Chapter 31
Gas Flame and Arc Processes

Before you begin: Turn on the sound on your computer. There is audio to accompany this presentation.

Materials Processing

Chapters 11-13
Chapters 20-27
Chapters 15-17
Chapters 30-33

Classification of Processes

Figure 30-1 Classification of common welding processes along with their AWS designations.
Oxyfuel-Gas Welding

Oxyfuel-Gas Welding (OFW)

- Refers to a group of welding processes that utilize flame as the heat source, produced by combustion of a fuel gas and oxygen.
- Fuel is typically acetylene (C₂H₂).
- Other processes have replaced largely gas-flame in large-scale manufacturing.
- Still popular with small-scale and repair operations because of portability, versatility and low capital investment.

Combination of Oxygen (O₂) and Acetylene (C₂H₂) produces a temperature of about 3250°C (5850°F) in a 2 stage process:

- In the 1st stage, Oxygen and Acetylene react to produce Carbon Monoxide and Hydrogen.
  \[ C₂H₂ + O₂ → 2CO + H₂ + \text{heat} \]
- This reaction occurs near the tip of the torch and generates intense heat.
The 2nd stage of the reaction involves the combustion of Carbon Monoxide and Hydrogen with Oxygen. The oxygen for these secondary reactions is generally obtained from the surrounding atmosphere.

\[
\text{heat} \quad \text{O}_2 + \text{H}_2 \rightarrow \text{H}_2\text{O} + \text{heat}
\]

Oxyfuel-Gas Welding

Figure 31-2 - Typical oxyacetylene flame and the associated temperature distribution.

Oxyfuel-Gas Welding

The combustion process produces a flame having two distinct regions. The maximum temperature occurs near the end of the inner cone and should be just above the metal being welded. The outer envelope serves to preheat the metal, provide shielding from oxidation since oxygen from the surrounding air is consumed in the secondary combustion.

The oxygen for these secondary reactions is generally obtained from the surrounding atmosphere.

\[
\text{heat} \quad \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{heat}
\]

\[
\text{heat} \quad \text{CO} + \text{O}_2 \rightarrow \text{CO}_2 + \text{heat}
\]
Oxyfuel-Gas Welding

Three different types of flames can be obtained by varying the Oxygen to Fuel Ratio.

- Neutral Flame
- Carburizing Flame
- Oxidizing Flame

Neutral Flame [1:1 to 1.15:1 ratio] – all reactions are carried to completion:

- Most welding is done with a neutral flame
- It will have the least chemical effect on the heated metal.

Oxidizing Flame [1.5:1 ratio] – excess oxygen:

- Hotter than the neutral flame (about 3600°C or 6000°F), but similar in appearance.
- Used when welding copper and copper alloys.
- Considered harmful when welding steel because the excess oxygen reacts with the carbon in the steel, lowering the carbon in the region around the weld.
Oxyfuel-Gas Welding
Carburizing or Reducing Flame [<1.0:1 ratio] – excess fuel decomposes to carbon and hydrogen:
- Flame temperature not as great (3000°C or 5500°F).
- No carburization occurs and the metal is well protected from oxidation.
- Used in welding Monel, high-carbon steel, some alloy steels and applying some types of hard-facing materials.

Welding torch tips:
- Orifice diameter can be varied to control shape of inner cone and flow of gases.
- Larger tips permit greater flow of gases:
  - Greater heat input.
  - Lower gas velocities which otherwise might blow out molten metal from puddle.
  - Used for welding thicker metal.

Oxyfuel Gases:
- Oxygen usually supplied in relatively pure form, pressurized air can be used but produce low heat flames typically not capable of welding most metals.
- Acetylene usually obtained in portable storage tanks.
  - Not safe when stored as a gas >15 psi, so it is usually dissolved in acetone.
  - Storage tanks are filled with a porous filler.
  - Acetone is absorbed into the voids and serves as a medium.
Oxyfuel-Gas Welding

Oxyfuel Gases (continued):

- Alternative fuel gases include: Propane, Propylene, and Stabilized Methyl Acetylene Propadiene (MAPP)
- While flame temperature is slightly lower, these gases can be safely stored in ordinary pressure tanks. Three to four times as much volume and decreased costs as compared to acetylene.
- Oxygen and fuel cylinders use right-hand and left-hand threads respectively to prevent connection errors.

Use of Flux

- Flux may be used to clean the surfaces and remove contaminating oxide to promote a better bond.
  - Flux can be added as a powder,
  - Welding rod can be dipped in a flux paste
  - Rods can be pre-coated.
- The gaseous shield produced by vaporizing flux can prevent further oxidation during the welding process.
- The slag produced by solidifying flux can protect the weld pool as it cools.

Uses, Advantages & Limitations

<table>
<thead>
<tr>
<th>Uses</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Pressure Gas Welding

- Process that uses equipment similar to the oxyfuel-gas process to produce butt joints between the ends of objects such as pipe and railroad rails.
- Ends are heated to a temperature below the melting point, and the soft metal is forced together under pressure to form the weld.

Classification of Processes

![Classification of thermal cutting processes along with their AWS designations.](image)

Oxygen Torch Cutting

- The most common thermal cutting process is oxyfuel-gas cutting (OFC).
- In some cases the metal is merely melted by the flame of the oxyfuel-gas torch and blown away by a stream of oxygen to form a gap or kerf.
Oxygen Torch Cutting Process

- When ferrous metal is cut, the process becomes one where the iron actually burns at high temperatures:
  \[ Fe + O \rightarrow FeO + \text{heat} \]
  \[ 3Fe + 2O_2 \rightarrow Fe_3O_4 + \text{heat} \]
  \[ 4Fe + 3O_2 \rightarrow 2Fe_2O_3 + \text{heat} \]
- Reactions do not occur until the metal is > 1500°F
  - Oxyfuel flame is first used to raise the metal to the temperature where burning can be initiated.
  - Stream of pure oxygen is added to oxidize the iron.
  - Liquid iron oxide and un-oxidized molten iron are expelled by oxygen gas stream.

- If the work piece is already hot, no supplemental heating is needed.
  - Temps greater that 1200°C (2200°F).
  - Known as oxygen lance cutting (LOC).
- Works best on metals that oxidize readily.
- Cutting speeds are low.
- Required equipment inexpensive.

Gases for Oxyfuel-Gas Cutting

- Acetylene is by far the most common fuel used in oxyfuel-gas cutting. Other gases used include:
  - Natural Gas
  - Propane
  - Hydrogen
- Cut quality depends on:
  - Pre-heat conditions
  - Oxygen flow rate
  - Cutting speed

Figure 31-5 Oxyacetylene cutting torch and cross-sectional schematic.
Underwater Torch Cutting

- Acetylene gas is used for depths up to about 25 ft.
- Hydrogen is used at greater depths since the environment pressure is too great for the safe use of acetylene.

Other Thermal Cutting Methods

- Stack Cutting – multiple sheets of thin metal clamped together and flame cut.
- Metal Powder Cutting (POC) – injects iron or aluminum powder into flame to increase temperature.
- Chemical Flux Cutting (FOC) – injects flux into the cutting oxygen to increase fluidity.

Flame Straightening

- Employs a controlled, localized upseting process to straightened warped or buckled material.
- Example:
  - Applying heat at point b causes a portion of the metal to first expand, then contract into the warped shape.
  - Applying heat at point a’ will return the piece a straight shape.
Attempts at welding began soon after development of commercial electricity. Early results were very uncertain. Many advances have been made over the years. All arc welding processes use same basic circuit:

- Currents range: 1 to 4000A
- Voltages range: 20 to 50v

**Direct Current Applications**

- **DCEN** (Direct Current Electrode Negative) or **SPDC** (Straight Polarity Direct Current) – welding processes where electrode is negative and workpiece is positive:
  - Characterized by fast melting of electrode and shallow penetration.
- **DCEP** (Direct Current Electrode Positive) or **RPDC** (Reverse Polarity Direct Current) – electrode is positive and workpiece is negative.
  - Characterized by slower melting rates and deeper penetration.
Arc Welding Categories

Two basic categories for arc welding processes:

- Consumable electrode – electrode is consumed during welding process and used to provide filler metal.
  - Electrodes can be ‘sticks’ or wire.
- Non-consumable electrode – electrode is not consumed during welding process and so separate filler metal must be provided.
  - Electrodes made of tungsten.

Consumable Electrode Processes

- Shielded Metal Arc Welding (SMAW)
- Flux-Cored Arc Welding (FCAW)
- Gas Metal Arc Welding (GMAW)
  - a.k.a. MIG welding
- Submerged Arc Welding (SAW)

General Characteristics

- All processes use a medium rate heat input.
- Produce fusion zone with a depth approximately equal to width.
- Fusion zone composed of metal from both pieces (parent/base metal) and filler metal – so electrode must be of same material as being welded.
- Processes cannot be used to join dissimilar metals.
SMAW (Shielded Metal Arc Welding)

- a.k.a. stick welding
- Most common arc welding process.
- Versatile and low cost.

Key to SMAW process: finite-length electrodes with bonded coating.

Functions of coating and electrode:
- Vaporize to provide protective atmosphere
- Stabilize arc, reduce spatter, increase efficiency
- Act as flux to deoxidize and remove impurities
- Provide protective slag
- Add alloying elements
- Add filler metal
- Influence shape of weld bead

Figure 31-12. Schematic diagram of shielded metal arch welding (SMAW).
Electrode Classification

Coated electrodes are classified by:
- Tensile strength of the deposited weld metal
- Welding positions
- Preferred type of polarity
- Type of coating

Figure 31-10 Designation system for arc-welding electrodes.

Example: E7016
- Minimum tensile strength – 70,000 psi
- All welding positions
- Coating – low hydrogen and potassium

SMAW Additional Notes

- Why are SMAW electrodes (rods) of finite length?
  - Versatility
  - Current is flowing through the electrode and longer lengths will cause heat build-up (overheating) which can ruin the coating.
- SMAW process best for steels including carbon, alloy and stainless, and cast irons.
Advantages and Disadvantages

- **Advantages**
  - Simple process and equipment
  - Low cost
  - Portable - can be powered by generators
  - Popular in job shops – low production
  - Easy to learn and use
- **Disadvantages**
  - Discontinuous process
  - Produces shallow welds
  - Requires slag removal after each pass

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**SMAW (continued)**

<table>
<thead>
<tr>
<th>Process Summary: Shielded Metal Arc Welding (SMAW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>Heat source</td>
</tr>
<tr>
<td>Protection</td>
</tr>
<tr>
<td>Electrode</td>
</tr>
<tr>
<td>Material used</td>
</tr>
<tr>
<td>Rate of heat input</td>
</tr>
<tr>
<td>Weld profile (OW/H)</td>
</tr>
<tr>
<td>Current</td>
</tr>
<tr>
<td>Arc length</td>
</tr>
<tr>
<td>Advantages</td>
</tr>
<tr>
<td>Limitations</td>
</tr>
</tbody>
</table>

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**FCAW (Flux-Cored Arc Welding)**

- Removes limitations of SMAW by moving the powdered flux to the interior of a continuous tubular electrode.
- Alloy additions can be added to the flux to create wide variety of filler metals.
- Continuous electrode is fed automatically through a welding gun.
- DCEP is almost always used for deepest penetration.
SMAW vs. FCAW

- **SMAW**
  - Discontinuous process
  - Low cost equipment
  - Requires slag removal
  - Overheating is concern

- **FCAW**
  - Continuous process
  - Equipment costs more because of wire feed and more costly power supply
  - Requires slag removal
  - Overheating is no longer concern

### Table 31.4: Process Summary: Flux-Cored Arc Welding (FCAW)

<table>
<thead>
<tr>
<th>Source</th>
<th>Electric arc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection</td>
<td>Slag and gas from flux (protective gas shield)</td>
</tr>
<tr>
<td>Electrode</td>
<td>Continuous electrode</td>
</tr>
<tr>
<td>Material</td>
<td>Iron-based metal</td>
</tr>
<tr>
<td>Rod type</td>
<td>Various</td>
</tr>
<tr>
<td>Wt. of flux (lb/ft)</td>
<td>1</td>
</tr>
<tr>
<td>Current</td>
<td>~500 amps</td>
</tr>
<tr>
<td>Min. penetration</td>
<td>6-10 mm</td>
</tr>
<tr>
<td>Max. penetration</td>
<td>~</td>
</tr>
<tr>
<td>Access</td>
<td>Continuous electrode</td>
</tr>
<tr>
<td>Limitations</td>
<td>Requires slag removal</td>
</tr>
</tbody>
</table>

Flux-cored arc welding (FCAW) equipment.
GMAW (Gas Metal Arc Welding)

- a.k.a. MIG (Metal Inert Gas).
- Uses inert gas to provide protective atmosphere, therefore eliminating need for flux coating.
- Utilizes continuous, solid, uncoated metal wire as electrode.

GMAW Characteristics

- Current, penetration depth and process costs are similar to FCAW.
- Argon, helium or a combination of the two gases are used to provide protective atmosphere. Oxygen and/or carbon dioxide can be added for ferrous materials to help stabilize arc and reduce weld spatter. Type of gas affects heat transfer:
  - Helium – produces hottest arc/deepest penetration.
  - Argon – medium arc temperature and penetration.
  - Carbon Dioxide – lowest arc temperature and penetration.

GMAW Metal Transfer Modes

- Consumable electrodes have melting temperatures below the arc temperature.
- Small droplets are melted from the electrode and passed to the workpiece.
- Transfer methods depend on:
  - Type of electrode
  - Current
  - Other process parameters
GMAW Metal Transfer Modes

- **Globular Transfer** – Named for “glob” of weld metal transferring across the arc in a gravity feed. It does not produce a very smooth weld bead appearance, and some spatter can occur. Usually limited to the flat and horizontal welding positions, and not used on thin metals.

- **Spray Transfer** – Named for a “spray” of tiny molten droplets across the arc. Uses relatively high voltage and amperage values, and the arc is “on” at all times after the arc is established. Very little if any spatter is produced. Usually used on thicker metals in the flat or horizontal welding positions.

- **Short Circuit Transfer** – Gets its name from the welding wire actually “short circuiting” (touching) the base metal many times per second. Some spatter is produced, but the transfer can be used in all welding positions and on all thicknesses of metal.

- **Pulsed-Spray Transfer** – For this variation of spray transfer, the welding machine “pulses” the output between high peak currents and low background currents. The weld pool gets to cool slightly during the background cycle, making it slightly different than Spray Transfer. This can allow for welding in all positions on either thin or thick metals.

GMAW Advantages

- Thinner materials can be welded.
- High conductivity metals can be joined.
- Welds can be made in all positions.
- High speed process good for productivity.
- Lower power/energy required to produce a weld (reduced $$).
- No frequent change of electrodes.
- No flux required.
- No slag forms over weld.
- Multiple passes can be made w/o intermediate cleaning.
- Process is readily automated, lightweight and lends itself to robotic manipulation.
GMAW (continued)

TABLE 31-3  Process Summary: Gas Metal Arc Welding (GMAW)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat source</td>
<td>Electric arc</td>
</tr>
<tr>
<td>Protection</td>
<td>Externally supplied shielding gas</td>
</tr>
<tr>
<td>Electrode</td>
<td>Continuous, consumable</td>
</tr>
<tr>
<td>Material jointed</td>
<td>All common steels</td>
</tr>
<tr>
<td>Rate of heat input</td>
<td>Medium</td>
</tr>
<tr>
<td>Weld profile (WPH)</td>
<td>1</td>
</tr>
<tr>
<td>Current</td>
<td>~500 amps</td>
</tr>
<tr>
<td>Mass penetration</td>
<td>~0.1 mm</td>
</tr>
<tr>
<td>Access</td>
<td>No flag required</td>
</tr>
<tr>
<td>Limitations</td>
<td>More costly equipment or flux SAW or TIG/W</td>
</tr>
</tbody>
</table>

SAW (Submerged Arc Welding)

- No shielding gas used – instead thick layer of granular flux is deposited just ahead of the bare-wire consumable electrode.
- Most suitable for making flat butt or fillet welds in low carbon (<0.3%) steels.

SAW (continued)

Figure 31-15 (Top) Basic features of submerged arc welding (SAW). (Bottom) Cutaway schematic of submerged arc welding.
SAW Advantages

- High welding currents can be used (600 – 2000A)
- High deposition rates
- Deep penetration
- High weld cleanliness
- Greater weld thicknesses can be obtained (requiring fewer passes)
- Enhanced weld quality
SAW Disadvantages

- Need for extensive flux handling
- Possible contamination of flux (due to moisture)
- Large volume of slag to be removed
- High heat input promotes large grain structure and possible hot-cracks
- Welding restricted to horizontal position (due to loose flux)
- Chemical control is very important

SAW (continued)

<table>
<thead>
<tr>
<th>TABLE 31-6</th>
<th>Process Summary: Submerged Arc Welding (SAW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Electrode</td>
</tr>
<tr>
<td>Protection</td>
<td>Granular flux provides slag and an isolation barrier</td>
</tr>
<tr>
<td>Electrode</td>
<td>Continuous, consumable</td>
</tr>
<tr>
<td>Method</td>
<td>Direct current (DC)</td>
</tr>
<tr>
<td>Rate of heat input</td>
<td>Medium</td>
</tr>
<tr>
<td>Weld profile (SAW)</td>
<td>1-3 mm</td>
</tr>
<tr>
<td>Current</td>
<td>&lt;3000 amperes</td>
</tr>
<tr>
<td>Max. penetration</td>
<td>25 mm</td>
</tr>
<tr>
<td>Assets</td>
<td>High-quality welds, high deposition rates</td>
</tr>
<tr>
<td>Limitations</td>
<td>Requires slag removal, difficult for overhead and out-of-position welding, joint afterwelds bending plates</td>
</tr>
</tbody>
</table>

Illustration of the SAW process and equipment.

SW (Stud Welding)

- Used to attach studs, screws, pins or other fasteners to metal surfaces.
- Stud acts as the electrode and DC arc established with mounting surface.
- Stud welding gun uses automatic control – low skill level process.
Non-Consumable Electrode Processes

- Tungsten used as the electrode.
- Electrode is not consumed except for relatively slow vaporization.
- Tungsten melting temperature = 6191 °F
- Filler material required.

GTAW (Gas Tungsten Arc Welding)

- a.k.a. TIG (Tungsten Inert Gas).
- Process takes improvements leading up to MIG (GMAW) and adds a new feature – non-consumable electrode.
- Tungsten electrode has very high melting point so it can withstand the heat generated by the arc and not melt or be consumed.
- Process also uses an inert gas (usually argon) to provide protective atmosphere.

GTAW (continued)

Figure 31-18 Welding torch used in non-consumable-electrode, gas tungsten arc welding (GTAW), showing feed lines for power, cooling water, and inert-gas flow.
GTAW Characteristics

- Filler metal (where needed) must be supplied externally.
- Because no flux is used, special care in cleaning materials must be taken.
- Very good for making small, barely visible welds.
- Localized, higher heat input also makes this process good for more difficult materials to weld (such as aluminum).
- Also good process for welding thin materials.
GTAW (continued)

**TABLE 31-7 Process Summary: Gas Tungsten Arc Welding (GTAW)**

<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat source</td>
<td>Electric arc</td>
</tr>
<tr>
<td>Protection</td>
<td>Externally supplied shielding gas</td>
</tr>
<tr>
<td>Electrode</td>
<td>Nonconsumable</td>
</tr>
<tr>
<td>Material joined</td>
<td>All common metals</td>
</tr>
<tr>
<td>Heat input</td>
<td>Medium</td>
</tr>
<tr>
<td>Weld profile (E%)</td>
<td>1</td>
</tr>
<tr>
<td>Current</td>
<td>&lt;200 amps</td>
</tr>
<tr>
<td>Max. penetration</td>
<td>3 mm</td>
</tr>
<tr>
<td>Aspects</td>
<td>High-quality welds, no slag to be removed</td>
</tr>
<tr>
<td>Limitations</td>
<td>Slower than consumable electrodes GTAW</td>
</tr>
</tbody>
</table>

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Gas Tungsten Arc Spot Welding

- Variation of GTAW used to produce spot welds.
- Spot welds are typically used to weld sheet metal.
- Typical spot welding methods require access to both sides of the sheets to be joined.
- Gas tungsten arc spot welding requires access to only one side of the joint.
- Modified tungsten inert-gas gun is utilized in conjunction with firm workpiece contact.

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**Figure 31-21** Process schematic of spot welding by the inert-gas-shielded tungsten arc process.

**Figure 31-22** Making a spot weld by the inert-gas-shielded tungsten arc process.
PAW (Plasma Arc Welding)

- Plasma processes can be used for welding & cutting.
- Again uses non-consumable tungsten electrode.
- A flow of inert gas (usually Ar) is heated to form a hot, fast moving plasma.
- A second flow of inert gas is used to provide protective atmosphere.
- Two different types of torches:
  - Transferred arc
  - Non-transferred arc

Figure 31-23 Two types of plasma arc torches. (Left) Transferred arc; (right) non-transferred arc.
PAW (continued)

![Figure 31-24 Comparison of the non-constricted arc of gas tungsten arc welding and the constricted arc of the plasma process. Not the level and distribution of temperature.](image)

PAW Characteristics

- This process has one of the highest rates of heat input and is also very localized.
- Temperatures produced are on the order of 30,000 °F
- Has the best penetration characteristics of all the processes:
  - Other arc processes produce weld depth equal to width (1:1 ratio).
  - Plasma has 3:1 depth to width ratio.

### Table 31.8: Process Summary: Plasma Arc Welding (PAW)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat source</td>
<td>Plasma arc</td>
</tr>
<tr>
<td>Protection</td>
<td>Externally supplied shielding gas</td>
</tr>
<tr>
<td>Electrode</td>
<td>Nonconsumable</td>
</tr>
<tr>
<td>Material joined</td>
<td>All common metals</td>
</tr>
<tr>
<td>Rate of heat input</td>
<td>High</td>
</tr>
<tr>
<td>Weld profile (IPW)</td>
<td>3</td>
</tr>
<tr>
<td>Current</td>
<td>&lt;500 amps</td>
</tr>
<tr>
<td>Max penetration</td>
<td>12 inches</td>
</tr>
<tr>
<td>Assets</td>
<td>Can be long arc length</td>
</tr>
<tr>
<td>Limitations</td>
<td>High initial equipment cost, large torches near 3m, accessibility</td>
</tr>
</tbody>
</table>
Welding Equipment

- Power supplies are the biggest concern for arc processes
  - Current ranges from 10 – 1000A.
  - Voltage ranges from 20 – 50v.
  - DC or AC used.
  - Gasoline/diesel generators can be used for remote locations.
- Jigs and Fixtures (Positioners) – used to hold and orient work during welding process.
- Robots and CNC Control – can automate welding process.

Classification of Processes

- Arc cutting (AO)
- Air-oxidant arc cutting (AOX)
- Oxygen arc cutting (OAC)
- Acetylene arc cutting (THAC)
- Automotive (AR)
- Selective laser cutting (SLC)
- Chemical vapor cutting (CVC)
- Laser beam cutting (LBC)
- Electron beam cutting (EBC)

Arc Cutting

- Most arc welding processes can be modified so that cutting can be performed.
- This modification generally includes the addition of high velocity jets of air to help remove molten metal.
Arc Cutting

Methods:
- Carbon arc and shielded metal arc cutting.
- Air carbon arc cutting.
- Oxygen arc cutting.
- Gas metal arc cutting.
- Gas tungsten arc cutting.
- Plasma arc cutting.

Table 31.1 Cutting Process Comparisons: Oxygen, Plasma Arc, and Laser

<table>
<thead>
<tr>
<th>Feature</th>
<th>Oxygen Cutting</th>
<th>Plasma Arc Cutting</th>
<th>Laser Cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Arc</td>
<td>Arc</td>
<td>Arc</td>
</tr>
<tr>
<td>Material</td>
<td>Carbon steel and alloy</td>
<td>Aluminum and stainless steel</td>
<td>Stainless steel, copper, brass</td>
</tr>
<tr>
<td>Quality of cut</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Residual stress</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Thicker than 1 in.</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Thermal gases</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Cutting speed</td>
<td>30 ft/min</td>
<td>40 ft/min</td>
<td>50 ft/min</td>
</tr>
<tr>
<td>Cooling speed</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Thermal Cutting

Metallurgical and Heat Effects
- Remember – any time a high heat process is used on a material, some effects on the material will occur.
- Depending on the process, the amount and severity of the effects will be different.
- All processes will produce residual stresses and these stresses may need to be removed by a stress-relief anneal.