ESPL Welding Training Course

Processes Allowed at ESPL:

- **TIG (Tungsten Inert Gas)**
- **MIG (Metal Inert Gas)**
- **Oxyacetylene annealing**
- **Soldering**

Topics Covered:
1. Theory
2. Operation and Best Practices
3. Welding Safety

- No “Stick” welding
- No welding of Stainless Steel
- No welding of Galvanized Steel

To learn more thoroughly about welding, consider taking TSM 233, 3hrs
“Joining” classifications

1) Welding (permanent)
- Solid state welding
- Fusion welding
  - Electrical energy (aka arc welding)
    - Consumable electrode
    - Non-consumable electrode
  - Friction welding
2) Soldering and Brazing (non-permanent)
  - Electromagnetic
    - Laser beam welding
    - Electron Beam welding
  - Chemical energy
    - Thermit welding
    - Oxyfuel welding

Soldering and brazing

- Alternative to welding that uses a filler metal between the parts.
- The entire joining area must be heated uniformly.
- Used when:
  - Metals have poor weldability
  - Dissimilar metals are to be joined
  - Intense heat of welding may damage components
  - Geometry of joint not suitable for welding
  - High strength is not required
- Brazing definition: filler metal $T_m > 450°C$ (840°F)
- Solder definition: filler metal $T_m < 450°C$ (840°F)
Brazing and soldering fluxes

- They dissolve or inhibit formation of oxides on the metal surface.
- Displaced by filler metal and facilitates wetting of filler metal.
- Required by virtually all soldering/brazing methods
  - Flux fumes are very dangerous, you must use snorkel ventilation, a fume hood, or fume capture.

Soldering & brazing at ESPL

- Only lead-free solders are allowed – with vapor capture and/or ventilation of flux fumes.
- Brazing requires too high a temperature to safely teach at ESPL and is more difficult since it requires the entire joint to be very evenly heated. Find a professional to do this for you.
Why no stick welding at ESPL?

- Stick welding, or SMAW, uses a flux coated consumable electrode, not a shielding gas to prevent oxides.
- According to OSHA, stick flux fumes are quite noxious:
  - MIG and TIG are less chemically dangerous because they can be done without using Flux.

ARC Welding in Decreasing Fume Production and Risk:

[Link to OSHA publication]

MIG (Metal Inert Gas) welding

- Accounts for about 50% of all welds
- Consumable wire electrode fed through a welding gun surrounded by an inert gas.
- Wire metal is the same metal as part;
- Argon gas with 25% CO₂ is required to do MIG welding at ESPL

[Link to fabrication welding page]
Current arcs between the filler rod and the part surface carrying charged molten metal droplets with it. Filler rod has inert gas flowing around it at all times.

TIG (Tungsten Inert Gas) welding

- Non consumable tungsten electrode.
- Welding can be done with or without filler metal.
- If filler metal is used, it is supplied typically as a stick.
Tungsten electrode is on the left and stays out of the molten pool. Filler rod is on right and goes in and out of molten pool. Direction is to the right.

Advantages and disadvantages

**MIG**

Pro:
- Faster welding
- Easier to learn

Con:
- Weld splatter
- Greater part distortion

**TIG**

Pro:
- Precision welding
  (smaller spot size)
- Can do thinner parts

Con:
- More dexterity required
- Slower process
Types of weld joints:

**Butt joint:** parts lie in same plane and are joined at their edges

**Corner joint:** parts form a right angle and are joined at the corner

**Lap joint:** consists of two overlapping parts

**Tee joint:** one part is perpendicular to the other. Weld on one or both sides.

**Edge joint:** parts parallel with at least one edges in common. The weld is made along the common edge.
Typical “groove” welds on butt joints:

- One or more edges can be beveled to facilitate the weld penetration. Dashed lines show original part edges.

(a) no bevel; (b) one-sided bevel; (c) both parts beveled; (d) U-groove bevel;
(e) single-sided U-bevel; (f) double sided bevels for thicker parts.

Typical “fillet” welds

- Filler metal used to form weld creates a right-triangle cross section. Minimal edge preparation needed.

(a) inside fillet corner joint; (b) outside fillet corner joint; (c) double fillet lap joint; and
(d) double fillet tee joint.
Weld quality problems:

1. Residual stresses and distortion
   - Due to rapid heating and cooling of small regions

2. Welding defects
   - Cracks, slag inclusions, cavities and incomplete penetration.

Weld distortion

- Part material will be consumed and weld area contracts:
Welding defects: incomplete fusion & distortion

(a) Incomplete fusion in fillet welds. B is often termed 'bridging'.
(b) Incomplete fusion from oxide or dross at the center of a joint, especially in aluminum.
(c) Incomplete fusion in a groove weld.

Angular distortion
Transverse shrinkage
Longitudinal shrinkage
Neutral axis

Welding defects: cracks

- Visible after shrinkage during solidification.

Transverse crack
Longitudinal crack
Underbead crack
Toe crack
Welding defects: cracks

- Crater cracks
- Toe crack
- Transverse crack
- Base metal
- Uncrushed crack
- Longitudinal crack
- Weld

(a)

Welding defects: cavities

- Caused by incomplete fusion of parts:

Incomplete fusion
Welding defects: penetration

(a) Underfill
Inclusions
Crack
Base metal
Incomplete penetration

(b) Overlap
Porosity
Undercut
Lack of penetration

(c) Good weld

Design advisor (i.e. green/blue are better, red is not)

Welding

(a) Load
(b) Load

(c) Cut not square
(d) Burr
Deburred edge

(e) Surface to be machined

Soldering
Weld inspection and testing

- Inspection methods – generally non-destructive
  - Visual inspection of surface for cracks and inclusions.
  - Ultrasound or x-rays to look for cracks and voids below the surface.
- Testing – generally destructive
  - Common tensile and shear tests:

![Diagrams of weld inspection methods](image)

Thermal changes and weld defects

Cross section of a typical fusion welded joint: (a) principal zones in the joint, and (b) typical grain structure.

![Cross section diagrams](image)

Mechanical properties are generally weaker in the HAZ (Heat Affected Zone), and this is typically were failures occur.
OxyFuel (e.g. oxyacetylene) flame temperature

Flame formed by acetylene (C₂H₂) and oxygen produces the highest flame temperature.

(a) Neutral flame
- 1:1 ratio of gases
- 2100°C (3800°F)
- 3040 to 3300°C (5500 to 6000°F)
- Inner cone
- Outer envelope

(b) Oxidizing flame
- Oxygen rich
- Bright luminous inner cone

(c) Carburizing (reducing) flame
- Acetylene rich
- Blue envelope

Table 0-1: Oxyacetylene Flame Temperatures

<table>
<thead>
<tr>
<th>Ratio of Oxygen to Acetylene</th>
<th>Type of Flame</th>
<th>Temperature °C</th>
<th>Temperature °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8 to 1.0</td>
<td>Carburizing</td>
<td>3065</td>
<td>5550</td>
</tr>
<tr>
<td>0.9 to 1.0</td>
<td>Carburizing</td>
<td>3150</td>
<td>5700</td>
</tr>
<tr>
<td>1.0 to 1.0</td>
<td>Neutral</td>
<td>3100</td>
<td>5600</td>
</tr>
<tr>
<td>1.5 to 1.0</td>
<td>Oxidizing</td>
<td>3427</td>
<td>6200</td>
</tr>
<tr>
<td>1.8 to 1.0</td>
<td>Oxidizing</td>
<td>3482</td>
<td>6300</td>
</tr>
<tr>
<td>2.0 to 1.0</td>
<td>Oxidizing</td>
<td>3379</td>
<td>6000</td>
</tr>
<tr>
<td>2.5 to 1.0</td>
<td>Oxidizing</td>
<td>3315</td>
<td>6000</td>
</tr>
</tbody>
</table>

OxyFuel (e.g. oxyacetylene) part identification

Diagram showing parts and components of an oxyfuel setup.
Oxyacetylene: lighting and setting the torch

1. Make sure your environment is free of flammable material
2. Open both gas cylinders, check for sufficient pressure.
3. Open “Oxy” valve on the torch, and set the output pressure of the oxygen gas to ~10 psi.
4. Clock-wise turning, increases regulator output pressure.
5. Close “Oxy” valve on the torch, open the “fuel” valve and set the output pressure to ~5 psi.
6. With the fuel flowing use the striker to light a flame.
7. Open “Oxy” valve and adjust to achieve a sharply defined inner cone with no outer feather.
8. When shutting down, first close the oxygen valve.

Welding

2. Operation & best practices
Ways to minimize weld warpage

• Use welding *fixtures* to physically restrain parts
• Use *heat sinks* to rapidly remove heat
• *Tack weld* at multiple points before seam welding
• *Preheat* base parts, primarily aluminum
• *Stress relief* by annealing after welding
• Weld material in *small increments*

Pre-setting parts to prevent distortion

Parts are pre-set by a pre-determined amount (often determined by experience) so that after welding parts are aligned correctly.
Melting and heating to remove distortion

Localized heating or melting can remove buckling in thin parts, or on the backside of a fillet welds can straighten angular distortions.

TIG welding part identification
TIG welding electrical settings

Typically use 1 amp for each 0.001” of metal thickness

Use DC for welding steel or AC for welding Aluminum

TIG and MIG ground clamp

- Completes the circuit, allows electrode to arc and allows electricity to flow through the part.

- Should be clamped as close to work piece as possible
TIG welding gas tank part identification

Typically gas pressure to the torch is 15-20 cubic feet per hour (cfh).

Incorrect gas glow causes inclusions & porosity

- Pressure should be adjusted to achieve between 15-25 cubic feet per hour (cfh).
- Don’t assume a higher rate is better. High flow rates can create turbulence that pulls in contaminants and also cause arc wondering.
Gas cylinder safety

- Cylinder caps MUST be on the tank BEFORE you remove the restraining chain or move a tank without a cart.
- Never drag a cylinder - roll it back and forth to move it.
- Cylinder must always be in the upright position.
- Chains should secure tank between midpoint and top shoulder.
- Do not leave tanks in egress routes.
- Never paint a cylinder.
- Separate full tanks from empty tanks.

TIG welding torch end

Tip sticks out $\frac{3}{16}$” to $\frac{1}{4}$”

Keep tip about the same distance above the surface.

Steel has sharp tip, aluminum needs a rounded tip
Weld puddle / pool

- Will appear as a bright circle when welding and is the section of the weld that is currently liquid.
- Controlling the puddle is key to making a good weld.

Filler rod

- Filler rod is coated in a protective layer but is made up of the same metal as the base part.
- Filler rod is added to the weld manually.
- Should be dipped into the puddle and quickly removed.
Welder setup videos

- **How to set up a TIG welding torch**
  www.youtube.com/watch?v=u8a999EIXfc

- **Holding a torch and grinding tungsten**
  www.youtube.com/watch?v=QSfeWtmWynI&t=1m22s

- **Torch angle and tip preparation**
  www.youtube.com/watch?v=tNYmo2_DI6c&t=39s

- **Safety and setting up gas cylinder**
  www.youtube.com/watch?v=bWlKtsiR68w&t=52s

Welding technique videos

- **Basic TIG & MIG welding techniques**
  www.youtube.com/watch?v=VEEpikDY058&t=30s

- **TIG welding troubleshooting – too hot or cold, too far or close**
  www.youtube.com/watch?v=CVAByfuZXlY&t=113s

- **TIG welding troubleshooting – tungsten tip and gas flow**
  www.youtube.com/watch?v=RTH49rGzspM
Rules of welding

• If something seems wrong STOP, remove foot from peddle, move torch away from work part and check your setup.
• Do not let the electrode touch the work part or the weld puddle.
• Remove paint and any coating at least 1” from weld area.
• Always clamp parts tight, heat from welding causes large warpage in work part.
• To get good at welding takes a lot of practice.

What to do before welding

1. You MUST have a buddy to weld
2. Remove flammable material from your work area.
3. Check for proper PPE
4. Open argon tank gas valve
5. Securely connect ground clip to the work part
6. Check tungsten electrode length and tip cleanliness
7. Turn on welder
8. Adjust torch argon pressure
What to do during welding

1. Flip mask down.
2. Hold torch near part (~2 mm away)
3. Slowly step on peddle until arc starts.
4. Adjust current with foot.
5. Weld (explained on next slide)
6. When done welding, stop pressing peddle.
7. Post-flow of argon prevents contamination: HOLD TORCH OVER WELD FOR ~7 sec.

Welding technique best practices

1. Create weld pool and ensure proper size.
2. Slightly zig zag torch along weld path.
3. Dip filler rod into weld pool to add material as needed.
4. Take care not to melt a complete hole in work part.
What to do after welding

1. Close argon tank gas valve
2. Empty gas line pressure to the torch
3. Turn off welder
4. Remove ground clip from work part
5. Wait for torch and work part to cool before moving them
6. Disassemble torch and clean up

Welding

3. Safety
Dangers when welding

1. Very High Heat
2. High Electric Current
3. Very Bright Light
4. UV Radiation
5. Dangerous Fumes

Biggest concern is the very high temperature

- Problem:
  - Burns
- PPE Needed:
  - Welding gloves
  - Face shield – welding helmet
  - Long sleeves
  - Pants
- Precautions:
  - Don’t touch recently welded parts
  - Pay attention where your filler rod is when it is hot
High temperature safety

- Problem:
  - Starting a nearby fire
- Precautions:
  - Do not weld within 10 feet of flammable cabinets.
  - Don’t have any flammables within 10 feet of the welding area, including trash cans!
  - “Buddy” is on “fire watch” during welding.


High electric current safety

- Problem:
  - Shocking yourself or potential electrocution.
- Precautions:
  - Always have the grounding clip on the work part.
  - Always work with a buddy, within line of sight.
Very bright light safety

• Problem:
  – Eye damage
• PPE needed:
  – Welding helmet
• Precautions:
  – Don’t look straight at someone else welding without a welding helmet

UV radiation safety

• Problems:
  – Sunburn
  – Eye damage
• PPE Needed:
  – Welding helmet
  – Long sleeves
  – Pants
Dangerous fumes safety

- Problems:
  - Lung damage
  - Cancer
  - Kidney damage
- Precautions:
  - Do only in a well ventilated area (e.g. place snorkel intake as close as reasonably possible to the welding.)

What is in welding fumes?

- Metals:
  - Aluminum, Antimony, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Molybdenum, Nickel, Silver, Tin, Titanium, Vanadium, Zinc.
- Gases:
  - Shield gas: Argon, Helium, Nitrogen, Carbon Dioxide.
  - By products: Nitric Oxide, Nitrogen Dioxide, Carbon Monoxide, Ozone, Phosgene, Hydrogen Fluoride, Carbon Dioxide.
- Chromium is in stainless steel, and can be converted to its hexavalent state which is highly toxic. 
  
  *No student welding of stainless steel or galvanized at ESPL!*

Ventilation safety

- Acute exposure to welding fumes and gases can result in *eye, nose* and *throat irritation, dizziness* and *nausea*.

- If you experience symptoms, *shut down* equipment and leave area immediately; *seek fresh air and medical attention*.

Welding safety summary

- Welding takes a lot of practice to master.
- Proper setup can improve welds and make learning easier.
- Welding has a number of very serious dangers:
  - Heat burns
  - Blinding light
  - Electric shock
  - Fires
  - Gas cylinders under pressure
- There is a lot to keep track of – let your buddy help to keep everyone safe!