limitations:

- Flat and horizontal positions only
- High radiated heat

Research:

- Why does 100% CO₂ work in the short circuit transfer mode and not with axial spray or pulsed transfer modes?
- What shielding gas characteristics need to be in place in order to achieve axial spray and pulsed transfer?

Mode of Transfer Lab:

- Students will weld using the different modes of transfer in order to understand the different arc characteristics associated with each mode.
- Students will record their data on a lab sheet that can be collected for a grade.

Knowing the characteristics of the different modes of metal transfer will be important as you begin to fabricate and build parts, machinery and equipment. Employers not only need welders, they need highly skilled welders who know how the different materials will react to the modes of transfer.
### Evaluation/Assessment:

Hand out AQ1 and read over the directions with the students.

### Assessment Key

1. A  
2. B  
3. C  
4. B  
5. D  
6. B  
7. A  
8. B
STUDENT ASSESSMENT
GMAW Modes of Metal Transfer Assessment

Name: ______________________________________ Date: ______________________

Directions: Circle the letter of the most correct answer.

1. Which mode of transfer would be best for an application where finished appearance is important?
   A. Short circuit  B. Globular  C. Axial spray  D. None of the above

2. Globular transfer should be used when cost is a large factor.
   A. True  B. False

3. Which mode of metal transfer is considered to have the highest operator appeal?
   A. Short circuit  B. Globular  C. Axial spray  D. None of the above

4. Globular mode of transfer was popular for high production sheet metal fabrication in the 1920s and 1930s.
   A. True  B. False

5. ______ metal transfer is the higher energy mode of transfer, resulting in a stream of small molten droplets.
   A. Pulse  B. Globular  C. Short circuit  D. Axial spray

6. Axial spray transfer is used mainly in the vertical and overhead positions.
   A. True  B. False

7. ______ handles poor fit-up extremely well and is capable of root pass work on pipe.
   A. Short circuit  B. Axial spray  C. Globular  D. None of the above

8. With ______ transfer mode there is little post-weld clean up, excellent weld fusion and no weld spatter.
   A. Short circuit  B. Globular  C. Axial spray  D. None of the above
LESSON PLAN HANDOUTS:
Know Your Role & Know Your Role Answers
# Know Your Role

<table>
<thead>
<tr>
<th></th>
<th>SHORT ARC</th>
<th>GLOBULAR</th>
<th>AXIAL SPRAY</th>
<th>PULSED SPRAY TRANSFER</th>
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<tr>
<td>Amperage range</td>
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<td>200A – 500A</td>
<td>200A – 500A</td>
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<td>0.035 and higher</td>
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<tr>
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# Know Your Role Answers

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LAB ACTIVITY: GMAW Modes of Metal Transfer
GMAW Modes of Metal Transfer

Objective(s):
1. Identify the arc characteristics for each mode of transfer
2. Identify the bead characteristics for each mode of transfer
3. Weld with short circuit, globular and axial spray transfer modes

Resources:

Handouts
- HO3: Modes of Metal Transfer Lab Sheet

Reference Materials
- SR1: GMAW Modes of Metal Transfer Student Reference
- LA1: Modes of Metal Transfer Lab Activity

Welding Lab Materials
- 250 Amp power source like Lincoln Electric® Power MIG® 250, Power MIG®350 MP, or Power Wave® C300
- VRTEX®
- Regulator
- Steel plate
- Wire brush
- Shielding:
  - Argon 75%/CO2 25%
  - Argon 90%/CO2 10%
- Wire/Electrode:
  - .035 in. (.9 mm) SuperArc® L-56
  - .045 in. (1.1 mm) SuperArc® L-56
- Wire cutters
- Pliers
- 4 in. grinder
- PPE

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Spray Transfer: Metal transfer in which molten metal from a consumable electrode is propelled axially across the arc in small droplets.

Course: GMAW  Estimated Time: Two 50-minute periods
**Situation:**
In this lab, students will weld with the three common modes of metal transfer: short circuit metal transfer, globular metal transfer and axial spray metal transfer. The students will record their data on the lab sheets and compare the arc characteristics for each mode.

**Interest Approach (Motivation):**
The welding industry is all about production, deposition rates, electrode efficiency and bottom line. Employers want their product manufactured as quickly as possible with good weld appearance and no discontinuities.
Use the VRTEX® to demonstrate to the students the short circuit transfer and axial spray transfer modes of metal transfer. Describe the following as you set up the machine:

- Machine settings
- Shielding gas
- All positions
- Unique characteristics

Review the modes of transfer with the students.
Be sure to point out proper welding techniques.

Virtual Lab
Station 1

Set the VRTEX® 360 to WPS#2010114

Short Circuit Transfer
Description: Flat bead on plate (stringers)
Wire/Electrode: .035 Super Arc® L-56
Gas: 75% Argon/25% CO₂ or 100% CO₂
Gas Flow: 25-35 CFH
Plate Thickness: 1/4 in.
IPM: 250
Voltage: 18
Polarity: DC+
CTWD 3/8 in.

Set the VRTEX® 360 to WPS#2010214

Axial Spray Transfer
Description: Flat bead on plate (stringers)
Wire/Electrode: .045 Super Ar®c L-56
Gas: 90% Argon/10% CO₂
Gas Flow: 25-40 CFH
Plate Thickness: 1/4 in.
IPM: 400
Voltage: 27
Polarity: DC+
CTWD 1/2 in.
**Instructional Directions / Teaching Tips / Materials**

- Have the students practice welding on the VRTEX before moving into the live welding lab.

- Prior to the students welding, the instructor should set up the booths for stations 2, 3 and 4. The students should not know which machine is set up for which mode of transfer. Students will decide which mode corresponds to which booth based on the arc characteristics, spatter level, bead shape and appearance.

  **Station 2: Short Circuit Transfer**
  **Station 3: Globular Transfer**
  **Station 4: Axial Spray Transfer**

- Depending on class size, the number of booths to be set up will vary.

**Live Welding Lab**

**Station 2**

- Short Circuit Metal Transfer

  - **Description:** Flat bead on plate (stringers)
  - **Wire/Electrode:** .035 Super Arc® L-56
  - **Gas:** 100% CO₂
  - **Gas Flow:** 30-50 CFH
  - **Plate Thickness:** 1/4 in.
  - **IPM:** 220 - 235
  - **Voltage:** 18
  - **Polarity:** DC+
  - **CTWD:** 3/8 in.
### Instructional Directions / Teaching Tips / Materials

To achieve this mode, the current must be between 125-150A. Make sure you are using the proper setting.

**Station 3**

Globular Metal Transfer

Description: Flat bead on plate (stringers)

Wire/Electrode: .035

Gas: 75%Argon / 25%CO₂

Gas Flow: 25-35 CFH

Plate Thickness: 1/4 in.

IPM: 240 - 260

Voltage: 20-22

Polarity: DC+

CTWD: 3/8 in.

**Station 4**

Axial Spray Metal Transfer

Description: Flat bead on plate (stringers)

Wire/Electrode: .045 Super Arc® L-56

Gas: 90%Argon/10%CO₂

Gas Flow: 25-40 CFH

Plate Thickness: 1/4 in.

IPM: 400

Voltage: 26.5

Polarity: DC+

CTWD: 1/2 in.- 5/8 in.

**Science:** Describe the relationship between the voltage, amperage, WFS, and CTWD for the different modes of metal transfer.

**STEM Connection**

Students will be challenged by this mode of metal transfer. They will have to adjust their CTWD to find the "sweet spot."
### Instructional Directions / Teaching Tips / Materials

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<tbody>
<tr>
<td><strong>Closure / Summary:</strong></td>
</tr>
<tr>
<td>Knowing the characteristics of the different modes of metal transfer will be important as you begin to fabricate and build parts, machinery, and equipment. Employers not only need welders, they need highly skilled welders who know how the different materials will react to the modes of transfer.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Evaluation/Assessment:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The instructor will assess whether the student was able to weld in each of the modes of metal transfer.</td>
</tr>
<tr>
<td>2. The instructor will collect the lab sheets and evaluate the student's observations.</td>
</tr>
</tbody>
</table>
LAB ACTIVITY HANDOUTS:
Modes of Metal Transfer
Modes of Metal Transfer

Name: ___________________________ Date: __________________

In today's lab, you will weld with three modes of metal transfer: short circuit, globular and axial spray. As you make a weld on a plate of mild steel, pay close attention to the arc and bead characteristics. Record these on the lab sheet.

Directions:

1. Form groups of two or three, depending on class size.
2. Dress out in all required safety PPE.

Station 2:

1. Which mode of transfer is being performed in Station 2? (Circle)
   - Short Circuit
   - Globular
   - Axial Spray

2. Amount of spatter: □ None □ Slight □ Moderate □ Excessive

3. Bead shape: □ Convex □ Concave □ Flat

4. Describe some of the arc characteristics:

   __________________________________________________________
   __________________________________________________________
   __________________________________________________________

5. Describe the bead appearance:

   __________________________________________________________
   __________________________________________________________
   __________________________________________________________

Station 3:

1. Which mode of transfer is being performed in Station 3? (Circle)
   - Short Circuit
   - Globular
   - Axial Spray

2. Amount of spatter: □ None □ Slight □ Moderate □ Excessive

3. Bead shape: □ Convex □ Concave □ Flat

4. Describe some of the arc characteristics:

   __________________________________________________________
   __________________________________________________________
   __________________________________________________________

5. Describe the bead appearance:

   __________________________________________________________
   __________________________________________________________
   __________________________________________________________
Modes of Metal Transfer

Station 4:

1. Which mode of transfer is being performed in Station 4? (Circle)
   - Short Circuit
   - Globular
   - Axial Spray

2. Amount of spatter:
   - None
   - Slight
   - Moderate
   - Excessive

3. Bead shape:
   - Convex
   - Concave
   - Flat

4. Describe some of the arc characteristics:______________________________________________________

5. Describe the bead appearance: _________________________________________________________________


WELD LESSON PLAN:
Short Arc Flat Bead on Plate 1/4 in.
Short Arc Flat Bead on Plate 1/4 in.

Objective:
Perform a bead on plate on 1/4 in. mild steel using a GMAW short arc welding process to the standards described on the weld grading rubric provided.

Materials

Handouts
- WPS Sheet #2010114
- HO1: Weld Inspection Checklist
- HO2: VRTEX® Lab Work

Reference Materials
- Short Arc Flat Bead on Plate 1/4 in. demo video
- Lincoln Electric® GMAW Welding Guide (C4.200)

Welding Lab Materials
- 1/4 in. (6.35 mm) mild steel plate welding coupons (2 in. x 6 in. or 50.8 mm x 152.4 mm preferred)
- Constant voltage power source
- Chipping hammers
- Wire brushes
- SuperArc® L-56 (ER70S-6); .035 in. (.89 mm); 75/25
- Vise grips
- Flush nozzle

Terms
- ARC CONTROL
- CONTACT TO WORK DISTANCE
- ELECTRICAL STICK OUT
- CONTACT TIP
- INDUCTANCE
- NOZZLE
- PINCH
- WIRE FEED SPEED (WFS)
- VOLTAGE
- POLARITY

Situation
Prior to this lesson, students should have completed all safety lessons and successfully passed the welding safety exams.

Interest Approach (Motivation)
In this lesson students will learn how to successfully initiate the arc and run a stringer bead. Show the Short Arc Flat Bead on Plate 1/4 in. weld video. Mastering this skill will allow the student to successfully complete other welds more quickly.
Hand out the WPS sheet #2010114 and review the weld requirements.

It is not important to review all the specifications of the WPS at this time. Specifications will be highlighted as they are required by different welds.

Important weld requirements for a short arc flat bead on 1/4 in. mild steel plate:

1. Welding process
2. Type of welding process
3. Joint design used
4. Welding on both sides
5. Material thickness
6. Filler material requirement
7. Position
8. Polarity to be used
9. Power source type
10. Welding technique
11. Welding procedure

Before starting the weld, review how to set up and use the VRTEX machine.

1. Turning on the VRTEX
2. Setting the VRTEX
3. Selecting the variables (already set)
4. Performing a weld with the VRTEX

Demonstration steps:

1. Describe the weld that is going to be completed:
   a. Short arc flat bead on 1/4 in. mild steel using the short arc process
2. Describe the proper techniques used to make a sound weld, including all of the following steps.
   a. Push travel angle: 10 to 15 degrees (deg.)
   b. Work angle: 90 deg.
   c. Wire feed speed: 250 (6.3 m/min)
   d. Volts: 18 V
   e. Aim (will impact penetration in root)
   f. Stringer technique
### Setting up the demonstration

Connect VRTEX to screen so that all students can see teacher demonstrate the weld.

Demonstrate the travel angle, work angle, aim and electrode placement for the welder.

Demonstrate first pass. Review first pass with students.

Padding is a common welding application. It is necessary to build up metal surfaces with one or more layers of weld deposit. Rebuilding a worn surface and repairing a machining error are two such applications. This work may be done on either flat or curved surfaces by depositing overlapping straight beads or weave passes.

To help reinforce the previous topics, use the pause function. This will freeze the replay and give time to discuss that part of the weld.

Make sure that the students have a clear view of the weld you are making.

Important: All of the important welding variables for using the VRTEX are also important in welding using a real welder.

1. Place the welding helmet on your head.
2. Clean and prepare 1/4 in. (6.35 mm) mild sheet metal base material.
3. Set up the welding machine: DC+ Polarity, Gas 75/25, CFH 25 to 35, WFS 250, voltage 18, CTWD 3/8 in. (9.53 mm); increase by 2 V for CO₂ gas.
Make sure that all students have proper face shields and safety glasses for the demonstration.

Go over the power source/wire feeder. Show how to position head to maintain a good view of the puddle.

Describe pass 1.

Weld first pass.

Evaluation

---

4. Assume a position that permits you to see behind and ahead of the puddle so that corrections can be made while welding.

5. Check area for flammables and potential obstacles.

PASS 1: First pass

1. Describe the weld that is going to be completed:
   a. Short arc flat bead on 1/4 in. mild steel using the short arc process.

2. Describe the proper techniques used to make a sound weld:
   a. Push Travel angle 10 to 15 deg.
   b. Work angle 90 deg.
   c. Aim (will impact penetration in root)
   d. Stringer bead

3. Place the welding helmet on your head.

4. Clean and prepare 1/4 in. (6.35 mm) mild sheet metal base material.

5. Set up the welding machine: DC+ Polarity, Gas 75/25, CFH 25 to 35, WFS 250, voltage 18, CTWD 3/8 in. (9.53 mm); increase by 2 V for CO₂ gas.

6. Position body so both the beginning and end of the weld can be reached comfortably.

7. Using a 90 deg. work angle and a 10 to 15 deg. push travel angle, make the first pass using a stringer technique. A slight oscillation can be used to smooth the bead out.

8. Clean the weld and visually inspect.

9. While welding for students be sure to demonstrate the following:
   a. Weld 50% with good technique.
   b. Travel fast.
   c. Travel slowly.
   d. Use incorrect angles.

10. Inspect the weld with the class and look for uniformity and discontinuities.

11. Instruct students to identify the good and bad elements of the weld.
### Instructional Directions / Materials

Be aware of common issues for students first attempting a short arc flat bead on 1/4 in. mild steel with a ER70S-6.

### Content Outline, Instructional Procedures and/or Key Questions

Guidelines below address common issues for students first attempting this weld:

1. Travel speed may be too high (ropy or string like bead).
2. Amperage may be too high (excessive spatter and wide flat bead).
3. Weld size may be inconsistent (a result of inconsistent speed)
4. WFS and voltage may be set incorrectly.

Instruct student to weld with opposite hand, making the pad as flat as possible. Make sure there are no crevices.

Depending on the number of VRTEX units available, the unit can be used in many ways to improve the students’ success in building a pad using the short arc process.

1. To teach proper welding technique:
   a. Use visual cues (aim, travel speed, position, etc).
   b. Use replay mode and have students critique their welds.
2. Technique Troubleshooting
   a. Have the student make a weld while watching the helmet cam on the monitor.
   b. Make sure that the students’ body position is not allowing the electrode clamp or other objects to block the view of the puddle.
   c. Use visual cues to aid in correcting technique problems.
3. Have students complete a series of welds on the VRTEX and save the LASER screen to the USB for later use.
   a. Use HO3: VRTEX Lab Work and have the students record their scores and reflect on how to better accomplish the weld.

### Application

Students building a pad using the short arc process

Time welding with the VRTEX

### Closure/Summary

Review technique and troubleshooting

### Evaluation

Grade 5 welds using the appropriate weld grading rubric
Weld Inspection Checklist

Name: ____________________________  Date: ____________________________

Directions: Read the information below. Keep this handout for future reference.

Now that you have made some welds it is time to evaluate them. Evaluation of welds is a critical part of becoming a welder. Being able to distinguish between a good weld and a bad weld starts with a visual inspection. Visual inspections are fast and inexpensive. At a basic level, only good eyesight, good lighting and some welding knowledge are required.

Table 1-1: Scoring a Weld

<table>
<thead>
<tr>
<th>WELD ID</th>
<th>FACE (fillet welds only)</th>
<th>PLACEMENT</th>
<th>UNIFORMITY</th>
<th>UNDERCUT</th>
<th>OVERLAP</th>
<th>POROSITY</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Concave Flat Convex</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Concave Flat Convex</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Concave Flat Convex</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Concave Flat Convex</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Concave Flat Convex</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>2</td>
</tr>
</tbody>
</table>

Total

What to Do:

Perform a visual inspection on five welds that you have created in this activity by using the chart provided. Numerically identify your weld and follow the steps below.

STEP 1: For a fillet weld, the face of the weld might be flat, concave (sunken inward like a valley), or convex (shaped like a hill). A flat or slightly convex shape is preferred in most cases. Does the face of the weld you are inspecting have a concave, flat, or convex shape?

STEP 2: A good weld also is placed properly in the joint and should have the same amount of weld on both sides. Does your weld have good placement in the joint?

STEP 3: Welds that are the same size and shape from one end of the joint to the other are said to be uniform. Is your weld uniform from one end to the other?

STEP 4: Undercut at the toe can cause a weaker joint caused by improper machine settings and technique. Overlap can also weaken the joint by showing a lack of fusion. Can you see undercut and/or overlap in the weld that you are evaluating?

STEP 5: Porosity can be caused by dirty material or because the molten puddle was not shielded. Does the weld have any porosity?
Welding Lab Work

Name: ____________________________ Date: __________________

Directions: Follow the directions below to complete the welding lab work for this lesson.

Exercise A: Short Arc Flat Bead on Plate 1/4 in.

PASS 1
The travel angle should be 10 to 15 deg.
Work angle should be 90 deg.
1. Place the welding helmet on your head.
2. Clean and prepare 1/4 in. (6.35 mm) mild sheet metal base material.
3. Set up the welding machine: DC+ Polarity, Gas 75/25, CFH 25 to 35, WFS 250, voltage 18, CTWD 3/8 in. (9.53 mm); increase by 2 V for CO₂ gas.
4. Position body so both the beginning and end of the weld can be reached comfortably.
5. Using a 90 deg. work angle and a 10 to 15 deg. push travel angle, make the first pass using a stringer technique. A slight oscillation can be used to smooth the bead out.
6. Clean and visually inspect the weld.
VRTEX® Lab Work

Name: ____________________________________________ Date: _______________________

**Directions:** Follow the directions below to complete the VRTEX® lab work for this lesson.

**Exercise A:** Weld a bead on plate using mild steel plate in the flat position with ER70S-6 in virtual reality.

Set up the VRTEX stand with the steel plate coupon in the flat position and adjust the arm and table so that you can comfortably use the VR welding gun on the coupon.

1. Make a practice weld to ensure that your body position allows you to weld comfortably from the beginning to the end of the weld.

2. Configure the VRTEX to weld a bead on a steel plate in the flat position with a .035 in. (.89mm) ER70S-6 electrode.

3. Using NEXT, change the image on the monitor to the LASER screen. If others are watching, you may want to use a different screen.

4. Use the welding technique described in the WELDING LAB WORK to completely weld this joint.

5. Select End Pass to receive your scores for this weld.

6. Record the scores from your first weld on the line to the right of each category.

7. Select New Coupon to receive a new weld coupon.

8. If needed, select Actions and Cues to trim the wire.

9. Weld the joint again and record your performance from the LASER screen.

**Reflection**

Think of some changes you could make to improve your scores. List them below.

__________________________________________

__________________________________________

Make a second weld using the changes listed above. Record your scores below.

**Position**

__________________________________________

**CTWD**

__________________________________________

**Work Angle**

__________________________________________

**Travel Angle**

__________________________________________

**Travel Speed**

__________________________________________

Compare the scores from your first weld to those from your second weld. Were the changes you made effective? Use the space below to explain.

__________________________________________

__________________________________________
Welding Procedure Specification (WPS) Instructor's Key

Company Name: Sample
Welding Process: GMAW

Type: Manual

JOINT DESIGN USED
Type: Lap

Welding Process: GMAW

Identification # Sample
Revision: Date: By
Authorized by: Date:
Supporting PQR No.(s)

POSITION 7
Groove: N/A Fillet: Double Weld
Vertical Progression: Up Down

ELECTRICAL CHARACTERISTICS
Transfer Short Circuit
Mode: Spray Pulse
Other: N/A
Current: AC DCEP DCEN
Power Source: CC CV
Tungsten Electrode (GTAW):
Size: Type:

BASE MATERIAL
Material Spec: ASTM A36
Type or Grade: N/A
Thickness: Groove: N/A Fillet: 10 ga (3.2 mm)

FILLER METALS
AWS Specification: A5.1
AWS Classification: ER70S-6 Size: XXX

SHIELDING
Electrode Flux (Class): N/A Gas: N/A
Composition: N/A
Flux: N/A Flow Rate:
Gas Cup Size:

WELDING PROCEDURE

<table>
<thead>
<tr>
<th>Pass or Weld Layer(s)</th>
<th>Technique</th>
<th>Filler Metals</th>
<th>Current</th>
<th>Travel Speed</th>
<th>Joint Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stringer</td>
<td>ER70S-6</td>
<td>DC-</td>
<td>105±15</td>
<td></td>
</tr>
</tbody>
</table>

Electrode Flux (Class):
Gas: N/A
Composition: N/A
Flow Rate:
Gas Cup Size:
# Welding Procedure Specification (WPS)

**Company Name:**  

**Welding Process:** GMAW

**Type:**  
- □ Manual  
- □ Semi-Automatic  
- □ Machine  
- □ Automatic

## JOINT DESIGN USED

**Type:**  
- □ Lap  
- □ T  
- □ Butt  
- □ Corner  
- □ Edge

- □ Single Weld  
- □ Double Weld

**Back Gore:**  
- □ Yes  
- □ No

**Root Opening:**  
- N/A

**Root Face Dimension:**  
- N/A

**Groove Angle:**  
- N/A

**Back Gouging:**  
- □ Yes  
- □ No

**Method:**  
- N/A

## BASE MATERIAL

**Material Spec:**  
- ASTM A36

**Type or Grade:**  
- N/A

**Thickness:**  
- 1/4”

**Groove:**  
- N/A

**Fillet:**  
- N/A

## FILLER METALS

**AWS Specification:**  
- A5.1

**AWS Classification:**  
- ER70S-6

## SHIELDING

**Electrode Flux (Class):**  
- N/A

**Gas:**  
- Argon/CO₂

**Composition:**  
- 75/25

**Flux:**  
- N/A

**Flow Rate:**  
- 25-35 cfh (12-16.5 l/min)

**Gas Cup Size:**  
- N/A

## ELECTRICAL CHARACTERISTICS

**Transfer:**  
- □ Short Circuit  
- □ Globular

**Mode:**  
- □ Spray  
- □ Pulse

**Current:**  
- □ AC  
- □ DCEP  
- □ DCEN

**Power Source:**  
- □ CC  
- □ CV

**Tungsten Electrode (GTAW):**  
- Size:  
- Type:  
- N/A

## TECHNIQUE

**Stringer, Weave Bead, Other:**  
- Stringer

**Multi- or Single-Pass (per side):**  
- Single Pass

**Number of Electrodes:**  
- Single

**Contact Tip to Work Distance:**  
- 3/8” (10 mm)

**Peening:**  
- □ Yes  
- □ No

**Interpass Cleaning:**  
- □ Yes  
- □ No

**Cleaning Method:**  
- Chipping Hammer and Wire Brush

## PREHEAT

**Preheat Temp:**  
- Min: N/A  
- Max: N/A

**Interpass Temp:**  
- Min: N/A  
- Max: N/A

## WELDING PROCEDURE

<table>
<thead>
<tr>
<th>Pass or Weld Layer(s)</th>
<th>Technique</th>
<th>Filler Metals</th>
<th>Current</th>
<th>Volts (V)/Trim</th>
<th>Travel Speed</th>
<th>Joint Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stringer</td>
<td>ER70S-6</td>
<td>DC⁺</td>
<td>250.0 ipm (6.4 m/min)</td>
<td>18.0</td>
<td>5.5 ipm±10% (0.14 m/min)</td>
</tr>
</tbody>
</table>